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MTE14

14th Symposium on Mesozoic Terrestrial Ecosystems and Biota

Utah Department of Natural Resources

Salt Lake City, Utah, USA

June 8-10, 2023

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FOREWORD

Welcome to the 14th Symposium on Mesozoic Terrestrial Ecosystems and Biota hosted by the Utah Geological Survey, Salt Lake City, USA!

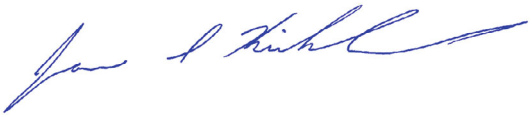
This is the first time that the Symposium on Mesozoic Terrestrial Ecosystems and Biota (MTE) has been held in the United States. Utah provides the perfect setting for this meeting. The first dinosaur discovered in western North America was stumbled upon by naturalist John S. Newberry in southwestern Utah in 1859, while the Macomb Survey was fruitlessly seeking a route off the high mesa's down to the "Grand" (Colorado) River at the bottom of the canyons further to the west. The few bones returned to Washington, now reside at the Smithsonian Museum of Natural History, and were described as *Dystropheus* by Edward Drinker Cope in 1877. Although the location was lost for over 100 years, the site has been reopened and the oldest large sauropod site in North America is currently being excavated again. Notable discoveries in the intervening decades include the Carnegie Quarry at Dinosaur National Monument (1909) and the Cleveland Lloyd Quarry at Jurassic National Monument (1923). Utah became justifiable famous for its Upper Jurassic dinosaur sites, setting the global standard for protecting and publicly interpreting paleontological sites in situ. The 1937 description of the titanosaurid sauropod *Alamosaurus sanjuanensis* and ceratopsian *Torosaurus utahensis* by the Smithsonians's C.W. Gilmore in the Uppermost Cretaceous North Horn Formation of central Utah rounded out these discoveries in the early twentieth century.

Surprisingly, as of 1990, only 22 dinosaurs were identified to genus in Utah. In the early 1980's, and continuing through today, hundreds of Mesozoic ichnology sites have been identified and studied across the state. Notable discoveries have been made available to the public through the Saint George Dinosaur Discovery Site in Saint George, and the various public tracksite trails located on public lands, most abundantly located in southeastern Utah. During the 1990s, the quest for Mesozoic mammals revealed the highly fossiliferous nature of the near continuous Upper Cretaceous terrestrial strata in southern Utah and became a focal point in the presidential proclamation establishing the Grand Staircase-Escalante National Monument (GSENM) in 1996. Seed money relative to inventorying the paleontology of GSENM and funding relative to the discovery of the real star of "Jurassic Park", the giant dromaeosaur *Utahraptor* in 1993, the discovery of *Utahceratops* and a wealth of other extraordinary paleontological discoveries in the Mesozoic of eastern and southern Utah. This "gold rush" of discovery increased the number of described dinosaurs by over 100 distributed in more than 30 sequential, non-overlapping faunal levels. Establishing that Utah preserves one of the most continuous, well-dated, Mesozoic terrestrial sequences in the world, it is only now, that it is being fully realized, the breadth of significant scientific research that can be developed in this sequence of rocks. Much of this research and efforts would not be possible without the concerted efforts of our federal and state land management agencies and staff, who work to preserve and protect these important fossil resources.

Many people and institutions came together to facilitate MTE14. We wish to express our sincere gratitude to the Utah Department of Natural Resources for hosting this conference. We would like to thank the Utah Friends of Paleontology, in particular Philip Policelli, for providing the financial framework for hosting this conference, and the many volunteers behind the scenes that have made this all work. Heather Smith and *The Anatomical Record* stepped up to sponsor the extended abstract volume. Martha Hayden, Don DeBlieux, Ethan Warner-Cowgill, Ben Sears, and Stefan Kirby have been with us every step of the way. BJ Nicholls designed our amazing logo and the registration page, without which, this conference would never have gotten off the ground. Paul Gedge is thanked for reserving the meeting rooms and setting up our audio-video system. Registration booth and packages are provided by Dinosaur National Monument, with thanks to the National Park Service for their time and participation in this event.MTE14 is a showcase for the most up-to-date and groundbreaking research on Mesozoic terrestrial ecosystems and organisms. Presentations cover a wide variety of Mesozoic life, from palynomorphs, plants, microfossils, arthropods, microvertebrates, to dinosaurs, and Mesozoic environments, paleoclimatology, paleogeography, and paleobiogeography. We are thrilled with the breadth of presentations submitted documenting exciting new discoveries and approaches to their understanding. We hope that you find MTE14 inspiring and that you enjoy the opportunity to interact with experts in Mesozoic terrestrial research from all over the world and that this

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conference will serve as a jumping off point for further collaboration and the next step in many lines of research on the Mesozoic world.



James Kirkland, Ph.D.
Utah State Paleontologist
Utah Department of Natural Resources Utah Geological Survey

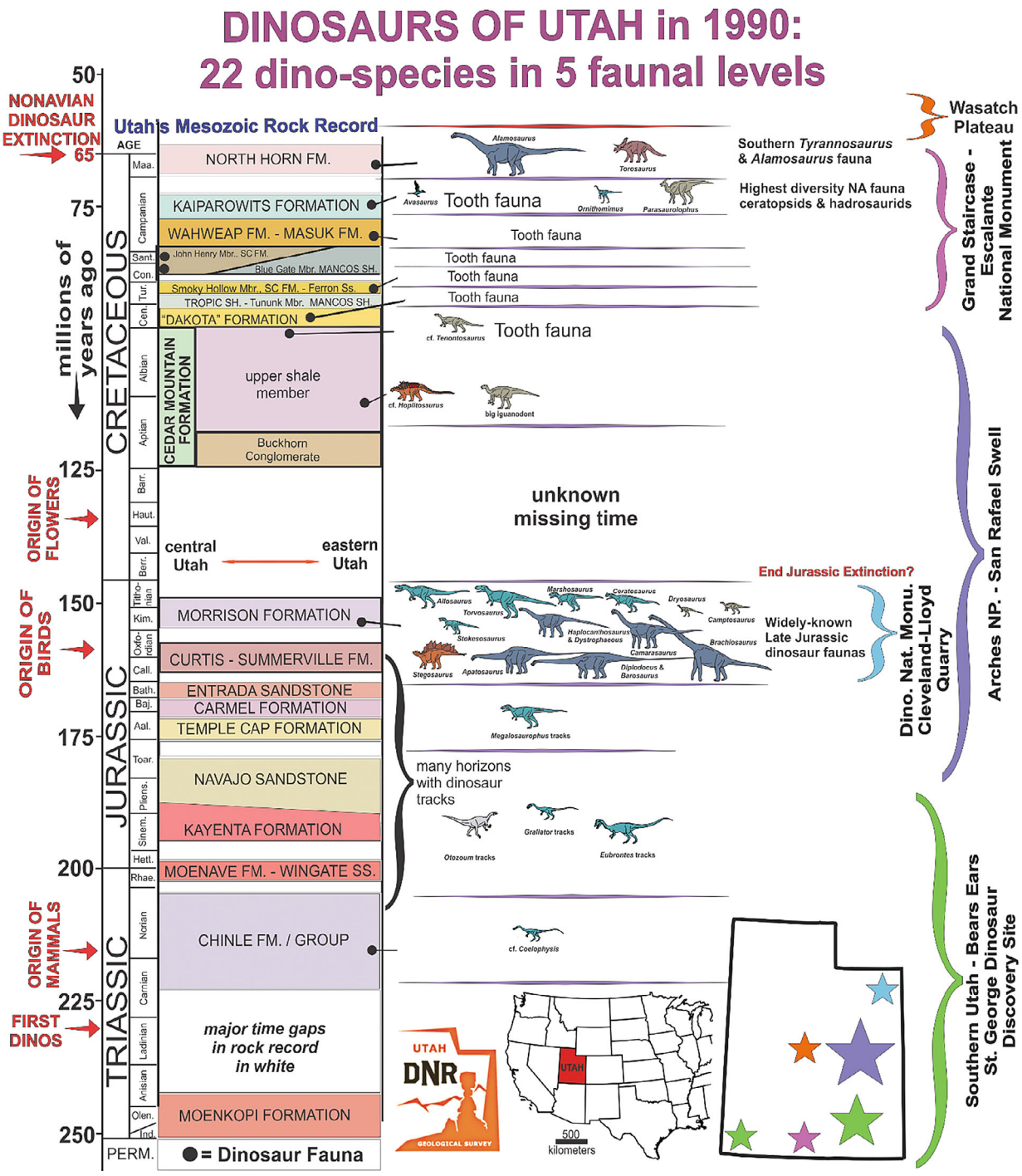


ReBecca Hunt-Foster, M.Sc.
Monument Paleontologist and Curator
National Park Service Dinosaur National Monument

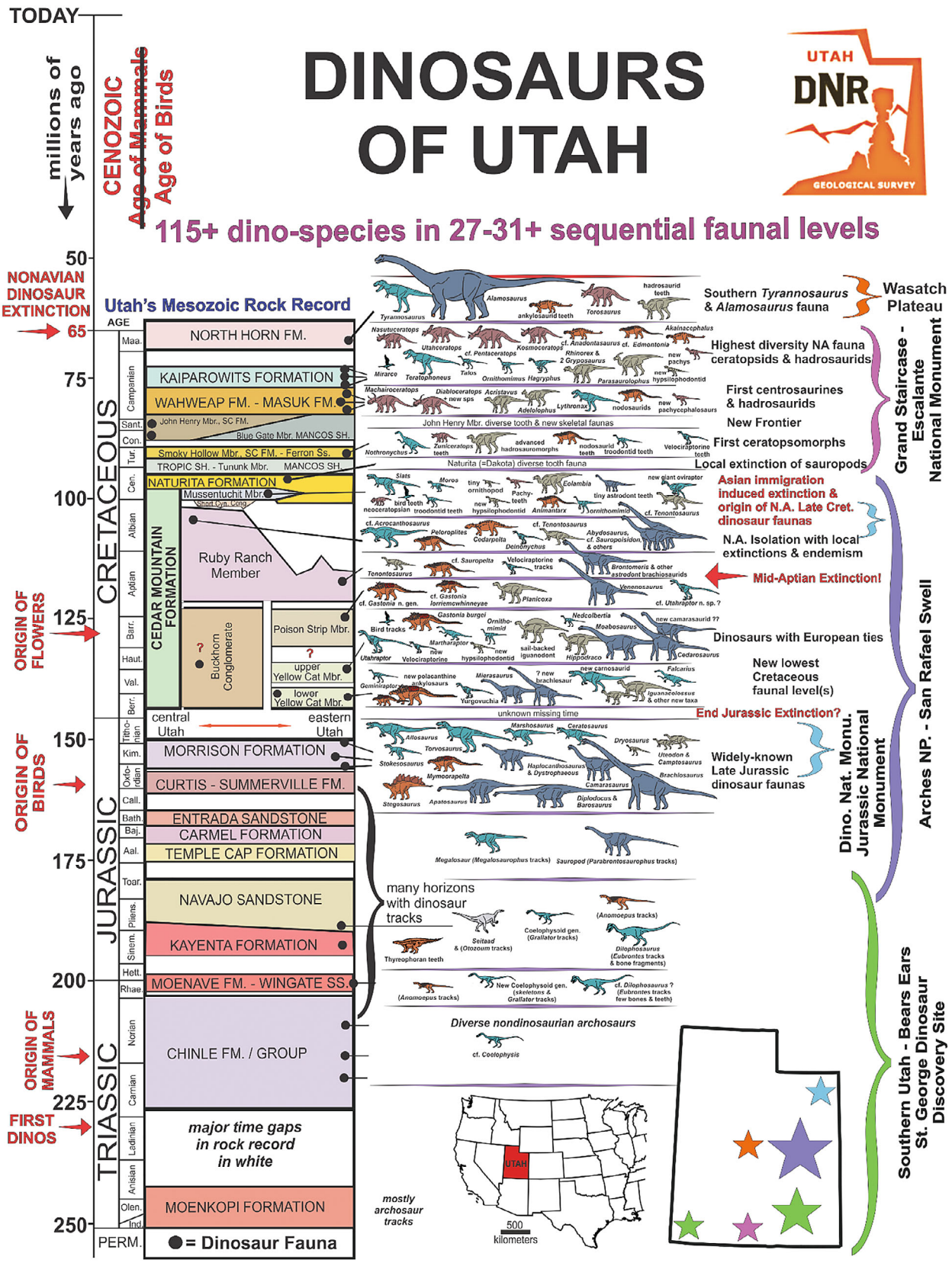


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PAST MEETINGS

Mesozoic Terrestrial Ecosystems Conference List

MTE -1	Sept. 1978, Paris France
MTE-2	Sept. 14-19, 1981, Jadwisin near Warsaw, Poland
MTE-3	1984, Tübingen, Germany
MTE-4	August 10-14, 1987, Drumheller, Alberta, Canada
MTE-5	August 12-15, 1991, Oslo, Norway
MTE-6	August 4, 1995, Beijing, China
MTE-7	September 26-October 1, 1999, Buenos Aires, Argentina
MTE-8	July 21-26, 2002, Cape Town, South Africa
MTE-9	June 27-29, 2006, Manchester, England
MTE-10	Sept. 2009, Teruel, Spain
MTE-11	August 15-18, 2012, Chonnam, Korea
MTE-12	August 16-20, 2015, Shenyang, China
MTE-13	July 21-23, 2018, Bonn, Germany
MTE-14	June 7-10, 2023, Salt Lake City, Utah, USA

SCHEDULE

Wednesday, June 7

Time	Title	Location
2 PM – 5 PM	Registration Open	Radisson Hotel Salt Lake City Airport (Host Hotel)
6 PM – 9 PM	Welcome Reception	Natural History Museum of Utah

Thursday, June 8

Time	Title	Location
7 AM – 5 PM	Registration Open	Utah Department of Natural Resources Building
7:30 AM – 9:30 AM	Poster Setup	Utah Department of Natural Resources Building
9:30 AM – 6 PM	Posters Open	Utah Department of Natural Resources Building
8:30 AM	Opening Remarks	Utah Department of Natural Resources Building
8:45 AM – 10:15 AM	Technical Session 1: Paleoclimatology & Paleogeography	Utah Department of Natural Resources Building
10:30 AM – 12 PM	Technical Session 2: Paleoecology	Utah Department of Natural Resources Building
12 PM – 1 PM	Lunch	
1 PM – 2:30 PM	Technical Session 2: Paleoecology	Utah Department of Natural Resources Building
2:45 PM – 5 PM	Symposium: Global Perspectives on Mesozoic Lacustrine Ecosystems	Utah Department of Natural Resources Building

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Friday, June 9

Time	Title	Location
8 AM – 5 PM	Registration Open	Utah Department of Natural Resources Building
7:30 AM – 9:30 AM	Poster Setup	Utah Department of Natural Resources Building
9:30 AM – 6 PM	Posters Open	Utah Department of Natural Resources Building
8:30 AM – 12 PM	Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic	Utah Department of Natural Resources Building
12 PM – 1 PM	Lunch	
1 PM – 2:45 PM	Technical Session 3: Terrestrial Ecosystems – Late Jurassic	Utah Department of Natural Resources Building
3 PM – 5:40 PM	Symposium: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory and ecosystem reconstruction	Utah Department of Natural Resources Building

Saturday, June 10

Time	Title	Location
8 AM – 5 PM	Registration Open	Utah Department of Natural Resources Building
7:30 AM – 9:30 AM	Poster Setup	Utah Department of Natural Resources Building
9:30 AM – 6 PM	Posters Open	Utah Department of Natural Resources Building
8:30 AM – 12:15 PM	Technical Session 3: Terrestrial Ecosystems – Early - Mid-Cretaceous	Utah Department of Natural Resources Building
12:15 PM – 1:15 PM	Lunch	
1:15 PM – 3 PM	Technical Session 3: Terrestrial Ecosystems – Late Cretaceous	Utah Department of Natural Resources Building
3:25 PM – 5:40 PM	Symposium: Laramidia to Asia: biota and biogeography of interconnected iconic Late Cretaceous ecosystems	Utah Department of Natural Resources Building

Thursday, June 8

Time	Speaker
8:30 AM	Keach
8:45 AM	Burgener
9:00 AM	Andrzejewski
9:15 AM	Carpenter
9:30 AM	Cilliers
9:45 AM	Xing
10:00 AM	**BREAK**
10:15 AM	Bordy
10:30 AM	Choiniere
10:45 AM	Engelmann
11:00 AM	Parrish
11:15 AM	Chan
11:30 AM	Benson
11:45 AM	**LUNCH**
1:00 PM	Donaldson
1:15 PM	Noto
1:30 PM	Diepenbrock
1:45 PM	Maccracken
2:00 PM	Gilbert
2:15 PM	Bamforth
2:30 PM	**BREAK**
2:45 PM	Bohacs
3:00 PM	Bordy
3:15 PM	Moisan
3:30 PM	Suarez

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3:45 PM	**BREAK**
4:00 PM	Suarez
4:15 PM	Withdrawn
4:30 PM	Milner
4:45 PM	Lara

Friday, June 9

Time	Speaker
8:30 AM	Napoli
8:45 AM	Smith
9:00 AM	Hancox
9:15 AM	Hasiotis
9:30 AM	Martz
9:45 AM	DeBlieux
10:00 AM	Heckert
10:15 AM	**BREAK**
10:30 AM	Barrett
10:45 AM	Singh
11:00 AM	Chinsamy
11:15 AM	Chapelle
11:30 AM	Zafaty
11:45 AM	Wills
12:00 PM	**LUNCH**
1:00 PM	Morrison
1:15 PM	Sciscio
1:30 PM	Russo
1:45 PM	Guillaume
2:00 PM	Curtice
2:15 PM	Weil
2:30 PM	Lee
2:45 PM	**BREAK**
3:00 PM	Gee
3:15 PM	Foster
3:30 PM	Gee
3:45 PM	Richmond
4:00 PM	Hoff
4:15 PM	**BREAK**
4:25 PM	Bennis
4:40 PM	Manchester
4:55 PM	Hotton
5:10 PM	Howell
5:25 PM	Philippe

Saturday, June 10

Time	Speaker
8:30 AM	Martin
8:45 AM	Kirkland
9:00 AM	Freimuth
9:15 AM	Beguesse
9:30 AM	Hunt-Foster
9:45 AM	Zanno
10:00 AM	Tucker
10:15 AM	Suarez
10:30 AM	**BREAK**
10:45 AM	Avrahami
11:00 AM	Hedge
11:15 AM	Makovicky
11:30 AM	Tsogtbaatar
11:45 AM	Huh
12:00 PM	Jung
12:15 PM	**LUNCH**
1:15 PM	Gobbo
1:30 PM	Noto
1:45 PM	Breithaupt
2:00 PM	Bender
2:15 PM	Lund
2:30 PM	Mansergh
2:45 PM	Longrich
3:00 PM	Tran
3:15 PM	**BREAK**
3:25 PM	Brinkman
3:40 PM	Lively
3:55 PM	Farke
4:10 PM	Loewen
4:20 PM	**BREAK**
4:35 PM	Sertich
4:50 PM	Titus
5:05 PM	Brink
5:20 PM	Warner-Cowgill

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Posters

Poster Number	Thursday, June 8	Friday, June 9	Saturday, June 10
1	Shibata	Celeskey	Breithaupt
2	Kalu	Wedel	Heck
3	Forster	Lauer	Jo
4	Ford	Rowland	Jorgensen
5	Brink	Armour Smith	Anderson
6	Ong	Trujillo	Smith
7	Hurlbut	Hasiotis	McCuen
8	Parrish	Lockley	Ostrowski
9	Guillaume	McCloskey	Smith
10	Kim	Lockley	Conway
11	Anduza	Krumenacker	Mallon
12	Bishop	Lee	Atkins-Weltman
13	Pedernera	Foster	Warner-Cowgill
14	Benavente.	Gee	Brinkman
15			Beveridge
16			Hunt-Foster

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List of Authors and Abstract Titles in Chronological Session Order

THURSDAY, JUNE 8, 2023

TECHNICAL SESSION 1: PALEOCLIMATOLOGY & PALEOGEOGRAPHY

MODERATORS: Celina Suarez & Queen Kalu

8:45 **L. Burgener, E. Hyland** PROXY-BASED RECONSTRUCTIONS OF CRETACEOUS CLIMATE EXTREMES

9:00 **K. Andrzejewski, M. Suarez, C. Noto** COMBINING PALEOSOL STABLE ISOTOPE PROXIES TO PROVIDE INSIGHT ON INTERACTIONS BETWEEN CLIMATIC, BIOTIC, AND ATMOSPHERIC PROCESSES DURING THE MID-CRETACEOUS IN TEXAS AND OKLAHOMA

9:15 **K. Carpenter** RECONSTRUCTING THE FLOODPLAIN PALEOGEOGRAPHY ASSOCIATED WITH THE QUARRY RIVER, DINOSAUR NATIONAL MONUMENT, UTAH, USA

9:30 **C. Cilliers, R. Tucker, L. Zanno** REAPPRAISAL OF THE MORENO HILL FORMATION, NEW MEXICO (USA)

9:45 **L. Xing, K. Niu, J. Mallon, T. Miyashita** A NEW ANKYLOSAUR FROM CHINA AND ITS SIGNIFICANCE TO ASIAN PALEOBIOGEOGRAPHY

THURSDAY, JUNE 8, 2023

TECHNICAL SESSION 2: PALEOECOLOGY

MODERATORS: Chris Noto & Clayton Forster

10:15 **E. Bordy, L. Sciscio, M. Lockley, H. Head** KAROO FOOTPRINTS MADE DURING THE CARNIAN PLUVIAL EVENT IN SW GONDWANA

10:30 **J. Choiniere, R. Benson, K. Dollman, K. Chapelle, C. Suarez, G. Sharman, E. Bordy, J. Botha, B. Weiss, P. Barrett** A NEW QUARRY IN THE UPPER TRIASSIC LOWER ELLIOT FORMATION PROVIDES EVIDENCE FOR CLASSICAL NORIAN FAUNAS IN THE MAIN KAROO BASIN OF SOUTHERN AFRICA

10:45 **G. Engelmann, D. Chure, B. Britt** CARBONATE MOUNDS IN THE TRIASSIC-JURASSIC NUGGET SANDSTONE NEAR DINOSAUR NATIONAL MONUMENT, NORTHEASTERN UTAH, OASES IN THE ERG

11:00 **J. Parrish, S. Hasiotis, M. Chan** FRESHWATER AQUATIC ECOSYSTEMS OF THE LOWER JURASSIC NAVAJO SANDSTONE, UTAH

11:15 **M. Chan, S. Hasiotis, J. Parrish** INDICATORS OF AN ACTIVE HYDROLOGY IN THE EOLIAN ECOSYSTEM OF THE JURASSIC NAVAJO SANDSTONE, SOUTHERN UTAH

11:30 **R. Benson, R. Butler, S. Evans, M. Jones, E. Panciroli, M. Tałanda, S. Walsh** SQUAMATES, MAMMALS, SALAMANDERS AND OTHER SMALL TETRAPODS FROM THE MIDDLE JURASSIC KILMALUAG FORMATION, ISLE OF SKYE, SCOTLAND

1:00 **S. Donaldson** MAGNIFICENT MOLLUSCS – THE FIRST REGIONAL PALAEOBIOGEOGRAPHICAL RECONSTRUCTION OF THE MID-CRETACEOUS GRIMAN CREEK FORMATION, LIGHTNING RIDGE, EASTERN AUSTRALIA USING FRESHWATER MOLLUSCS

1:15 **C. Noto, S. Drumheller, T. Adams, B. Adrian, H. Smith, R. Tykoski, P. Flaig** FAUNAL COMPOSITION, DISTRIBUTION, AND PALEOBIOGEOGRAPHY OF FOSSIL VERTEBRATES FROM THE LEWISVILLE FORMATION (WOODBINE GROUP, CENOMANIAN)

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1:30 **J. Diepenbrock** THE FERRIS FORMATION: AN OVERLOOKED YET DIVERSE END-CRETACEOUS FORMATION IN WYOMING

1:45 **S. Maccracken, I. Miller, C. Labandeira** AN INTERCONTINENTAL ASSOCIATION OF DRAGONFLY OVIPOSITION ON A FLOATING AQUATIC PLANT FROM THE LATE CRETACEOUS OF NORTH AMERICA AND ASIA

2:00 **M. Gilbert, E. Bamforth** PALEOECOLOGY OF VERTEBRATE MICROFOSSIL ASSEMBLAGES FROM THE EASTERNMOST DINOSAUR PARK FORMATION (UPPER CAMPANIAN) SASKATCHEWAN, CANADA: RECONSTRUCTING DIVERSITY THROUGH TRANSGRESSIVE SEQUENCES

2:15 **E. Bamforth** NEW PALEOFLORAL SITES FROM THE LATE CRETACEOUS WAPITI FORMATION OF ALBERTA, CANADA: IMPLICATIONS FOR UNDERSTANDING THE PALEOECOLOGY OF BOREAL DINOSAUR COMMUNITIES

THURSDAY, JUNE 8, 2023

THEME SESSION: GLOBAL PERSPECTIVES ON MESOZOIC LACUSTRINE ECOSYSTEMS

MODERATORS: Cecilia Benavente & Randy Irmis

2:45 **K. Bohacs, C. Benavente, A. Mancuso** NOTES FROM THE UNDERGROUND—A GLOBAL PERSPECTIVE ON THE ESSENTIAL ROLE OF GROUNDWATER AND CONTINGENCIES IN FORMING AND PRESERVING PALEOENVIRONMENTAL INDICATORS AND CLIMATE PROXIES IN CONTINENTAL SETTINGS

3:00 **E. Bordy** 'THE LAKE AS A MICROCOSM': LACUSTRINE ECOSYSTEMS FROM THE EARLY JURASSIC OF SOUTHERN PANGEA

3:15 **P. Moisan, S. Voigt, B. Bomfleur, H. Kerp, J. Schneider, J. Fischer, I. Kogan** THE MIDDLE–LATE TRIASSIC FLORA FROM THE MADYGEN LAGERSTÄTTE, SW KYRGYZSTAN

3:30 **M. Suarez, A. Al-Suwaidi, J. Kirkland, K. Snell, A. Möller, N. McLean, C. Suarez, E. Montgomery, M. Paige** A WINDOW TO THE EARLY CRETACEOUS NORTH AMERICAN CLIMATE AND ENVIRONMENT: THE 'LAKE CARPENTER' LACUSTRINE STRATA OF THE CEDAR MOUNTAIN FORMATION

4:00 **C. Suarez, G. Sharman, L. Boush, A. Milner, A. Stigall, L. Antonietto, J. Whiteside** LOCATING THE TRIASSIC-JURASSIC BOUNDARY WITHIN THE MOENAVE FORMATION: IMPLICATIONS FOR CLIMATIC, FAUNAL, AND ENVIRONMENTAL CHANGE OF THE LACUSTRINE WHITMORE POINT MEMBER FOLLOWING THE END-TRIASSIC EXTINCTION EVENT

4:15 Withdrawn

4:30 **A. Milner, J. Harris, J. Kirkland, M. Lockley, C. Suarez, G. Sharman, P. Olsen, J. Buchwitz** ECOSYSTEMS OF THE MOENAVE FORMATION ACROSS THE TRIASSIC–JURASSIC TRANSITION

4:45 **M. Lara, J. Foster, T. Howells, J. Kirkland** ARTHROPODA BODY FOSSILS FROM THE JURASSIC SALAD BAR SITE IN THE UPPER JURASSIC MORRISON FORMATION IN SOUTHEASTERN UTAH, USA

THURSDAY, JUNE 8, 2023

POSTER SESSION 1

1 **K. Shibata, B. Adhiperdana, M. Ito, A. Milner, M. Lockley** MODERATELY HUMID PALEOCLIMATES IN WESTERN PANGAEA DURING THE LATE TRIASSIC: EVIDENCE FROM DETRITAL COMPOSITIONS OF THE CHINLE FORMATION IN SOUTHWESTERN UTAH

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2 **Q. Kalu, C. Suarez, G. Sharman, M. Suarez, M. Allen, M. D'Emic** PCO 2 CALCULATIONS FROM CLOVERLY FORMATION IN NORTHERN WYOMING USING PEDOGENIC CARBONATE NODULES

3 **C. Forster, C. Suarez** PRELIMINARY WATER OXYGEN ISOTOPIC LANDSCAPE OF THE EARLY CRETACEOUS IMPLIES PRONOUNCED LATITUDINALLY INDUCED RAINOUT EFFECT

4 **T. Ford** MONGOLIA TO THE WEST COAST OF CALIFORNIA: A POSSIBLE SAUROLOPHINE LARAMIDIA CONNECTION

5 **A. Brink, G. Phillips, S. Kennedy** NEW LATE CRETACEOUS MAMMALS FROM APPALACHIA: ADDITIONS FROM MISSISSIPPI

6 **N. Ong** USING SHELL ORNAMENTATION TO DOCUMENT PAN-TRIONYCHID TURTLE DIVERSITY AND DISTRIBUTION ACROSS THE K-PG BOUNDARY

7 **M. Hurlbut** PLANT FOSSIL LOCALITY IN THE SHINARUMP MEMBER OF THE CHINLE FORMATION (UPPER TRIASSIC) OF SOUTHWESTERN UTAH (WASHINGTON COUNTY)

8 **J. Totman Parrish, S. Hasiotis, M. Chan** PALEOECOLOGY AND BIOFACIES OF THE LOWER JURASSIC NAVAJO SANDSTONE

9 **A. Guillaume, L. Ezquerro, M. Moreno-Azanza, O. Mateus** VERTEBRATE MICROFOSSIL ASSEMBLAGES FROM THE LOURINHÃ FORMATION: A SNEAK PEEK ON THE PALEOECOLOGY OF THE LATE JURASSIC IN PORTUGAL

10 **K. Kim, M. Lockley, J. Lim** A CRETACEOUS FROG FOOTPRINT FORUM: A HIGHLY DIVERSE ICHNOFAUNA FROM THE JINJU FORMATION (CRETACEOUS) OF KOREA HIGHLIGHTS THE PALEOECOLOGICAL IMPORTANCE OF RARE TRACKS

11 **D. Anduza, J. Kirkland** LIAONINGOSAURUS AS AN ALGAL GRAZER: CLUES FROM MARINE IGUANAS AND RAY-FINNED FISHES

12 **G. Bishop, B. Kržič, M. Samms, B. Meyer, A. Rindsberg, F. Pirkle** ON THE TERRESTRIAL EDGE - CRETACEOUS SEA TURTLE NESTS; ECOLOGY, PALEOECOLOGY, AND ICHNOLOGY

13 **T. Pedernera, C. Mancuso, C. Benavente, E. Ottone** PLANT PRESERVATION IN LAKES FROM TRIASSIC BASINS OF ARGENTINA **Part of the Global Perspectives on Mesozoic Lacustrine Ecosystems Theme Session

14 **C. Benavente, T. Pedernera, S. Suarez-Davi, P. Guillermina Giordano, A. Mancuso** FISH DIVERSITY AND LAKE BASIN TYPE FROM TRIASSIC RIFT BASINS OF ARGENTINA **Part of the Global Perspectives on Mesozoic Lacustrine Ecosystems Theme Session

FRIDAY, JUNE 9, 2023

TECHNICAL SESSION 3: TERRESTRIAL ECOSYSTEMS – TRIASSIC – MIDDLE JURASSIC

MODERATORS: Jessie Atterholt & Marina Suarez

8:30 **J. Napoli, J. Flynn, M. Norell** THE VAST MISSING DIVERSITY OF THE DINOSAUR FOSSIL RECORD

8:45 **R. Smith, J. Botha, P. Viglietti** DROUGHT-AFFLICTED TETRAPODS IN THE EARLY TRIASSIC KAROO BASIN, SOUTH AFRICA

9:00 **P. Hancox, C. Montgomery, A. Heckert, C. Duffin, D. Hoffman, E. Schneiderhan** THE FAUNA OF THE LOWER BURGERSDORP FORMATION (*CYNOGNATHUS* ASSEMBLAGE ZONE – LANGBERGIA SUBZONE) OF SOUTH AFRICA

9:15 **S. Hasiotis, J. Totman Parrish, M. Chan** USING THE DIVERSITY AND DISTRIBUTION OF VERTEBRATE BURROWS TO RECONSTRUCT PALEOECOLOGICAL RELATIONSHIPS IN THE LOWER JURASSIC NAVAJO SANDSTONE, SOUTHEASTERN UTAH

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9:30 **J. Martz, B. Small** COLORADO'S OLDEST DINOSAURS: THEROPODS FROM THE RED SILTSTONE MEMBER OF THE CHINLE FORMATION IN THE EAGLE BASIN OF COLORADO AND A SUMMARY OF LATE TRIASSIC ORNITHODIRAN BIOCHRONOLOGY IN WESTERN NORTH AMERICA

9:45 **D. DeBlieux, A. Milner, R. Irmis, J. Kirkland** GEOLOGY AND PALEONTOLOGY OF THE UPPER TRIASSIC CHINLE FORMATION IN THE NORTHERN PARADOX BASIN OF SOUTHEASTERN UTAH: COMPARING SURVEYS FROM CANYONLANDS NATIONAL PARK AND INDIAN CREEK IN BEARS EARS NATIONAL MONUMENT

10:00 **A. Heckert, J. Crothers, L. Rose, S. Nesbitt, I. Pugh, M. Stocker, P. Barrett, S. Wills, D. Ward, B. Lauer, R. Lauer** AN EXCEPTIONALLY RICH UPPER TRIASSIC MICROVERTEBRATE SITE FROM THE ?EARLY REVUELTIAN (MID-NORIAN) GARITA CREEK FORMATION OF EAST-CENTRAL NEW MEXICO, USA

10:30 **P. Barrett, L. Sciscio, M. Zondo, T. Broderick, D. Munyikwa, P. Viglietti, S. Edwards, K. Chapelle, K. Dollman, J. Choiniere** FAUNAL CHANGE ACROSS THE TRIASSIC–JURASSIC BOUNDARY: NEW INSIGHTS FROM THE MID-ZAMBEZI BASIN OF ZIMBABWE

10:45 **S. Singh, A. Elsler, T. Stubbs, E. Rayfield, M. Benton** DIFFERENCES IN ARCHOSAUROMORPH FUNCTIONAL MORPHOLOGY REVEAL A SHIFT IN APEX CARNIVORE ECOLOGIES DURING THE RISE OF THE DINOSAURS

11:00 **A. Chinsamy, I. Cerda, D. Pol** ADVANCES IN OUR UNDERSTANDING OF THE GROWTH PATTERNS OF SAUROPODOMORPHA

11:15 **K. Chapelle, J. Botha, J. Choiniere** THE SMALLEST ADULT JURASSIC SAUROPODOMORPH

11:30 **O. Zafaty, M. Oukassou, X. Pereda-Suberbiola, F. Riguetti, J. Company, S. Bendrioua, R. Tabuce, A. Charrière** A NEW PARTIAL SKELETON INCLUDING DERMAL ARMOR OF A THYREOPHORAN (ORNITHISCHIA) DINOSAUR FROM MIDDLE JURASSIC OF NORTH AFRICA (MOROCCO)

11:45 **S. Wills, A. Cavosie, V. Fernandez, C. Underwood, D. Ward, E. Bernard, P. Barrett** HIGH DIVERSITY MIDDLE JURASSIC DINOSAUR FAUNAS REVEALED THROUGH MICROVERTEBRATE ANALYSIS

FRIDAY, JUNE 9, 2023

TECHNICAL SESSION 3: TERRESTRIAL ECOSYSTEMS – LATE JURASSIC

MODERATORS: John Foster & Elliott Armour Smith

1:00 **C. Morrison, P. Barrett, P. Mannion, L. Porro** EVIDENCE FOR POTENTIAL PISCIVORY IN JURASSIC MEGALOSAUROID THEROPODS

1:15 **L. Sciscio, C. Meyer, M. Belvedere, M. Lockley, B. Schumacher** SURF AND TURF: A WINDOW INTO LATE JURASSIC SAUROPOD AND THEROPOD POPULATIONS FROM LACUSTRINE AND COASTAL AREAS AT THE PURGATOIRE VALLEY (USA) AND JURA (SWITZERLAND) TRACK SITES

1:30 **J. Russo, O. Mateus** REVIEW OF *DRACOPELTA ZBYSZEWSKII*, AN ANKYLOSAUR FROM THE UPPER JURASSIC OF PORTUGAL

1:45 **A. Guillaume, O. Mateus, M. Moreno-Azanza** THE ALBANERPETONTIDAE (LISSAMPHIBIA) FROM THE LOURINHÃ FORMATION (UPPER JURASSIC, PORTUGAL)

2:00 **B. Curtice, M. Wedel, R. Wilhite, C. Boisvert** NEW MATERIAL OF *HAPLOCANTHOSAURUS* (HATCHER 1903) FROM THE DRY MESA DINOSAUR QUARRY AND A COMMENT ON SAUROPOD DIVERSITY

2:15 **A. Weil, M. Wedel, L. Hall** MICROVERTEBRATE EXPANSION OF KNOWN FAUNA OF THE MORRISON FORMATION OF OKLAHOMA WILL ENABLE MORE MEANINGFUL COMPARISONS WITH OTHER REGIONS

2:30 **J. Lee** MESIC LATE JURASSIC COASTAL FLORAS FROM PACIFIC NORTH AMERICA

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FRIDAY, JUNE 9, 2023

THEME SESSION:

GREENING OF THE UPPER JURASSIC MORRISON FORMATION, USA: HUGE ADVANCES IN PALEOBOTANY WITH IMPLICATIONS FOR DINOSAUR HERBIVORY AND ECOSYSTEM RECONSTRUCTION

MODERATORS: **Carole Gee**

3:00 **C. Gee** PALEOBOTANY OF THE UPPER JURASSIC MORRISON FORMATION: WHAT'S NEW AND WHAT'S TO COME?

3:15 **J. Foster, C. Gee, S. Ash, J. Kirkland** PRELIMINARY OBSERVATIONS ON THE JURASSIC SALAD BAR, A NEW GINKGOPHYTE-DOMINATED FLORA FROM THE UPPER JURASSIC MORRISON FORMATION IN SOUTHEASTERN UTAH, USA

3:30 **C. Gee** ELUCIDATING ECOLOGICAL INTERACTIONS BETWEEN TREES, INSECTS, FUNGI, AND DINOSAURS IN THE UPPER JURASSIC BIOTA OF THE MORRISON FORMATION

3:45 **D. Richmond** A STRANGE WOOD IN A STRANGE LAND: THE PALEOECOLOGY OF THE FOSSIL WOOD *XENOXYLON* IN THE LATE JURASSIC OF NORTH AMERICA

4:00 **F. Hoff, C. Gee** DECIDUOUS OR EVERGREEN? A CASE STUDY ON A NEW SPECIES OF UPPER JURASSIC WOOD FROM THE MORRISON FORMATION OF MONTANA, USA

4:25 **M. Bennis, C. Gee, D. Gray, R. Love** RECOVERY OF AN EXCEPTIONAL PERMINERALIZED TREE TRUNK FROM THE SALT WASH MEMBER OF THE MORRISON FORMATION OF NE UTAH: THE MANWELL LOG

4:40 **S. Manchester, C. Gee, P. Crane** NEWLY RECOGNIZED GYMNOSPERM DIVERSITY IN THE UPPER JURASSIC BRUSHY BASIN MEMBER OF THE MORRISON FORMATION BASED ON 3-DIMENSIONALLY PRESERVED REPRODUCTIVE STRUCTURES FROM THE HENRY MOUNTAINS OF UTAH, USA

4:55 **C. Hotton, N. Baghai-Riding** CONTRAST BETWEEN THE PALYNOFLORA AND MEGAFLORA IN THE JURASSIC SALAD BAR SITE, UTAH, USA: IMPLICATIONS FOR THE REGIONAL FLORA

5:10 **M. Howell, C. Gee, K. Südekum** PRELIMINARY OBSERVATIONS ON EXPERIMENTALLY PRODUCED PLANT-BASED COPROLITES AS A BASIS TO UNDERSTANDING DINOSAUR HERBIVORY

5:25 **M. Philippe, D. Richmond, R. Lupia, D. McLemore** REAPPRASIAL OF *XENOXYLON MORRISONENSE* LEADS TO RECOGNITION OF A NEW FOSSIL WOOD GENUS

FRIDAY, JUNE 9, 2023

POSTER SESSION 2

1 **M. Celeskey, A. Heckert, H. Klein** CHIROTHERES: CINDERELLA AND THE ADVENT OF ARCHOSAURIAN LOCOMOTOR INNOVATIONS–A PICTORIAL GUIDE

2 **M. Wedel, J. Atterholt** EXPANDED NEUROCENTRAL JOINTS IN THE VERTEBRAE OF SAUROPOD DINOSAURS

3 **R. Lauer, B. Lauer, D. Ward, A. Ward** ACQUIRING THE HOMESTEAD UPPER TRIASSIC SITE: AN INTERNATIONAL COLLABORATION THAT PROVIDES EDUCATIONAL, RESEARCH AND PUBLICATION OPPORTUNITIES

4 **S. Rowland, T. Cluff, N. Saines** FIRST REPORT OF VERTEBRATE BURROWS IN THE EARLY JURASSIC AZTEC SANDSTONE OF SOUTHERN NEVADA

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5 **E. Armour Smith, C. Sidor** A NEW SHUVOSAURID FROM THE UPPER TRIASSIC CHINLE FORMATION OF PETRIFIED FOREST NATIONAL PARK: IMPLICATIONS FOR THE SYSTEMATICS AND BIOGEOGRAPHY OF THE CLADE

6 **K. Trujillo, K. Chamberlain, J. Foster** CHALLENGES AND SUCCESSES OF DATING MESOZOIC TERRESTRIAL ROCKS: AN UPDATE ON THE MORRISON FORMATION DATING PROJECT

7 **S. Hasiotis, J. Totman Parrish, M. Chan** A FRAMEWORK TO CONSTRUCT EOLIAN ICHNOCOENOSES AND ICHNOFACIES: EXAMPLES FROM THE LOWER JURASSIC NAVAJO SANDSTONE, SOUTHEASTERN UTAH

8 **M. Lockley, P. Murphey, A. Romilio** MULTIPLE DINOSAUR TRACKSITES DOMINATED BY DIMINUTIVE TRIDACTYL TRACKMAKERS FROM THE UPPER JURASSIC, MOAB MEMBER (CURTIS FORMATION), GRAND COUNTY, UTAH

9 **J. McCloskey, J. Peterson, J. Warnock, C. Dooms** VERTEBRATE ICHNOFOSSILS FROM JURASSIC NATIONAL MONUMENT, UPPER MORRISON FORMATION, UTAH - A PRELIMINARY CENSUS

10 **M. Lockley, P. Murphey, A. Romilio** A LARGE, SAURISCHIAN-DOMINATED, TRACKSITE IN THE UPPER JURASSIC MORRISON FORMATION, GRAND COUNTY, UTAH: A SPECTACULAR EXAMPLE OF EXTENSIVE DINOTURBATION

11 **L. Krumenacker, K. Carpenter, J. Moore, D. Varricchio** PRELIMINARY REPORT ON A PARTIAL NODOSAUR SKELETON FROM THE WAYAN FORMATION OF IDAHO

12 **J. Lee, K. Kim** THE FLORA OF THE EARLY CRETACEOUS JINJU KONSERVAT-LAGERSTATTE (110-106 MYA, ALBIAN), SOUTH KOREA

13 **J. Foster, C. Gee, S. Sroka** FIRST REPORT ON THE TURTLE ISLAND FLORA, A NEW UPPER JURASSIC PLANT ASSEMBLAGE FROM THE MORRISON FORMATION OF NORTHEASTERN UTAH, USA **Part of the Greening of the Upper Jurassic Morrison Formation, USA: Huge Advances in Paleobotany with Implication for Dinosaur Herbivory and Ecosystem Reconstruction Theme Session

14 **C. Gee, P. Sander, F. Hoff, D. Richmond, A. Xie, Y. Wang** FIRST PALEOBOTANICAL REPORT ON THE ESCALANTE PETRIFIED FOREST OF THE UPPER JURASSIC MORRISON FORMATION IN UTAH, USA: SURVEY AND DATA COLLECTION OF TRAIL LOGS, OCCURRENCE OF GIANT TREES, GENESIS OF FOSSIL DEPOSIT **Part of the Greening of the Upper Jurassic Morrison Formation, USA: Huge Advances in Paleobotany with Implication for Dinosaur Herbivory and Ecosystem Reconstruction Theme Session

SATURDAY, JUNE 10, 2023

TECHNICAL SESSION 3: TERRESTRIAL ECOSYSTEMS – EARLY-MID CRETACEOUS

MODERATORS: Kyla Beguesse & Heather Smith

8:30 **T. Martin, A. Averianov, J. Schultz, A. Schwermann, O. Wings** LATE JURASSIC AND EARLY CRETACEOUS MAMMALS FROM GERMANY

8:45 **J. Kirkland, D. DeBlieux, S. Madsen** THE DAWN OF THE CRETACEOUS IN EASTERN UTAH

9:00 **W. Freimuth, J. Lively, L. Zanno** A THERIZINOSAUR IN TROODONTID'S CLOTHING? REASSESSING THE TROODONTID *GEMINIRAPTOR SUAREZARUM* IN LIGHT OF NEW THERIZINOSAURIAN MATERIAL FROM THE LOWER CRETACEOUS YELLOW CAT MEMBER OF THE CEDAR MOUNTAIN FORMATION, UTAH, USA

9:15 **K. Beguesse, W. Freimuth, L. Herzog, L. Zanno** A SURVEY OF PALEOPATHOLOGIES IN THE EARLY CRETACEOUS THERIZINOSAURIAN *FALCARIUS UTAHENSIS* FROM CRYSTAL GEYSER QUARRY UTAH

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9:30 **R. Hunt-Foster, J. Kirkland** THE EARLY CRETACEOUS ORNITHOMIMOSAUR RECORD IN NORTH AMERICA

9:45 **L. Zanno, R. Tucker, C. Suarez, H. Avrahami, L. Herzog, J. Hedge, E. Lund, W. Freimuth, K. Beguesse, P. Makovicky** PALEOBIODIVERSITY OF THE MUSSENTUCHIT MEMBER, CEDAR MOUNTAIN FORMATION (UTAH): NEW DISCOVERIES ENHANCE AND CONTEXTUALIZE AN EXCEPTIONAL WINDOW INTO MID-CRETACEOUS TERRESTRIAL ECOSYSTEMS

10:00 **R. Tucker, P. Makovicky, R. Cifelli, L. Zanno** GEOLOGICAL REVISION OF THE EARLY CENOMANIAN MUSSENTUCHIT MEMBER, CEDAR MOUNTAIN FORMATION, CENTRAL UTAH (USA)

10:15 **C. Suarez, C. Forster, G. Sharman, J. Fekete, M. Suarez, L. Zanno, R. Tucker** UPDATES ON THE CHRONOSTRATIGRAPHIC FRAMEWORK OF THE CEDAR MOUNTAIN FORMATION OF UTAH AND IMPLICATIONS FOR FAUNAL COMPARISONS AND THE CRETACEOUS TERRESTRIAL REVOLUTION

10:45 **H. Avrahami, P. Makovicky, L. Zanno** AN EXCEPTIONAL ASSEMBLAGE OF NEW ORODROMINE DINOSAURS FROM THE POORLY CHARACTERIZED MID-CRETACEOUS OF NORTH AMERICA

11:00 **J. Hedge, L. Zanno** REASSESSING THE ALPHA-TAXONOMY OF THE OOGENUS *MACROELONGATOOLITHUS* BASED ON A NEW NEST FROM THE CENOMANIAN-AGE MUSSENTUCHIT MEMBER OF THE CEDAR MOUNTAIN FORMATION (UTAH)

11:15 **P. Makovicky, R. Cifelli, L. Zanno** THE MID-CRETACEOUS FOSSIL RECORD OF CAENAGNATHIDS IN NORTH AMERICA AND ITS IMPLICATIONS FOR THE TIMING OF FAUNAL INTERCHANGE WITH ASIA

11:30 **C. Tsogtbaatar, R. Takasaki, J. Yoshida, B. Buyantegsh, B. Mainbayar, L. Zanno** THE OLDEST PACHYCEPHALOSAUR (ORNITHISCHIA: MARGINOCEPHALIA) FROM THE EARLY CRETACEOUS KHUKHTEEG FORMATION AT KHUREN DUKH LOCALITY OF MONGOLIA

11:45 **M. Huh, J. Kim, J. Jung, H. Jo, M. Kim** REVIEW OF DINOSAURS, PTEROSAURS, AND BIRDS OF KOREA

12:00 **J. Jung, M. Huh, H. Jo** THE PTEROSAUR TRACKS OF KOREA: THE DIVERSITY AND ECOLOGY OF THE CRETACEOUS PTEROSAURS THROUGH THE FOOTPRINTS

SATURDAY, JUNE 10, 2023

TECHNICAL SESSION 3: TERRESTRIAL ECOSYSTEMS – LATE CRETACEOUS

MODERATORS: Tut Tran & Summer Ostrowski

1:15 **S. Gobbo, R. Bertini** UPPER CRETACEOUS CONTINENTAL DEPOSITS FROM THE BAURU GROUP, PARANÁ BASIN, SOUTHEASTERN BRASIL. STRATIGRAPHY, PALEOENVIRONMENTS, PALEOBIOTAS AND BIOCHRONOSTRATIGRAPIC ATTEMPTS

1:30 **C. Noto, P. Flaig, D. Contreras, P. Zippi, M. Lorente, K. Andrzejewski, R. Tykoski** DECIPHERING THE WOODBINE GROUP (LATE CRETACEOUS; CENOMANIAN) OUTCROPS OF THE DALLAS–FT. WORTH METROPLEX: NEW DATA AND NEW HORIZONS

1:45 **B. Breithaupt, N. Matthews** EARLY CAMPANIAN FOOTPRINTS FROM THE EAST COAST OF MID-LARAMIDIA: STEPS FROM THE ORNITHOPOD HARBINGERS OF THE "CAMPANIAN EXPLOSION"

2:00 **E. Bender, T. Gates, E. Johnson, L. Zanno** A NEW KRITOSAURIN HADROSAURID (DINOSAURIA: ORNITHOPODA) FROM THE LATE CRETACEOUS OF COLORADO, USA

2:15 **E. Lund, L. Zanno** CENTROSAURINE CERATOPSID MATERIAL FROM THE LATE CRETACEOUS (CAMPANIAN) MENEFEE FORMATION OF NORTHWEST NEW MEXICO

2:30 **R. Mansergh, P. Upchurch, S. Maidment** SAMPLING BIAS IN CERATOPSID PHYLOGENIES

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2:45 **N. Longrich, P. Makovicky, T. Tokaryk, D. Cooper, E. Saitta, G. Erickson, T. Szekely, E. Snively** HATCHLINGS OF *TYRANNOSAURUS REX* AND THE EVOLUTION OF DINOSAUR REPRODUCTIVE STRATEGIES

3:00 **T. Tran, D. Pittinger, T. Olstad, B. Cockrell** HOODOO-THUNKIT? THE BEGINNINGS OF A LATE CRETACEOUS PALEONTOLOGY PROGRAM AT BRYCE CANYON NATIONAL PARK

SATURDAY, JUNE 10, 2023

THEME SESSION:

LARAMIDIA TO ASIA: BIOTA AND BIOGEOGRAPHY OF INTERCONNECTED ICONIC LATE CRETACEOUS ECOSYSTEMS

MODERATORS: **Alan Titus, Mark Loewen & Joe Sertich**

3:25 **D. Brinkman, P. Druckenmiller, J. López, G. Erickson, J. Eberle, L. Van Loon, N. Banerjee** FISHES FROM THE LATE CRETACEOUS PRINCE CREEK FORMATION, NORTH SLOPE OF ALASKA AND THEIR IMPLICATIONS FOR INTERCHANGE BETWEEN ASIA AND NORTH AMERICA

3:40 **J. Lively** NEW VERTEBRATE RECORDS FROM THE UPPER CRETACEOUS (CAMPANIAN) NESLEN FORMATION, EASTERN UTAH

3:55 **A. Farke** VERTEBRATE PALEONTOLOGY AND BIOSTRATIGRAPHY OF THE MESAVERDE FORMATION (MIDDLE CAMPANIAN) IN THE BIGHORN BASIN OF WYOMING, USA

4:10 **M. Loewen, J. Sertich** CAMPANIAN CENTROSAURINE CERATOPSID DIVERSITY AND REGIONAL ENDEMISM IN SOUTHERN LARAMIDIA

4:35 **J. Sertich, M. Loewen, E. Lund** NEW SPECIMENS FROM THE UPPER CAMPANIAN OF 'SOUTHERN' LARAMIDIA REVEAL UNEXPECTED COMPLEXITY IN "*PENTACERATOPS*-LIKE" CHASMOSAURINE RICHNESS

4:50 **A. Titus, J. Sertich, R. Irmis, M. Loewen** TYRANNOSAURID DINOSAUR DIVERSITY IN MIDDLE AND UPPER CAMPANIAN (LATE CRETACEOUS) ECOSYSTEMS OF LARAMIDIA: NEW INFORMATION FROM THE KAIPAROWITS FORMATION OF SOUTHERN UTAH, USA

5:05 **A. Brink, R. Cifelli, S. Wisk** LATITUDINAL VARIATION OF EARLY CAMPANIAN MAMMALIAN FAUNAS FROM THE LOWER SHALE MEMBER OF THE AGUJA FORMATION IN WEST TEXAS, THE WAHWEAP FORMATION IN UTAH, AND THE MENEFEE FORMATION IN NEW MEXICO

5:20 **E. Warner-Cowgill, G. Storrs, L. Ashurst-Mcgee, M. Affolter, Q. Hawkins, A. Stringham, E. Tamez-Galvan, L. Kosowatz, T. Tran, A. Lujan** VERTEBRATE PALEOFAUNA OF THE CAMPANIAN ALMOND FORMATION OF WYOMING: HISTORY OF STUDY, BIOGEOGRAPHIC SIGNIFICANCE, AND EARLY RESULTS OF AN ONGOING PALEONTOLOGICAL SURVEY

SATURDAY, JUNE 10, 2023

POSTER SESSION 3

1 **B. Breithaupt, N. Matthews, R. Hunt-Foster** USING PHOTOGRAMMETRY FOR LONG-TERM PRESERVATION AND MANAGEMENT OF IN SITU MESOZOIC PALEONTOLOGICAL RESOURCES: PRESERVING ANCIENT ECOSYSTEMS

2 **M. Heck, S. Mohler, C. Sickles, J. Noviello, D. Hoffman, L. Thrasher, J. Borst, B. Mohler** LOCATING SUBSURFACE FOSSILS USING STATISTICAL ANALYSIS OF GAMMA DETECTION

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3 **H. Jo, M. Huh, J. Jung, M. Kim** THE DIVERSITY OF DINOSAUR EGG FOSSILS FROM KOREA AND THE PRELIMINARY STUDY ON THE NEW DINOSAUR EGGS FROM SHINAN, JEOLLANAM-DO PROVINCE

4 **R. Jorgensen, J. Kirkland, D. DeBlieux, L. Zanno, M. Loewen** REASSESSMENT OF *YURGOVUCHIA* PELVIC MATERIAL AND THEROPOD DIVERSITY IN THE LOWER YELLOW CAT MEMBER OF THE CEDAR MOUNTAIN FORMATION OF CENTRAL UTAH

5 **P. Anderson, M. King** UPPER TURONIAN UNIDENTIFIED PLANT FOSSIL IN A MARGINAL MARINE SAND BODY, FERRON SANDSTONE, EMERY COUNTY, UTAH

6 **D. Smith, S. Ritchey** LOCOMOTION IN THE HERBIVOROUS THEROPOD *NOTHRONYCHUS* AND ITS POSITION IN THE TURONIAN FAUNAL ECOSYSTEM

7 **W. McCuen, L. Zanno** REASSESSMENT OF VERTEBRATE MICROFOSSILS FROM THE STRAIGHT CLIFFS FORMATION (TURONIAN-EARLY CAMPANIAN) OF SOUTHERN UTAH

8 **S. Ostrowski, C. Noto** HAVE YOUR SNAKE AND EAT IT TOO: SNAKE MATERIAL FROM THE ARLINGTON ARCHOSAUR SITE (LEWISVILLE FORMATION, CENOMANIAN) OF NORTH-CENTRAL TEXAS

9 **H. Smith, B. Adrian, A. McDonald, D. Wolfe** THE ORIGINS OF UPPERMOST CRETACEOUS FOSSIL TURTLE ASSEMBLAGES IN NORTHWESTERN NEW MEXICO

10 **B. Conway, J. Peterson** BROKEN BONES AND BRUISED EGOS: TRAUMA AND INFECTION IN CERATOPSID DINOSAURS

11 **J. Mallon, M. Roloson, R. Holmes, E. Bamforth** LATE MAASTRICHTIAN CHASMOSAURINE CERATOPSIDS OF CANADA AND HORNED DINOSAUR EVOLUTION PRECEDING THE TERMINAL CRETACEOUS

12 **K. Atkins-Weltman, E. Snively** MASS PROPERTIES OF DINOSAURS FROM THE LATE MAASTRICHTIAN OF NORTHERN LARAMIDIA AND THEIR PALEOECOLOGICAL IMPLICATIONS

13 **E. Warner-Cowgill, M. Loewen** REASSESSMENT OF *TOROSAURUS UTAHENSIS* WITH A FOCUS ON MATERIAL FROM THE MAASTRICHTIAN NORTH HORN FORMATION OF CENTRAL UTAH

14 **D. Brinkman, M. Kundrat** NON-MARINE FISH FROM THE TURONIAN BISSEKTY FORMATION OF UZBEKISTAN PROVIDE EVIDENCE FOR INTERCHANGE IN THE FISH ASSEMBLAGES OF ASIA AND NORTH AMERICA **Part of the Laramidia to Asia: biota and biogeography of interconnected iconic Late Cretaceous ecosystems Theme Session

15 **T. Beveridge, E. Roberts, J. Ramezani** PRECISE BENTONITE CHRONOSTRATIGRAPHY FOR FOSSILIFEROUS CAMPANIAN STRATA ACROSS WESTERN NORTH AMERICA **Part of the Laramidia to Asia: biota and biogeography of interconnected iconic Late Cretaceous ecosystems Theme Session

16 **R. Hunt-Foster, J. Foster, J. Eberle, A. Heckert, J. Hartman, S. Sroka** NEW ELEMENTS OF THE PALEOBIOTA OF THE WILLIAMS FORK FORMATION (CAMPANIAN–MAASTRICHTIAN) OF NORTHWESTERN COLORADO AND NORTHEASTERN UTAH, USA **Part of the Laramidia to Asia: biota and biogeography of interconnected iconic Late Cretaceous ecosystems Theme Session

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ABSTRACTS

Poster Session 3 (Saturday, June 10, 2023)

UPPER TURONIAN UNIDENTIFIED PLANT FOSSIL IN A MARGINAL MARINE SAND BODY, FERRON SANDSTONE, EMERY COUNTY, UTAH

Anderson, Paul B.[1] and King, M. Ryan[2]
[1]Consulting Geologist, Salt Lake City, UT, paul@pbageo.com; [2]Western Colorado University, Gunnison CO, mrking@ualberta.ca

Unidentified fossil plants occur along the landward side of nearshore marine (shoreface) deposits near the sand body's landward pinchout in the uppermost portion of the Ferron Sandstone Member of the Mancos Shale. The occurrence is near a famous petroglyph known as the Rochester Panel, a few miles east of the town of Emery, UT. Individual specimens at the general locale number well above 30. They are generally about 2-4 m in height but vary considerably. The overall shape is conical (ice cream cone shaped) with the large dimension aperture of the cone in an up-stratigraphic position and the orientation relative to the strata is vertical. These fossils occur as distinct individuals but originate from a variety of stratigraphic positions within the landward side of the shoreface (back-barrier). The host sandstone ranges from 2 to 6 meters thick in the occurrence zone. Primary bedding in the sandstone body is horizontal, with minor trough cross strata. The grain-size of the sand ranges from fine to medium-grained. Individual specimens initiate from the various vertical positions. It appears they tended to be buried and regenerate to keep pace with vertical aggradation of the sand during deposition. The spatial distribution pattern of specimens is linear in two dimensions, paralleling the orientation of the pinchout of the nearshore sand body (NW-SE), exposures run about 400 m, and specimens only occurring in a band about 75 m wide. This suggests a preservational (taphonomic), salt water, or water table control on distribution of the fossils. The plant fossil is identified by straight to curved surfaces which are generally smooth. In rare cases, a distinct imprint pattern exists on these surfaces appearing "woody", but a distinct coloration related to weathering helps surfaces stand out in outcrop. The surfaces flare up and outward from a lowest "tip" or probably root. Two-thirds to the top of the length of the object is often a "pod' of chaotic carbonaceous-rich area. In many specimens this appears as the top (Figure 1). From top to bottom the flaring is generally linear in the lower portion and increases somewhat near the top. Only one other occurrence is known in the Ferron Sandstone outcrops which parallel the edge of the Wasatch Plateau.



Figure 1. Tap-root shaped unknown plant fossil exposed in a back-barrier sandstone. The fossil is approximately 5 m in height and stands vertical through bedding.

Technical Session 1: Paleoclimatology & Paleogeography (Thursday, June 8, 2023, 9:15 AM)

COMBINING PALEOSOL STABLE ISOTOPE PROXIES TO PROVIDE INSIGHT ON INTERACTIONS BETWEEN CLIMATIC, BIOTIC, AND ATMOSPHERIC PROCESSES DURING THE MID-CRETACEOUS IN TEXAS AND OKLAHOMA

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Terrestrial deposits, including paleosols, contain an abundance of paleoclimate and paleoenvironmental data. Chemical, mineralogical, and stable isotopic proxies that have been developed to study paleosols can be applied to the geologic record to answer questions regarding the interaction between climatic, biotic, and atmospheric processes. For example, the $\delta^{13}C$ of C_3 plant organic matter is thought to be driven by isotopic composition of atmospheric CO_2 and climatic conditions, in particular mean annual precipitation. The magnitude in which these factors influence the $\delta^{13}C$ of plant organic matter is still debated and few studies have analyzed these relationships in deep geologic time. In this study multiple

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stable isotope proxies including analyses of pedogenic carbonate and pedogenic phyllosilicates are used to reconstruct paleoclimatic and paleoatmospheric conditions during the Mid-Cretaceous (Aptian-Cenomanian) using terrestrial deposits in north-central Texas and southern Oklahoma. These results in conjunction with analyses of the $\delta^{13}C$ of plant organic material at each locality were then compared. Samples were collected from 5 localities: the Proctor Lake (PL) and Jones Ranch (JR) localities from the Twin Mountains Formation (Aptian/Albian); the Cross locality (CR) from the Antlers Formation (Albian); and the Arlington Archosaur Site (AAS) and Acme Brick Pit locality (ABP) from the Woodbine Group (Cenomanian).

Pedogenic calcite and their co-existing occluded organic matter were used to develop pCO_2 estimates ranging from 67-1100 ppmV (Andrzejewski et al., 2022). The $\delta^{13}C$ of plant organic matter ranged from -21.08‰ to -26.09‰. Stable hydrogen and oxygen isotopes from pedogenic phyllosilicates were used in conjunction with mineralogical and chemical data to estimate paleotemperatures ranging from 26 ± 3°C to 31± 3°C. Major element compositions of paleosol matrix materials were used to calculate CALMAG weathering values which correspond to paleoprecipitation estimates ranging from 270 ± 110 mm/yr to1490 ± 110 mm/yr (Andrzejewski & Tabor, 2020). Results of $\delta^{13}C$ of plant organic matter, mean annual precipitation estimates, and atmospheric pCO_2 estimates are shown in Figure 1.

Mean annual precipitation (MAP) is often argued as the largest influence on $\delta^{13}C$ of plant organic matter with water stressed plants correlating with more positive $\delta^{13}C$ values. In this study the PL locality recorded the most positive $\delta^{13}C$ organic matter values averaging -21.30‰ which correlate with the lowest MAP estimates averaging 331 ± 110 mm/yr. Localities including sites CR, AAS, and ABP with significantly higher MAP estimates ranging from 952 ± 110 mm/yr to 1486± 110 mm/yr contain more negative $\delta^{13}C$ organic matter values ranging from -23.28‰ to -26.09. These results support the current understanding of mean annual precipitation and its influence on the $\delta^{13}C$ of plant organic matter.

Less understood and constrained is the influence that changes in pCO_2 levels have on the $\delta^{13}C$ of plant organic matter. Recent studies by Hare et al. (2018) found a pCO_2 effect in gymnosperms of -1.7 ± 1.5‰ per 100 ppmV while studies on speleothems by Breecker (2017) shows -1.6 ± 0.3‰ per 100 ppmV (1σ). The two localities contained within the Twin Mountains Formation (Aptian), PL and JR, have consistent mean annual precipitation estimates, 365 ± 110 mm/yr and 331± 110 mm/yr, but show significant differences in $\delta^{13}C$ of plant organic matter. The average $\delta^{13}C$ of plant organic matter at locality

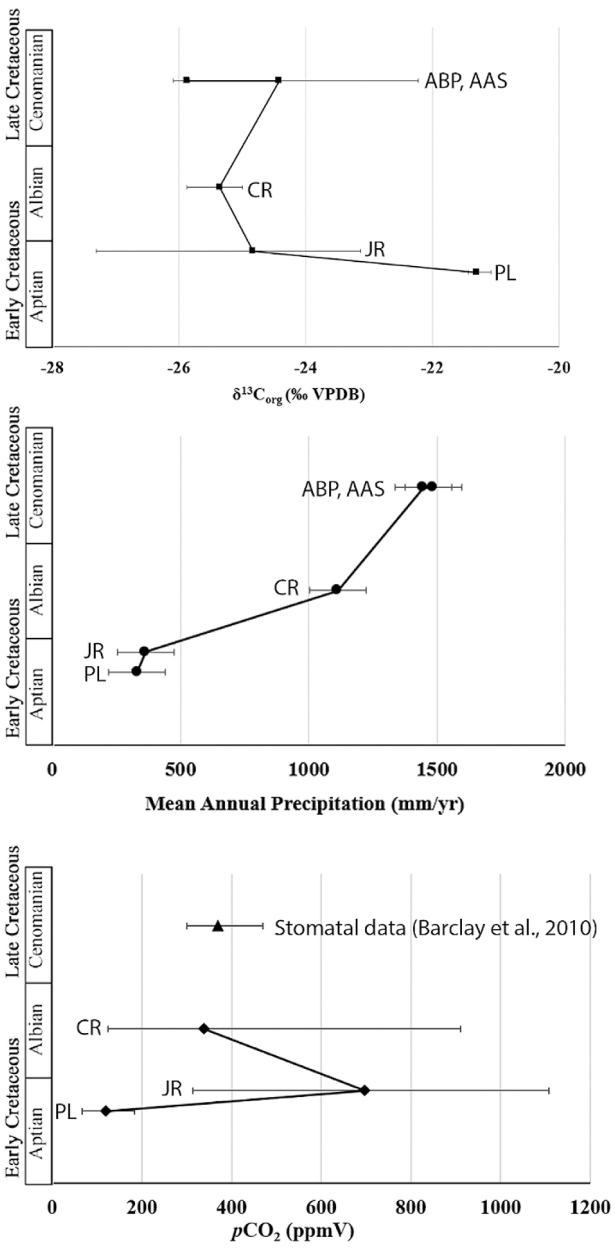


Figure 1. Top: Results showing $\delta^{13}C$ of organic matter from study localities (Locality abbreviations are listed on figure and described in text). Black boxes represent the mean $\delta^{13}C$ of organic matter for each locality and error bars show minimum and maximum values recorded. Middle: Mean annual precipitation estimates for study localities generated using bulk paleosol XRF data and applying CALMAG weathering index (data from Andrzejewski & Tabor, 2020). Bottom: Atmospheric pCO_2 estimates for study localities. Diamonds represent estimates mean pCO_2 estimates from Andrzejewski et al. (2022) using paleosol carbonate, with error bars showing minimum and maximum estimates. Triangle represents pCO_2 from Barclay et al. (2010) generated using stomatal index from Cenomanian deposits in southwest Utah.

PL is -21.30‰ while the average $\delta^{13}C$ at locality JR averages -24.83‰. The other notable difference between the two localities are estimates in atmospheric pCO_2.

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Estimates from Andrzejewski et al. (2022) show a sharp increase in atmospheric pCO_2 from locality PL ranging from 67 to 183 ppmV to locality JR ranging from 313-1108 ppmV. This dramatic increase in pCO_2 correlates with the negative shift in $\delta^{13}C$ of plant organic matter. Average pCO_2 estimates from both localities compared with the negative 3.53‰ shift in organic carbon values reveal a range of pCO_2 effect of -0.4‰ to -1.4‰ per 100 ppmV. This range appears consistent with studies conducted by Hare et al. (2018) and Breecker (2017). This data exhibits how deep time proxies from terrestrial deposits can contribute to our understanding of the relationship between the effect of mean annual precipitation and atmospheric pCO_2 on plant organic matter. Furthermore, they provide crucial paleoclimatic and paleoatmospheric data during greenhouse climate conditions.

References

Andrzejewski, K., & Tabor, N. (2020). Paleoenvironmental and paleoclimatic reconstruction of Cretaceous (Aptian-Cenomanian) terrestrial formations of Texas and Oklahoma using phyllosilicates. *Palaeogeography, Palaeoclimatology, Palaeoecology, 543*, e109491.

Andrzejewski, K., Tabor, N., Winkler, D., & Myers, T. (2022) Atmospheric pCO_2 reconstruction of Early Cretaceous terrestrial deposits in Texas and Oklahoma using pedogenic carbonate and occluded organic matter. *Geosciences, 12*(4), 148.

Barclay, R. S., McElwain, J. C., & Sageman, B. B. (2010). Carbon sequestration activated by a volcanic CO_2 pulse during Ocean Anoxic Event 2. *Nature Geoscience, 3*, 205-208.

Breecker, D.O. 2017. Atmospheric pCO_2 control on speleothem stable carbon isotopecompositions. *Earth and Planetary Science Letters, 458*, 58-68.

Hare, V. J., Loftus, E., Jeffrey, A., & Ramsey, C. B. (2018). Atmospheric CO_2 effect on stable carbon isotope composition of terrestrial fossil archives. *Nature Communications, 9*(1), 252.

Poster Session 1 (Thursday, June 8, 2023)

LIAONINGOSAURUS AS AN ALGAL GRAZER: CLUES FROM MARINE IGUANAS AND RAY-FINNED FISHES

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Liaoningosaurus is a small ankylosaur, known from many well-preserved skeletons from the Early Cretaceous

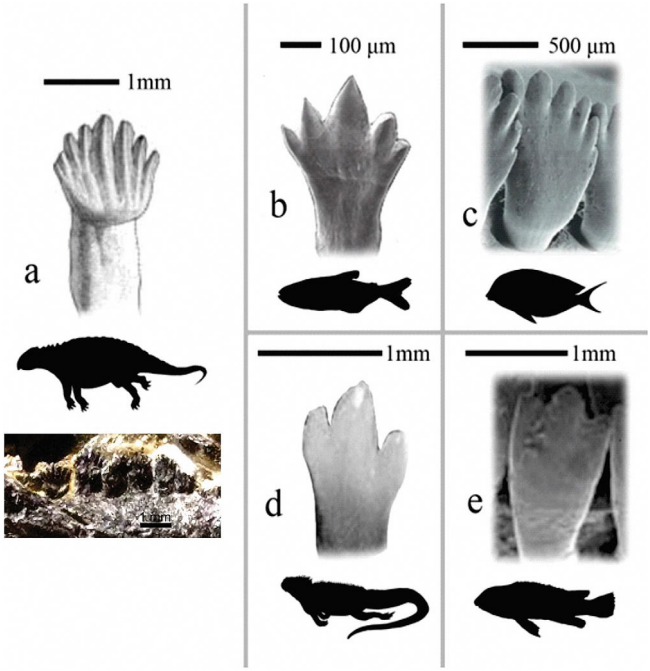


Figure 1. Maxillary tooth of *Liaoningosaurus* (a) (reproduced from Xu et al., 2001) with set of dentary teeth from specimen on exhibit at Beijing Museum of Natural History, compared with teeth of various extant algal grazers: (b) *Bryconamericus* (reproduced from Hirschmann et al. 2017), (c) *Acanthurus* (from Tebbett et al., 2017), (d) *Amblyrhynchus* (from Paparella & Caldwell, 2021), and (e) *Labeotropheus* (from Albertson & Kocher, 2006). Silhouettes not to scale.

(Aptian age) Yixian Formation of Liaoning, China. Its anatomy is highly unusual, and previous authors have pointed to its sharp claws, ventral armor, and elongated, pectinate teeth as possible adaptations for an aquatic foraging lifestyle — unique among ornithischian dinosaurs. It has also been suggested that *Liaoningosaurus* may have been partly carnivorous, owing to a fish skeleton reported from within the ribcage of one individual. While intriguing, the habits and diet of this animal remain poorly understood.

To explore the aquatic foraging hypothesis further, we set out to compare the dentition of *Liaoningosaurus* to that of extant marine iguanas (*Amblyrhynchus cristatus*), which show a superficially similar tooth shape, adapted for feeding on algae. In order to identify the adaptations which evolved for algal grazing, we contrast the dental morphology of *Amblyrhynchus* with that of their presumed ancestor (the land iguana, genus *Conolophus*, which feeds primarily on land plants). Unlike in their terrestrial ancestors, marine iguana teeth are larger proportional to skull size and more complex, with exaggerated and highly defined cusps — traits which *Liaoningosaurus* also shares. Exploring further across vertebrata, the teeth of extant

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algae-grazing actinopterygians such as surgeonfish (*Acanthurus*), royal blue tang (*Paracanthurus*), Brazilian characin (*Bryconamericus*), and Lake Malawi cichlids (*Labeotropheus*) exhibit similar multicusp morphology, as does the extinct (but presumed herbivorous) *Hemicalypterus* — further suggesting that the peculiar pectinate teeth of *Liaoningosaurus* — unique among ankylosaurs and indeed among all dinosaurs — evolved as an adaptation for algal grazing.

We therefore envision *Liaoningosaurus* as a semi-aquatic dinosaur, inhabiting the lakes of the Yixian Formation, and feeding in much the same manner as a marine iguana. By anchoring itself to the lakebottom with its sharp claws, it may have tilted its triangular head to bring the sides of its jaws to bear against firm substrates, rasping at algae with its pectinate teeth.

While this hypothesis seeks to explain the highly unusual morphology of *Liaoningosaurus*, it also suggests an unexpected versatility in the general ankylosaurian body plan and might provide insight into the success of this clade through the Cretaceous.

References

Albertson, R. C., & Kocher, T. D. (2006). Genetic and developmental basis of cichlid trophic diversity. *Heredity, 97*(3), 211-221. https://doi.org/10.1038/sj.hdy.6800864.

Christensen, K., & Melstrom, K. M. (2021). Quantitative analyses of squamate dentition demonstrate novel morphological patterns. *PLoS ONE, 16*(9), e0257427. https://doi.org/10.1371/journal.pone.0257427.

Dawson, W. R., Bartholomew, G. A., & Bennett, A. F. (1977). A reappraisal of the aquatic specializations of the Galápagos marine iguana (*Amblyrhynchus cristatus*). *Evolution, 31*(4), 891-897. https://doi.org/10.1111/j.1558-5646.1977.tb01083.x.

Gibson, S. Z. (2015). Evidence of a specialized feeding niche in a late Triassic ray-finned fish, evolution of multidenticulate teeth and benthic scraping in *Hemicalypterus. The Science of Nature, 102*(3-4), 10. https://doi.org/10.1007/s00114-015-1262-y.

Gibson, S. Z. (2016). Redescription and phylogenetic placement of *Hemicalypterus weiri* Schaeffer, 1967 (Actinopterygii, Neopterygii) from the Triassic Chinle Formation, southwestern United States, New insights into morphology, ecological niche, and phylogeny. *PLoS ONE, 11*(9), e0163657. https://doi.org/10.1371/journal.pone.0163657.

Hirschmann, A., Fagundes, N., & Malabarba, L. (2017). Ontogenetic changes in mouth morphology triggers conflicting hypotheses of relationships in characid fishes (Ostariophysi, Characiformes). *Neotropical Ichthyology, 15*, e160073. https://doi.org/10.1590/1982-0224-20160073.

Kocher, T., Fernald, R., Hofmann, H., Okada, N., & Baroiller, J. N. (2005). Genome sequence of a cichlid fish, The Nile tilapia (*Oreochromis niloticus*). *JGI Community Sequencing*.

Melstrom, K. M. (2017). The relationship between diet and tooth complexity in living dentigerous saurians. *Journal of Morphology, 278*, 500-522.

Paparella, I., & Caldwell, M. W. (2022). Cranial anatomy of the Galápagos marine iguana *Amblyrhynchus cristatus* (squamata, iguanidae). *The Anatomical Record, 305*(7), 1739-1786. https://doi.org/10.1002/ar.24797.

Pindakiewicz, M., Tałanda, M., Sulej, T., Niedźwiedzki, G., Sennikov, A., Bakaev, A., Bulanov, V., Golubev, V., & Minikh, A. (2020). Feeding convergence among ray-finned fishes, teeth of the herbivorous actinopterygians from the latest Permian of East European Platform, Russia. *Acta Palaeontologica Polonica, 65*, 71-79. https://doi.org/10.4202/app.00620.2019.

Ji, Q., Wu, X., Cheng, Y., Ten, F., Wang, X., & Ji, Y. (2016). Fish hunting ankylosaurs (Dinosauria, Ornithischia) from the Cretaceous of China. *Journal of Geology, 40*, 183-190.

Shepherd, S. A, & Hawkes, M. W. (2005). Algal food preferences and seasonal foraging strategy of the marine iguana, *Amblyrhynchus cristatus*, on Santa Cruz, Galápagos. *Bulletin of Marine Science, 77*(1), 23.

Tebbett, S., Goatley, C., & Bellwood, D. (2017a). The effects of algal turf sediments and organic loads on feeding by coral reef surgeonfishes. *PLoS ONE, 12*, e0169479. https://doi.org/10.1371/journal.pone.0169479.

Tebbett, S., Goatley, C., & Bellwood, D. (2017b). Clarifying functional roles, algal removal by the surgeonfishes *Ctenochaetus striatus* and *Acanthurus nigrofuscus*. *Coral Reefs, 36*, 803-13. https://doi.org/10.1007/s00338-017-1571-z.

Vitousek, M. N., Rubenstein, D. R., & Wikelski, M. (2007). The evolution of foraging behavior in the Galápagos marine iguana, Natural and sexual selection on body size drives ecological, morphological, and behavioral specialization. In S. M. Reilly, L. B. McBrayer, & D. B. Miles (Eds.), *Lizard ecology* (1st ed.) (pp. 491-507). Cambridge University Press. https://doi.org/10.1017/CBO9780511752438.018.

Wikelski, M., & Trillmich, F. (1994). Foraging strategies of the Galápagos marine iguana (*Amblyrhynchus cristatus*), Adapting behavioral rules to ontogenetic size change. *Behaviour, 128*(3-4), 255-279. https://doi.org/10.1163/156853994X00280.

Xu, X., Wang, X. L., & You, H. L. (2001). A juvenile ankylosaur from China. *Naturwissenschaften, 88*(7), 297-300. https://doi.org/10.1007/s001140100233.

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Poster Session 2 (Friday, June 9, 2023)

A NEW SHUVOSAURID FROM THE UPPER TRIASSIC CHINLE FORMATION OF PETRIFIED FOREST NATIONAL PARK: IMPLICATIONS FOR THE SYSTEMATICS AND BIOGEOGRAPHY OF THE CLADE

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We present information on a new species of shuvosaurid from the Upper Triassic Chinle Formation of Petrified Forest National Park (PEFO), Arizona. The new taxon is known from an extremely productive bonebed that is stratigraphically positioned near the base of the Sonsela Member, within the Jim Camp Wash beds. Previous radiometric geochronology indicates that the site is approximately 214-218 Ma. The bonebed preserves disarticulated material almost exclusively and hosts at least 22 taxa, including theropods, aetosaurs, azendohsaurs, drepanosaurs, metoposaurs, chondrichthyans, coelocanthiforms, and actinopterygians. The new shuvosaurid is represented by much of the skull, mandible, vertebrae, and appendicular skeleton, with over 700 elements currently catalogued. Autapomorphies for the new shuvosaurid taxon include a maxilla with a reduced body and a thin and delicate anterior process, as well as a dorsal process with a posteroventral inflection at its midpoint. The quadrate has an expanded pterygoid flange with a ridge on its lateral side that runs dorsoventrally. Additionally, the quadrate has a thin and pointed ventral process, ventral to the pterygoid flange. The pterygoid has a robust, crescent-shaped lateral process that tapers laterally. In dorsal view, the orbital margin of the frontal is more concave than in *Effigia* or *Shuvosaurus*. As in *Shuvosaurus*, the new PEFO taxon has a reduced mandibular fenestra, which is unlike the condition proposed for *Effigia*. Postcranial autapomorphies include a dorsoventrally undulating pubic shaft, which contrasts with the posterodorsally curved shaft in *Effigia* and *Shuvosaurus*. In sum, this suite of anatomical features suggests the PEFO shuvosaurid represents a distinct species of shuvosaurid, but this hypothesis awaits phylogenetic testing. Numerous features suggest that the bulk of the material referred to the new shuvosaurid represent skeletally immature individuals. For example, the PEFO taxon has an unfused mandibular symphysis, and an angular that is not fused to adjacent mandibular elements, unlike the condition in *Effigia*. In addition, the laterosphenoid is not fused to the skull roof and the parietals are only partially fused along midline and do not form a pronounced sagittal crest. The new shuvosaurid from PEFO occurs stratigraphically in between the two previously described shuvosaurid genera from North America, *Shuvosaurus* and *Effigia*, suggesting that shuvosaurids were persistent components of terrestrial faunas for nearly the entire Norian.

Poster Session 3 (Saturday, June 10, 2023)

MASS PROPERTIES OF DINOSAURS FROM THE LATE MAASTRICHTIAN OF NORTHERN LARAMIDIA AND THEIR PALEOECOLOGICAL IMPLICATIONS

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Much of northern Laramidia in the late Maastrichtian was a subtropical floodplain ecosystem, in which non-avian dinosaurs were predominant large vertebrates. These dinosaurs occupied a variety of niches, varying both in diet and body size, and understanding their roles and interactions is vital to reaching a more complete understanding of the ecosystem. Ecological roles and adaptations in animals relate to their mass properties (mass, centers of mass, and rotational inertia), which influence ecologically critical aspects of an animal's lifestyle including speed, agility, life history, and thermoregulation. While this is informative for an individual animal's potential performance, investigating mass properties of multiple taxa within the same ecosystem allows for comparisons pertinent to intraspecific interactions, such as those between predators and prey.

Here, we have sculpted life restorations (ZBrush & Autodesk 3DS Max; see Atkins-Weltman et al., 2021), created using skeletal diagrams and examination of mounted fossils where possible, of nine non-avian dinosaurs known from the late Maastrichtian of northern Laramidia. We split the models into functionally-relevant segments of the limbs and axial bodies, and calculated whole-body and segmental mass properties (Meshlab). We obtained among the first volumetric mass and rotational inertia estimates for small Laramidian ornithischians, including *Thescelosaurus* (137 kg) and *Leptoceratops* (122 kg).

Large well-preserved specimens of *Tyrannosaurus* and *Triceratops* have body volumes bracketing 9 cubic meters, but intriguingly the *Triceratops* has half the rotational inertia for lateral pivoting of the entire body, including

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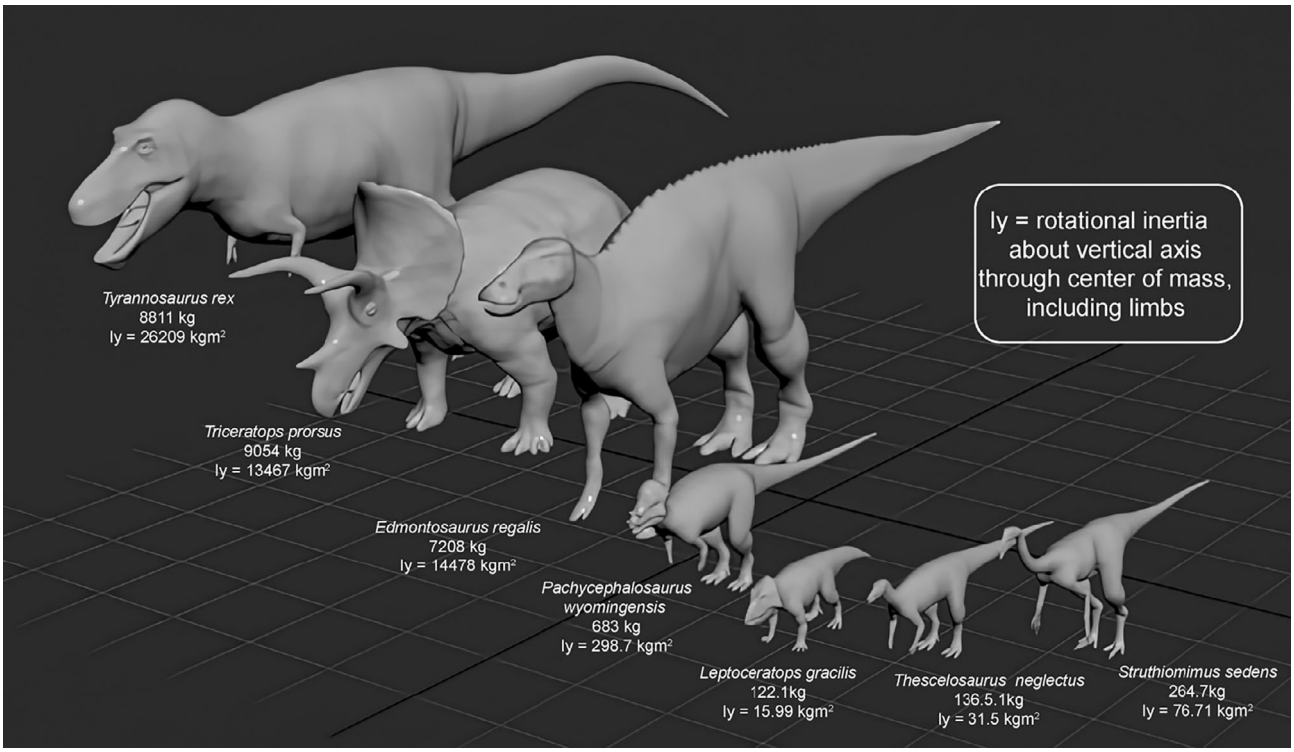


Figure 1. Models and mass property results for representative late Maastrichtian dinosaurs of northern Laramidia. Ceratopsians *Triceratops prorsus* and *Leptoceratops gracilis* have notably lower rotational inertias than other taxa of similar mass. Grid lines = 1 meter.

the limbs. *Edmontosaurus* scaled to the same mass as a large adult *Tyrannosaurus* has 77% of the predator's full body rotational inertia, but values converge when *Tyrannosaurus* pivoted only its axial body, as with both hind limbs planted.

These results suggest different predator-prey interactions between *Tyrannosaurus* and *Edmontosaurus* or *Triceratops*, with each requiring a different hunting strategy. For a predatory adult *T. rex*, the lower rotational inertia of *Triceratops* would likely necessitate a quicker ambush to avoid being outmaneuvered, while *Edmontosaurus* could be more closely matched in a brief pursuit. Mass property refinements for Laramidian dinosaurs will focus the bounds of uncertainty for such inferences, incorporated with musculoskeletal simulation and validation against extant ecological analogs.

References

Atkins-Weltman, K., Snively, E., & O'Connor, P. (2021). Constraining the body mass range of *Anzu wyliei* using volumetric and extant-scaling methods. *Vertebrate Anatomy Morphology Palaeontology*, *9*(1), Article 1. https://doi.org/10.18435/vamp29375

Snively, E., O'Brien, H., Henderson, D. M., Mallison, H., Surring, L. A., Burns, M. E., Jr, T. R.H., Russell, A. P., Witmer, L. M., Currie, P. J., Hartman, S. A., & Cotton, J. R. (2019). Lower rotational inertia and larger leg muscles indicate more rapid turns in tyrannosaurids than in other large theropods. *PeerJ*, *7*, e6432. https://doi.org/10.7717/peerj.6432

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 10:45 AM)

AN EXCEPTIONAL ASSEMBLAGE OF NEW ORODROMINE DINOSAURS FROM THE POORLY CHARACTERIZED MID-CRETACEOUS OF NORTH AMERICA

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Orodromines were a group of small-bodied, herbivorous, bipedal, neornithischian dinosaurs hypothesized to have lived in burrows (Varricchio et al., 2007). They are represented by approximately seven to nine species spanning

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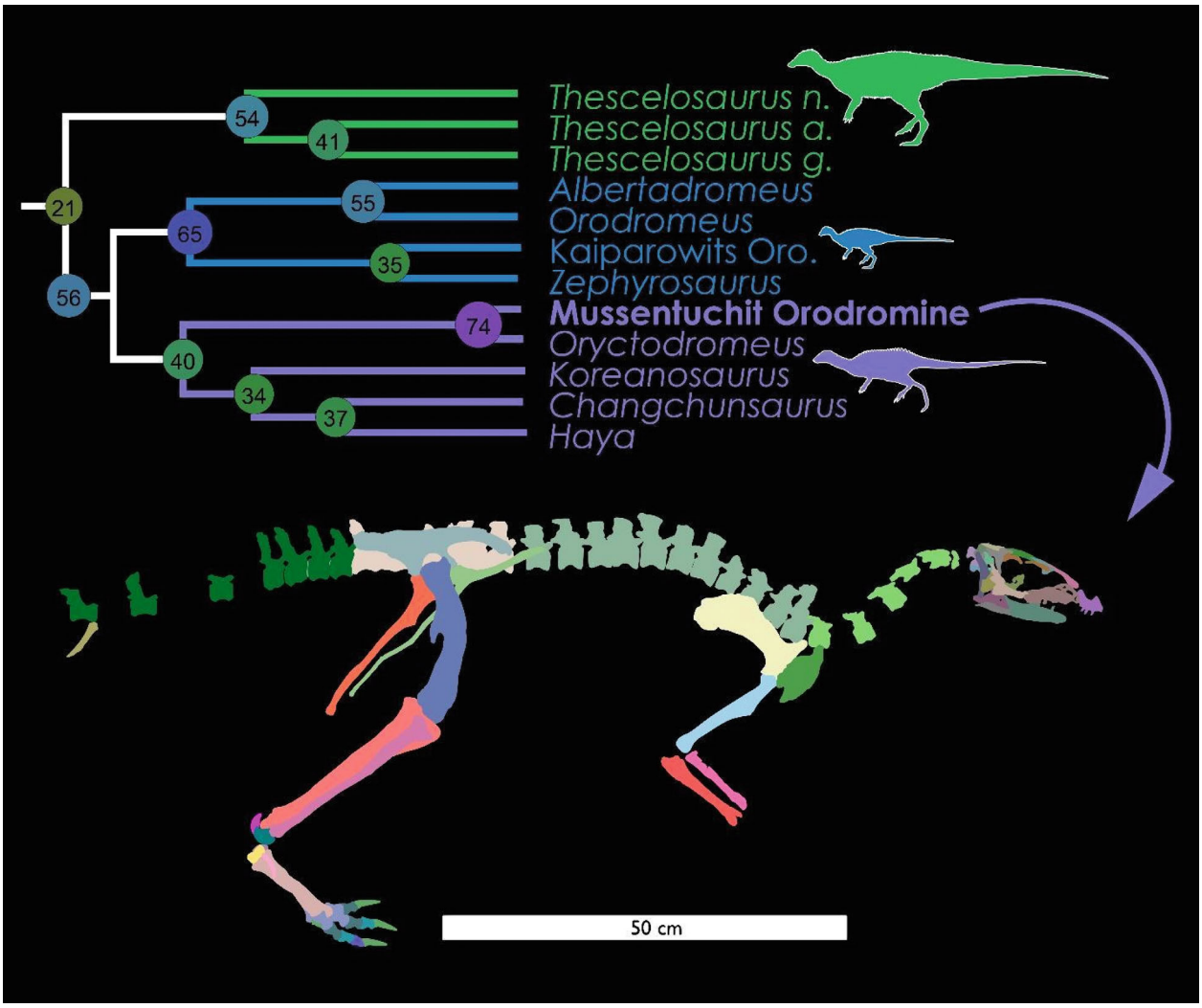


Figure 1: Bayesian Phylogenetic analysis of a modified version of the Barta & Norell (2021) matrix (top), and skeletal reconstruction of the Mussentuchit Orodromine. Numbers at nodes represent the posterior probability, with higher numbers supporting stronger confidence for the monophyly of the clade.

the Aptian through the Campanian and are largely restricted to North America, with at least one, but possibly three species represented from Korea, Northeast China, and Mongolia (Madzia et al., 2018). However, their taxonomic diversity, phylogenetic relationships, and ecology remain enigmatic. Moreover, the broader interrelationships of early-diverging ornithischians persist as one of the most problematic areas of dinosaur phylogenetics, with different studies resolving dramatically different interrelationships, often with poorly supported nodes (e.g., Boyd, 2015; Dieudonné et al., 2021).

This lack of resolution hampers the pursuit of broader questions relating to ornithischian ecology, biogeography, evolutionary rates, diversification, and morphological trends. Inconsistencies in hypothesized evolutionary relationships are due in part to the incomplete preservation of many specimens, lack of detailed osteological descriptions, and the influence of ontogeny, taphonomy, and individual variation within species composed of multiple individuals. Remediating such a deficit requires the comprehensive evaluation of new and existing materials, especially those that fit in between the current evolutionary gaps.

The Cenomanian-aged (99–98 Myr) Mussentuchit Member (MM) of Utah's Cedar Mountain Formation (CMF) has produced a rich record of a new species of orodromine. Materials collected to date include approximately 10 individuals of various ontogenetic stages (based on different sizes of skeletal elements and histological assessment of relative maturity) from five localities spanning less than 600 kyr of geologic time (Tucker et al., 2020). Specimens represent at least one (Makovicky et al., 2014) and possibly multiple new taxa.

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To explore the evolutionary relationships of the new taxon, we conducted a series of Bayesian phylogenetic analyses using Beast 2.6.7. We selected the Barta and Norell (2021) matrix because it contains the highest number of thescelosaurids and orodromines. Several character scorings of multiple taxa were reassessed in person and via photographs and 3D models. These analyses recover the MM orodromine as sister to *Oryctodromeus* at a high Posterior Probability of 0.75, together being more closely related to the Asiatic ornithopods *Haya, Changchunsaurus, and Koreanosaurus* than to the other North American orodromines (Figure 1).

Synapomorphies with *Oryctodromeus* include a medial tuberosity on the scapula, an acromion process that is craniodorsally inflected (~105°) from the craniodorsal margin, a non-flaring scapular blade with the distal margin between the superior and inferior angle running in parallel with the ventral margin of the scapula, and a subtle ridge on the caudal surface of the paroccipital process. The MM orodromine differs from *Oryctodromeus* in lacking the sharp and ventrally folded scapular spine, but possessing a dorsoventrally elongate fossa on the medial surface of the occipital condyle located directly caudal to the medial opening of CN XII, and a rostrocaudally oriented ventral canal on the prootic. The latter two traits are absent in *Orodromeus*, *Oryctodromeus*, and *Thescelosaurus*. Dentary teeth show a unique vertical wear facet on the labial surface that terminates abruptly near the crown base. A parietal sagittal crest is absent, a condition only shared by *Lesothosaurus* and *Changmiania*. Intraspecific variation is observed in the postcranial skeleton with some individuals possessing inflated ischial shafts immediately distal to the obturator process and the presence or absence of deep cavities along the ventrolateral margin of fused sacral centra two and three, possibly representing pneumaticity or pathology.

Although there is no direct sedimentological evidence to date that this new species inhabited burrows as in other orodromines, taphonomic patterns are consistent with a subterranean lifestyle. First, orodromines are by far the most abundant small-bodied vertebrates known from macroskeletal remains in the MM, in contrast to the expected sparsity of small-bodied vertebrates with hollow bones (Brown et al., 2013). Second, they represent one of the only vertebrates from the MM that are preserved in partial or full articulation, a condition shared by *Oryctodromeus* from the coeval Wayan-Vaughn Assemblage (WVA) of Montana and Idaho (Krumenacker et al., 2019). Lastly, multiple individuals are often found buried together, with the largest density of bone usually constrained to a one- to two-meter square block in which elements are tightly packed and border or overlay each other. This is in contrast to the most common taphonomic pattern in the MM, in which skeletal elements are often fragmentary, eroded, and/or disassociated. Altogether, these patterns may indicate fossorial behavior, a hypothesis supported by ongoing histological analyses (Avrahami et al., 2019) as well as other studies on closely related species (Fearon & Varricchio, 2016). Additional evidence for fossorial behaviors stems from our morphometric analysis using a dataset expanded from Fearon and Varricchio (2015). The MM orodromine scapulae form a cluster that is similar to yet distinct from *Oryctodromeus*. The close scapular morphology may suggest fossorial behavior that is more widely distributed across early diverging ornithischians than previously considered.

References

Avrahami, H. M., Zanno, L.E., & Mackovicky, P. J. (2019). Paleohistology of a new orodromine from the Upper Cretaceous (Cenomanian) Mussentuchit Member of the Cedar Mountain Formation, Utah; Histological implications for burrowing behavior. *Journal of Vertebrate Paleontology Program Abstracts, 2019*, 56 79.

Barta, D., & Norell, M. A. (2021). The osteology of *Haya griva* (Dinosauria: Ornithischia) from the Late Cretaceous of Mongolia. *Bulletin of the American Museum of Natural History, 445*.

Boyd, C. A. (2015). The systematic relationships and biogeographic history of ornithischian dinosaurs. *PeerJ, 3*, e1523.

Brown, C. M., Evans, D. C., Campione, N. E., O'Brien, L. J., & Eberth, D. A. (2013). Evidence for taphonomic size bias in the Dinosaur Park Formation (Campanian, Alberta), a model Mesozoic terrestrial alluvial-paralic system. *Palaeogeography, Palaeoclimatology, Palaeoecology, 372*, 108-122.

Dieudonné, P.-E., Cruzado-Caballero, P., Godefroit, P., & Tortosa, T. (2021). A new phylogeny of cerapodan dinosaurs. *Historical Biology, 33*, 2335-2355.

Fearon, J. L., & Varricchio, D. J. (2015). Morphometric analysis of the forelimb and pectoral girdle of the Cretaceous ornithopod dinosaur *Oryctodromeus cubicularis* and implications for digging. *Journal of Vertebrate Paleontology, 35*, e936555.

Fearon, J. L., & Varricchio, D. J. (2016). Reconstruction of the forelimb musculature of the Cretaceous ornithopod dinosaur *Oryctodromeus cubicularis*: Implications for digging. *Journal of Vertebrate Paleontology, 36*, e1078341.

Krumenacker, L., Varricchio, D. J., Wilson, J. P., Martin, A., & Ferguson, A. (2019). Taphonomy of and new burrows from *Oryctodromeus cubicularis*, a burrowing neornithischian dinosaur, from the mid-Cretaceous (Albian-Cenomanian) of Idaho and Montana, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology, 530*, 300-311.

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Madzia, D., Boyd, C. A., & Mazuch, M. (2018). A basal ornithopod dinosaur from the Cenomanian of the Czech Republic. *Journal of Systematic Palaeontology, 16*, 967-979.

Makovicky, P. J., Shinya, A., & Zanno, L. E. (2014). New additions to the diversity of the Mussentuchit Member, Cedar Mountain Formation dinosaur fauna. *Journal of Vertebrate Paleontology Program and Abstracts, 2014*, 175.

Tucker, R. T., Zanno, L. E., Huang, H.-Q., & Makovicky, P. J. (2020). A refined temporal framework for newly discovered fossil assemblages of the upper Cedar Mountain Formation (Mussentuchit Member), Mussentuchit Wash, Central Utah. *Cretaceous Research, 110*, 104384.

Varricchio, D.D., Martin, A.J., & Katsura, Y. (2007). First trace and body fossil evidence of a burrowing, denning dinosaur. *Proceedings of the Royal Society B, 274*, 1361-1368.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 2:15 PM)

NEW PALEOFLORAL SITES FROM THE LATE CRETACEOUS WAPITI FORMATION OF ALBERTA, CANADA: IMPLICATIONS FOR UNDERSTANDING THE PALEOECOLOGY OF BOREAL DINOSAUR COMMUNITIES

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The Late Cretaceous (80 – 68Ma) Wapiti Formation of northwestern Alberta and northeastern British Columbia, Canada spans an interval of geologic time from the lower Campanian to the upper Maastrichtian. The first notable fossil locality from the Wapiti Formation was discovered fifty years ago on Pipestone Creek, near the city of Grande Prairie in northwestern Alberta. This locality, a moxotaxic *Pachyrhinosaurus lakusti* bonebed is one of densest dinosaur deposits in North America, with an average of 100-300 fossils per square metre and with an estimated size of three football fields (Currie et al., 2008). Subsequent paleontological interest in the region led to the discovery of other dinosaur bonebeds (e.g., Fanti et al., 2015), several microvertebrate localities (Fanti & Miyashita, 2009; Fanti et al., 2022), dinosaur trackway sites (Enriquez et al., 2022; Fanti et al., 2013), and hadrosaur specimens displaying soft-tissue preservation (Bell et al., 2014). While the dinosaur fossils and trackways have been well studied, the fossil plant deposits of the Wapiti Formation have received comparatively less attention.

Fossil plant assemblages are of critical importance for recreating the paleoenvironment and understanding the paleoecology of past ecosystems. Assemblages of woody angiosperm dicot leaves and gingkoes can also be an invaluable proxy for paleoclimate reconstruction using the Climate-Leaf Analysis Multivariate Program (CLMAP) (Spicer, 2006). Plant community data is particularly important when elucidating how high seasonality and large changes in photoperiod at high paleolatitudes influenced palaeoecological patterns. Until recently, the limited scientifically rigorous plant collection in Alberta's Wapiti Formation was done in association with dinosaur excavations, which may represent a collection bias.

For the first time in the 2022, a concerted effort was made to find, document, and collect new paleofloral macrosites from the Wapiti Formation in the Grande Prairie area. Prospecting was done on foot and by boat along the Wapiti, Beaverlodge, and Smoky Rivers. Potential fossil plant horizons were identified, test excavations were performed, and collection took place where necessary. During the prospecting trips, a wide range of fossil plant material was recovered, including leaf, flower, stem, and frond fossils, silicified and coalified wood, pinecone casts, paleosols and rooting structures, and amber. Four new paleofloral assemblages were identified and collected.

The first assemblage, from the Spring Creek Paleofloral Site, was dominated by the fronds and cones of the conifers *Metasequoia* and *Parataxodium* in a laminated fine-grained siltstone. Common leaves in this assemblage included *Platanus* and *Merispermities* morphotypes, three types of *Gingkoes* (including an unknown taxon), and a potential water plant (*cf. Ceratophyllum*). In contrast, the assemblage at the DC Bonebed Paleofloral Site contained comparatively few gymnosperms and was dominated by broad-leafed angiosperm fossils (*Colocasia, Merispermities*, *Vitus* morphotypes) in a fine-grained siltstone. This site also contained abundant deposits of amber in the overlying coal layer, which will be used for geochemical paleoclimate analyses. The Pipestone Creek Mouth Paleofloral Site had a lower diversity assemblage preserved in a course sandstone, but containing well-preserved fossils of an angiosperm tree (c.f. *Merispermities* morphotype) and at least one large *Gingko* taxon. The assemblage at the Beaverlodge River Paleofloral Site was dominated by the conifers *Metasequoia* and *Parataxodium and* contained well-presented fossils of both terrestrial and aquatic angiosperms (c.f. *Merispermities, Vitis* and *Cercidiphyllum* morphotypes).

While this data is still preliminary, one important observation noted was the paucity of fern fossils and the

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prevalence of deciduous vegetation. No evergreen angiosperms and few cycads were found. Given that these floras would have provided the dietary biases for megaherbivores such as *Pachyrhinosaurus* and *Edmontosaurus*, it lends support to the theory that these animals were migratory. A largely deciduous forest with little evergreen vegetation may not have been able to support such animals year-round. Absolute paleoclimate analyses based on plant leaf assemblages and amber geochemistry from these sites may further elucidate exactly how cold the 'cold' season got, with implications for seasonal tolerances of boreal dinosaurs.

While work is currently ongoing in the preparation and identification of fossils from these localities, their discovery in 2022 demonstrates the excellent potential of the Wapiti Formation to produce diverse, abundant, and well-preserved palaeofloras. This, in turn, speaks to the potential to discover much more about the seasonal paleoecology and paleoclimatology of the region. Understanding the seasonal nature of the Late Cretaceous boreal forests and floodplains may help to elucidate inferred behaviors such as herding and migration and may provide clues as to the environmental tolerances of these animals.

References

Bell, P. R., Fanti, F., Currie, P. J., & Arbour, V. M. (2014). A mummified duck-billed dinosaur with a soft-tissue cock's comb. *Current Biology, 24*(1), 70-75.

Currie, P. J., Langston, W., Tanke, D. H., Ralrick, P. E., Ridgely, R. C., & Witmer, L. M. (2008). *A new horned dinosaur from an Upper Cretaceous bone bed in Alberta*. NRC Research Press.

Enriquez, N.J., Campione, N. E., White, M. A., Fanti, F., Sissons, R. L, Sullivan, C., Vavrek, M. J., & Bell, P. R. (2022). The dinosaur tracks of Tyrants Aisle: An Upper Cretaceous ichnofauna from Unit 4 of the Wapiti Formation (upper Campanian), Alberta, Canada. *PLoS One, 17(2)*, e0262824.

Fanti, F., & Miyashita, T. (2009). A high latitude vertebrate fossil assemblage from the Late Cretaceous of west-central Alberta, Canada: evidence for dinosaur nesting and vertebrate latitudinal gradient. *Palaeogeography, Palaeoclimatology, Palaeoecology, 275*(1-4), 37-53.

Fanti, F., Bell, P. R., & Sissons, R. L. (2013). A diverse, high-latitude ichnofauna from the Late Cretaceous Wapiti Formation, Alberta, Canada. *Cretaceous Research, 41*, 256-269.

Fanti, F., Currie, P.J., & Burns, M. E. (2015). Taphonomy, age, and paleoecological implication of a new *Pachyrhinosaurus* (Dinosauria: Ceratopsidae) bonebed from the Upper Cretaceous (Campanian) Wapiti Formation of Alberta, Canada. *Canadian Journal of Earth Sciences, 52* (4), 250-260.

Fanti, F., Bell, P. R., Vavrek, M., Larson, D., Koppelhus, E., Sissons. R. L., Langone, A., Campione, N.E., & Sullivan, C. (2022). Filling the Bearpaw gap: Evidence for palaeoenvironment-driven taxon distribution in a diverse, non-marine ecosystem from the late Campanian of west-Central Alberta, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology, 592*, 110923. https://doi.org/10.1016/j.palaeo.2022.110923

Spicer, R. A. (2006). CLAMP. www.open.ac.uk./earth-research/spicer/CLAMP/Clampset1.html6/3/2006.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 10:30 AM)

FAUNAL CHANGE ACROSS THE TRIASSIC–JURASSIC BOUNDARY: NEW INSIGHTS FROM THE MID-ZAMBEZI BASIN OF ZIMBABWE

Barrett, Paul M.[1,2], Sciscio, Lara[3], Zondo, Michel[2,4], Broderick, Timothy J.[5], Munyikwa, Darlington[6], Viglietti, Pia A.[2,7], Edwards, Steve F.[8], Chapelle, Kimberley E. J.[9], Dollman, Kathleen N[10], Choiniere, Jonah N.[2]

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The Triassic-Jurassic boundary is marked by several major biotic transitions, including the extinctions of various reptile and synapsid lineages, the establishment of dinosaurs as the dominant terrestrial vertebrates, and the initial radiations of several 'modern' lineages, such as amphibians and mammals. However, only a handful of localities worldwide capture this transition in its entirety, and most of our knowledge of these changes comes from combining discontinuous records that sample sporadically across this interval. Several Karoo-aged basins in Zimbabwe, such as the Mid-Zambezi and Tuli basins, are infilled by a sequence of late Carboniferous–Jurassic sediments that have the potential to add crucial new data to our understanding of faunal change during this important period in Earth history.

Although the faunas and stratigraphy of the contemporaneous Karoo Supergroup of South Africa and Lesotho have been studied intensively, there has been relatively little work on the Zimbabwean portions of the Mid-Zambezi or Tuli basins, even though the deposits in both have been correlated with those of the main Karoo Basin for many decades (Bond & Falcon, 1973). In order to rectify this deficit, we initiated a new field program to integrate data from the Mid-Zambezi and Tuli basins with that gathered from the main Karoo Basin and elsewhere. This program has the aims of: documenting the Late Triassic–Early Jurassic faunas from Zimbabwe; establishing regional and global bio-, chrono- and lithostratigraphical correlations for these deposits; and determining if there were any regional differences in those faunas.

Fieldwork along the southern shoreline of Lake Kariba in northern Zimbabwe has revealed the first new fossil vertebrate localities in the area since those reported in the 1970s (Sciscio et al., 2021). The majority of these are situated in the Pebbly Arkose Formation (PAF), which appears to have been deposited in the Late Triassic, during the Norian on the basis of U-Pb dates obtained from detrital zircon samples (Barrett et al., 2020). This contrasts with other sections of the PAF from the neighboring Cabora Bassa Basin, which have been dated as Carnian based on their faunal content (Griffin et al., 2022). These conflicting dates suggest either an extended depositional history for the PAF, requiring more detailed correlations between sites within and between basins, or might imply the diachronous deposition of similar sediments, whose diachronicity might have been under tectonic and/or climatic control. In the Kariba area, the PAF has yielded the first freshwater biome to be recovered from any Karoo-aged basin in the region, with a fauna consisting of phytosaurs, temnospondyls and lungfish. Given their provenance, these all likely represent new taxa, but the available material of phytosaurs and temnospondyls is not adequate to erect new species. Nevertheless, preliminary work on a large assemblage of isolated lungfish tooth plates indicates that a new taxon is warranted for this material. Other sites in the PAF of the Kariba area have yielded a more terrestrial fauna with abundant sauropodomorph material and rare teeth of carnivorous archosaurs (Sciscio et al., 2021). All sites appear to be from similar horizons within the PAF, so the presence of either strongly terrestrial or aquatic components in different quarries might be capturing landscape-scale differences in the habitats then present (although additional work on the stratigraphy is required to confirm this hypothesis).

Associated partial sauropodomorph skeletons have been discovered at three separate sites in the PAF ('East Dock Palaeosol', 'Musango' and 'Bumi Hills'). The 'East Dock Palaeosol' taxon consists of an articulated partial hind limb and a preliminary phylogenetic analysis recovers this as a massopodan that is closely related to *Riojasaurus*, signalling a potential correlation with the Norian-aged Los Colorados Formation of Argentina. The 'Musango' sauropodomorph includes vertebrae, elements of the pectoral and pelvic girdles, and fore- and hind limb bones. It also appears to be a massopodan but probably a separate taxon due to differences in tibial morphology; it also possesses potentially diagnostic features of the hip and foot, such as a proximally narrow metatarsal V. By contrast, the presence of a complete acetabular wall in the 'Bumi Hills' specimen suggests that it represents an earlier-diverging taxon than either of the other specimens.

Several new vertebrate localities were also found within the overlying Forest Formation of the Kariba area, although no significant material was discovered (mainly isolated bone fragments). However, new stratigraphical observations placed the type locality of *Vulcanodon* within the Forest Formation, rather than in the intertrappean sediments of the overlying Batoka Basalts (Viglietti et al., 2018).

The Tuli Basin of southern Zimbabwe has also yielded several new sites, all situated within the boundaries of Sentinel Ranch, on the north shore of the Limpopo River. The Karoo-aged deposits in this region are termed the Mpandi Formation (Rogers et al., 2004) and have been considered as Late Triassic–Early Jurassic in age. New dates derived from detrital zircons collected from several horizons on Sentinel Ranch all indicate a Late Triassic (~Norian–Rhaetian) age for this formation, suggesting that despite their lithological similarities to the Early Jurassic sediments of the upper Elliot Formation (Karoo Basin), these sediments might have been deposited

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earlier than thought previously. Numerous dinosaur specimens have been collected from the area historically, which have usually been identified as massospondylids (Cooper, 1981; Rogers et al., 2004) and we recovered similar material as well as a much larger, more robust sauropodomorph and potential theropod specimens.

Taken together, these results highlight the potential for new palaeontological discoveries in Zimbabwe, which will ultimately provide additional data for understanding the dynamics of the Triassic/Jurassic transition.

References

Barrett, P. M., Sciscio, L., Viglietti, P. A., Broderick, T. J., Suarez, C. A., Sharman, G. R., Jones, A. S., Munyikwa, D., Edwards, S. F., Chapelle, K. E., & Dollman, K. N. (2020). The age of the Tashinga Formation (Karoo Supergroup) in the Mid-Zambezi Basin, Zimbabwe and the first phytosaur from mainland sub-Saharan Africa. *Gondwana Research, 81*, 445-460.

Bond, G., & Falcon, R. (1973). The palaeontology of Rhodesia, with a section on the palynology of the Middle Zambezi Valley. *Rhodesia Geological Survey Bulletin, 70*, 1-121.

Cooper, M. R. (1981). The prosauropod dinosaur *Massospondylus carinatus* Owen from Zimbabwe: its biology, mode of life and phylogenetic significance. *Occasional Papers of the National Museums and Monuments Rhodesia, 6*(10), 690-840.

Griffin, C.T., Wynd, B. M., Munyikwa, D., Broderick, T. J., Zondo, M., Tolan, S., Langer, M. C., Nesbitt, S. J., & Taruvinga, H. R. (2022). Africa's oldest dinosaurs reveal early suppression of dinosaur distribution. *Nature, 609*, 313-319.

Rogers, R. R., Rogers, K. C., Munyikwa, D., Terry, R. C., & Singer, B. S. (2004). Sedimentology and taphonomy of the upper Karoo-equivalent Mpandi Formation in the Tuli Basin of Zimbabwe, with a new $^{40}Ar/^{39}Ar$ age for the Tuli basalts. *Journal of African Earth Sciences, 40* (3-4), 147-161.

Sciscio, L., Viglietti, P. A., Barrett, P. M., Broderick, T. J., Munyikwa, D., Chapelle, K. E., Dollman, K. N., Edwards, S. F., Zondo, M. & Choiniere, J. N. (2021). Sedimentology and palaeontology of the Upper Karoo Group in the Mid-Zambezi Basin, Zimbabwe: new localities and their implications for interbasinal correlation. *Geological Magazine, 158*(6), 1035-1058.

Viglietti, P. A., Barrett, P. M., Broderick, T. J., Munyikwa, D., MacNiven, R., Broderick, L., Chapelle, K., Glynn, D., Edwards, S., Zondo, M., & Broderick, P. (2018). Stratigraphy of the *Vulcanodon* type locality and its implications for regional correlations within the Karoo Supergroup. *Journal of African Earth Sciences, 137*, 149-156.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 9:15 AM)

A SURVEY OF PALEOPATHOLOGIES IN THE EARLY CRETACEOUS THERIZINOSAURIAN *FALCARIUS UTAHENSIS* FROM CRYSTAL GEYSER QUARRY UTAH

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Paleopathological research provides information on the evolution and epidemiology of disease generally, and can be used to shed light on the behavior of extinct organisms and their state of health or disease at the time of death. Paleopathological survey of mass-death events are especially useful in that they capture a broad snapshot of a species health (including common injuries) in a single time and place, in contrast to attritional assemblages. Such data can be used to understand the frequency, skeletal distribution, and age-distribution of trauma and disease at the population level, a scale that is difficult to study.

One such sample is that of the early-diverging, therizinosaurian dinosaur, *Falcarius utahensis*, recovered from a paucispecific bonebed in the Lower Cretaceous Cedar Mountain Formation of eastern Utah (Kirkland et al., 2005). This bonebed is comprised of hundreds of individuals from hatchlings to subadults hypothesized to have perished in one or two catastrophic events (Suarez, C. et al., 2007; Suarez, M. et al., 2007). Although taphonomic studies have yielded important information on the depositional history of the quarry itself, the cause of this mass mortality event has remained unresolved for over two decades. Here we add new data to the study of the Crystal Geyser Quarry (CGQ) mass death assemblage, and the behavior of *Falcarius utahensis* by surveying the assemblage for evidence of paleopathology.

Osteopathologies (abnormalities in the bone) are observed in a right metatarsal II, left humerus, right tibia, and left tibia of *Falcarius* individuals. The metatarsal and humerus were collected approximately 52 meters apart, and the tibiae vary in size, making it unlikely that any of these elements are from the same individual. Interpretation of bone pathologies are based on macroscopic and histologic analysis, and computed tomography (CT) of

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Table 1. Paleopathological survey of therizinosaur, theropod and hadrosaurid dinosaurs

Taxon	No. of elements examined	No. of pathological elements	Pathologic element(s)	Suspected pathological cause	Reference
Falcarius utahensis	521	4	Right metatarsal II Left humerus Right tibia Left tibia	Healing fracture Osteomyelitis, infectious Reactive bone deposition Reactive bone deposition	This study
Albertosaurus sarcophagus	190	6	1 Left dentary 2 Ribs 3 Pedal phalanges 1 Gastralia	Bite wounds Healing fractures Enthesiophytes Healing fractures	Bell, 2010
Edmontosaurus sp.	>6000	13	Most caudal vertebrae 1 Left tibia 2 Pedal phalanges	Osteochondrosis Healing fractures	Gangloff & Fiorillo, 2010
Mapusaurus rosea	176	5	1 Cervical vertebra 2 Ribs 1 Pedal phalanx 1 Ilium	Infectious Healing fracture +/- infectious Infectious Unknown	Bell & Coria, 2013
Edmontosaurus annectens	1806	45	Most caudal vertebrae Ribs Pubic blade Presumed Tibia Manual ungual Pedal ungual	Healing fractures Osteochondrosis Unknown	Ullmann et al., 2017
Edmontosaurus annectens	3013	55	44 Caudal vertebrae 3 Dorsal vertebrae 4 Chevrons 2 Ribs 2 Manual phalanges	Healing fractures General bone remodeling Hypertrophic ossification Tooth traces Unknown	Siviero et al., 2020
Lambeosaurine	350	1	Partial ilium	Langerhans cell histiocytosis	Holland et al., 2021

the fossilized lesions, coupled with comparative pattern recognition analysis of histomorphologic and radiographic features in vertebrate pathologic processes.

Macroscopically, both right metatarsal II and left humerus exhibit irregular, nearly circumferential bulbous expansion in the mid-diaphyseal region. Similar irregular bulbous expansion is observed on the distal end of the left tibia in the region between the medial and lateral condyles. The right tibia exhibits a focal region of periosteal reactive bone growth on the caudal aspect of the diaphysis approximately 86 mm from the distal end.

Histologic examination of the right metatarsal II reveals two healing fractures stabilized by a chronic callus; however, one region of the callus is disrupted by a large fragment of necrotic bone (sequestrum). Large sequestra are documented to complicate fractures and delay healing by causing instability at the fracture ends, thereby inhibiting the normal development of a callus (Craig et al., 2016). The histomorphologic features in this metatarsal II provide evidence that this was a complicated fracture in the pes of a subadult individual with delayed healing. Histologic examination of the left humerus reveals lesions most consistent with chronic osteomyelitis with microabscess formation, cortical bone destruction/death, and both subperiosteal and endosteal reactive bone formation. The pattern and distribution of these lesions strongly suggest an infectious cause. Histologic features of the right tibia are characterized by a focally extensive region of periosteal reactive new woven bone formation oriented perpendicularly to the cortex. Within this same region, there is disruption and loss of the endosteal compact lamellar bone and replacement by similar reactive woven bone deposition. Although this element is distorted taphonomically, an increased diameter of the

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medullary cavity and circumferentially decreased thickness of the cortex is evident on both macroscopic and histologic examination. The exact cause of this lesion is currently unknown. Reactive new woven bone formation is considered a generalized response of the bone, and can be seen associated with several different types of disease processes and trauma (Craig et al., 2016). Lastly, the pathology observed in the left tibia is characterized by irregular bulbous expansion of the distal end in the middle region between the medial and lateral condyles that macroscopically resembles abundant intramedullary reactive bone deposition. Evaluation of these latter two lesions via additional histology and CT scanning is necessary to further identify pathologic features.

North Carolina Museum of Natural Sciences crews have logged approximately 1,795 specimens (including some sauropod elements) from the CGQ since 2012, and of those *Falcarius* specimens collected, approximately 521 elements have been prepped, and 325 cataloged with a total of 26 metatarsals, 15 humeri and eight tibiae identified. Of these, only four elements show evidence of osteopathology. Therefore, the frequency of pathology in the assemblage is low (<1% of elements). It is also markedly unevenly distributed. To date, no osteopathologies are observed on the axial skeleton or phalanges; all are localized to the appendicular skeleton. Moreover, the frequency of osteopathology in *Falcarius* tibia is highest (25% in our sample), with 75% of the pathologies observed localized to the hind limb. This is in contrast to results observed in other paleopathological bonebed surveys of theropod and hadrosaur species that report a greater percentage of pathology in the axial skeleton with the caudal vertebrae and ribs being overrepresented (Table 1). Additionally, nearly all of these studies report pathologies in the phalanges.

Further research is required to evaluate the prevalence of additional osteopathologies, and if these pathologies have any correlation with the mass mortality event(s). This data will ultimately help us piece together key components in the paleobiology of this enigmatic dinosaur, and may also reveal potential mechanisms of mortality that may have resulted in such a unique mass death assemblage.

References

Bell, P. R. (2010). Palaeopathological changes in a population of *Albertosaurus sarcophagus* from the Upper Cretaceous Horseshoe Canyon Formation of Alberta, Canada. *Canadian Journal of Earth Sciences, 47*, 1263-1268.

Bell, P. R., & Coria, R. A. (2013). Palaeopathological survey of a population of *Mapusaurus* (Theropoda: Carcharodontosauridae) from the Late Cretaceous Huincul Formation, Argentina. *PloS One, 8*, e63409.

Craig, L. E, Dittmer, K. E., & Thompson, K. G. (2016). Bones and Joints. In M. G. Maxie (Ed.), *Jubb, Kennedy, and Palmer's pathology of domestic animals* (pp. 16-163). Elsevier.

Gangloff, R. A, & Fiorillo, A. R. (2010). Taphonomy and paleoecology of a bonebed from the Prince Creek Formation, North Slope, Alaska. *Palaios, 25*, 299-317.

Holland, B., Bell, P. R., Fanti, F., Hamilton, S. M., Larson, D. W., Sissons, R., Sullivan, C., Vavrek, M. J., Wang, Y., & Campione, N. E. (2021). Taphonomy and taxonomy of a juvenile lambeosaurine (Ornithischia: Hadrosauridae) bonebed from the late Campanian Wapiti Formation of northwestern Alberta, Canada. *PeerJ, 9*, e11290.

Kirkland, J. I, Zanno. L. E., Sampson, S. D., Clark, J. M., & DeBlieux, D. D. (2005). A primitive therizinosauroid dinosaur from the Early Cretaceous of Utah. *Nature, 435*, 84-87.

Siviero, B. C., Rega, E., Hayes, W. K., Cooper, A. M., Brand, L. R., & Chadwick, A. V. (2020). Skeletal trauma with implications for intratail mobility in *Edmontosaurus annectens* from a monodominant bonebed, Lance Formation (Maastrichtian), Wyoming USA. *Palaios, 35*, 201-214.

Suarez, C. A., Suarez, M. B., Terry D. O., & Grandstaff, D. E. (2007). Rare earth element geochemistry and taphonomy of the Early Cretaceous Crystal Geyser Dinosaur Quarry, east-central Utah. *Palaios, 22*, 500-512.

Suarez, M. B., Suarez, C. A., Kirkland, J. I., González, L. A., Grandstaff, D. E., & Terry, D. O. (2007). Sedimentology, stratigraphy, and depositional environment of the Crystal Geyser Dinosaur Quarry, east-central Utah. *Palaios, 22*, 513-527.

Ullmann, P. V., Shaw, A., Nellermoe, R., & Lacovara, K. J. (2017). Taphonomy of the Standing Rock Hadrosaur Site, Corson County, South Dakota. *Palaios, 32*, 779-796.

Poster Session 2 associated with the Theme Session: Global Perspectives on Mesozoic Lacustrine Ecosystems (Thursday, June 8, 2023)

FISH DIVERSITY AND LAKE BASIN TYPE FROM TRIASSIC RIFT BASINS OF ARGENTINA

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Lake basins are one of the most detailed environmental archives that can be found in the geologic record for terrestrial ecosystems, preserving changes in space and time with high fidelity allowing their reconstruction with high resolution (Gierlowski-Kordesch & Kelts, 1994). In the last two decades, an integrative classification for lake basin types has been proposed considering the major controls of evolution of lacustrine basins and the interplay between accommodation and water+sediment supply (Bohacs et al., 2000). Each major category of basin defined (overfilled, balanced-fill and underfilled lake basin) represents a state of equilibrium and fluctuations from it according to variations in the accommodation and sediment supply. This is strongly linked to hydrological conditions such as surface or subsurface flow (Benavente et al., 2019). Many proxies can be studied from a lake basin to unravel parts of the ecosystem, one of them is the paleontological content. Fish remains and their preservation can provide information regarding conditions of the water column they inhabited (Benavente et al., 2020). Evolutionary questions such as speciation patterns and their causes can also be studied (McCune, 2004).

The Triassic Cuyana and Ischigualasto-Villa Unión rift basins in Argentina present all three lake basin types in their sub-basins. The Cuyana Basin presents two overfilled lakes in the Late Triassic Agua de la Zorra and Cacheuta formations (Pedernera et al., 2021), an underfilled lake in the Middle Triassic Cerro de las Cabras Formation (Benavente et al., 2015), and a balanced-fill lake in the Middle Triassic Santa Clara Abajo Formation (Benavente et al., 2021). The Ischigualasto-Villa Unión Basin presents an overfilled lake in the Late Triassic Los Rastros Formation (Mancuso & Caselli, 2012). Each of these lake systems preserve fish remains with taxonomical determination constituting an excellent opportunity to study paleobiotic and evolutionary questions about the ichthyofauna linked to the lacustrine ecosystems they inhabited. The goal of our work is to compare the diversity of the ichthyofauna at the genera and species level for each lake basin type.

We did a literature review and included each taxon for each lake basin studied in a data base. For the Cacheuta Formation (Potrerillos sub-basin) a high resolution sedimentary log was done, facies and facies associations and the stacking pattern were determined and the lake basin type was interpreted. For genera and species richness for each geologic unit a rarefaction analysis was conducted using the software Paleontological Statistics (PAST 4.02 [Hammer et al., 2001]).

The highest richness at the genus and species level was found in the Agua de la Zorra overfilled system (Taxa_S 8) and the lowest in the Cerro de las Cabras underfilled system (Taxa_S 2). The Santa Clara Abajo balanced-fill paleolake presented a low genera richness but a high species richness (Taxa_S 3) (Figure 1). Cacheuta and Los Rastros overfilled paleolakes presented higher richness

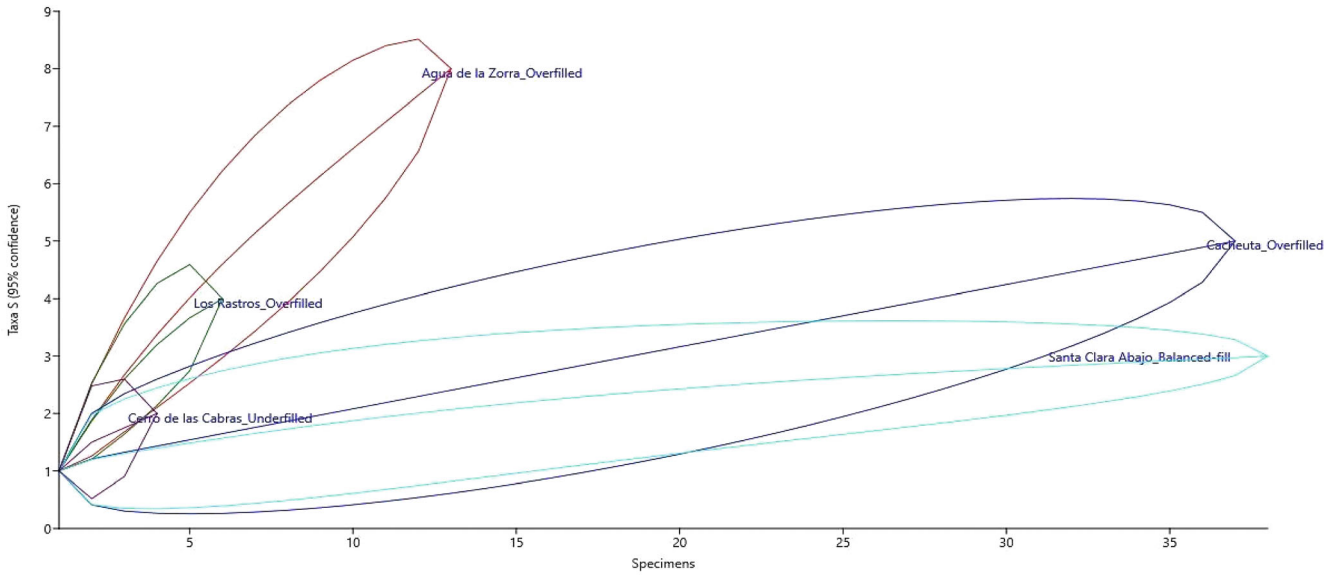


Figure 1. Rarefaction curves for fish richness (Taxa S) in each lake basin studied: Agua de la Zorra, Cacheuta, Los Rastros (overfilled), Santa Clara Abajo (balanced-fill) and Cerro de las Cabras (underfilled) from the Triassic Cuyana and Ischigualasto-Villa Unión rift basins in Argentina.

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than balanced- and underfilled systems (Taxa_S 5 and 4 respectively) and share a genus (*Challaia*). Cerro de las Cabras and Cacheuta also shared a genus even though they represent Middle and Late Triassic respectively but are from the same sub-basin. Most genera and species are not common to all lakes. The highest match at the species level is found between the Agua de la Zorra and Cacheuta overfilled paleolakes formed during the Late Upper Triassic in adjacent sub-basins within the rift. There is a genus common to Cacheuta and Los Rastros paleolakes representing both the Upper Triassic from different basins.

The rarefaction curves of the Agua de la Zorra and Los Rastros (overfilled), and Cerro de las Cabras (underfilled) formations suggest that richness may be higher than that recorded and that a sampling increase would lead to an increase in richness recorded (Figure 1). The curves for the Cacheuta (overfilled) and Santa Clara Abajo (balanced-fill) formations indicate that the richness recorded in these lakes would not be substantially modified with additional sampling.

Overall, overfilled lake basins of the Cuyana and Ischigualasto-Villa Unión Triassic rifts show the highest richness. The balanced-fill lake basin analyzed shows high species richness but low genera richness which might be linked to the high instability of some subenvironments within these water bodies. For the underfilled Cerro de las Cabras paleolake, a high ichthyofauna diversity had been interpreted previously but our results show that in an integrated analysis, relative to other lake basins of the Cuyana and Ischigualasto-Villa Unión rifts, taxa diversity at this system was low. Common species are found across different lake basin types suggesting there might be a time component influencing ichthyofauna composition more than lake basin type within the lakes of the Triassic rifts of Argentina.

References

Benavente, C. A., Mancuso, A. C., & Bohacs, K. M. (2021). Chapter 14, Reconstructing paleoenvironmental conditions through integration of paleogeography, stratigraphy, sedimentology, mineralogy, and stable isotope data of lacustrine carbonates—an example from early Middle Triassic strata of southwest Gondwana, Cuyana Rift, Argentina. In M. R. Rosen, L. Park-Bousch & D. B. Finkelstein (Eds.), *Limnogeology: Progress, challenges and opportunities: A tribute to Beth Gierlowski-Kordesch* (pp. 471-509). Springer.

Benavente, C. A., Giordano, P. G., & Mancuso, A. C. (2020). Paleolimnology of the Santa Clara Abajo Formation (Triassic, Cuyana Basin) inferred from fish taphonomy. *Lethaia, 54*, 40-54, doi.org/10.1111/let.12381.

Bohacs, K. M., Carroll, A. R., Neal, J. E., & Mankiewicz, P. J. (2000). Lake-basin type, source potential, and hydrocarbon character: an integrated sequence-stratigraphic-geochemical framework. In E. H. Gierlowski-Kordesch & K. R. Kelts (Eds.), *Lake basins through space and time. AAPG Studies in Geology, 46*, 3-34.

Gierlowski-Kordesch, E. H., & Kelts, K. R. (1994). *Global geological record of lake basins, 1*. Cambridge University Press.

Hammer, Ø., Harper, D. A., & Ryan, P. D. (2001). PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica, 4*(1), 9.

Mancuso, A. C., & Caselli, A. T. (2012). Paleolimnology evolution in rift basins: The Ischigualasto-Villa Unión Basin (central-western Argentina) during the Triassic. *Sedimentary Geology, 275*, 38-54.

McCune, A. (2004). Diversity and Speciation of Semionotid Fishes in Mesozoic Rift Lakes. In U. Dieckmann, M. Doebeli, J. A. J. Metz & D. Tautz (Eds.), *Adaptive speciation* (pp. 362-379). Cambridge University Press.

Pedernera, T. E., Ottone, E. G., Mancuso, A. C., Erra, G., Larriestra, F., Benavente, C. A., Pineda Alvarez, J. A., Campos, C., Bustos-Escalona, E. L., Krapovickas, V. & Marsicano, C. A. (2021). A multiproxy analysis of the Triassic Agua de la Zorra Formation, Cuyana Basin, Argentina: palynofacies, geochemistry, and biotic record. *Journal of South American Earth Sciences, 110*, 103374.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 2:15 PM)

A NEW KRITOSAURIN HADROSAURID (DINOSAURIA: ORNITHOPODA) FROM THE LATE CRETACEOUS OF COLORADO, USA

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Institutional abbreviations ---- **CNFM,** Colorado Northwestern Field Museum

Duck-billed dinosaurs (Hadrosauridae) were a clade of megaherbivorous ornithopods that reached a near-global distribution during the Late Cretaceous, forming a

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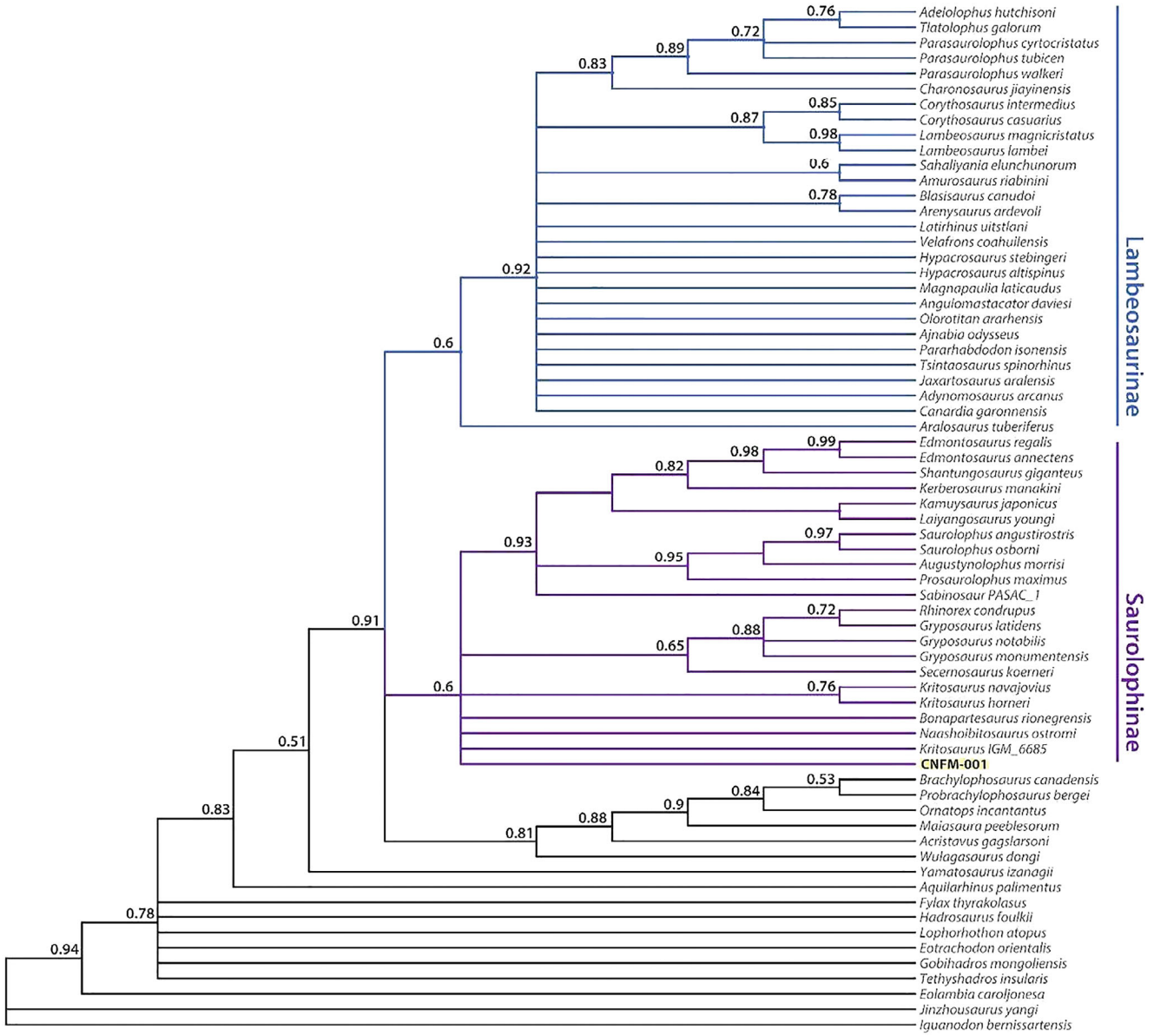


Figure 1: Consensus tree topology (22500 trees after burn-in) recovered from Bayesian phylogenetic analysis. Posterior node probabilities greater than 0.5 are represented on the tree; nodes with posterior probability values less than 0.5 are collapsed. The Williams Fork Fm taxon, CNFM-001 is highlighted in yellow. 'Saurolophinae' is restricted to the largest monophyletic group of taxa more closely related to *Saurolophus* than *Hadrosaurus* (Prieto-Márquez, 2010).

cornerstone of terrestrial ecosystems. The Late Cretaceous Western Interior Basin (WIB) of North America possesses the highest diversity of hadrosaurids in the fossil record, and the past decade has provided discoveries that continue to refine the spatiotemporal resolution of hadrosaurid biodiversity and clarify the phylogenetic relationships of this clade. We present a preliminary cranial osteology and phylogenetic placement of a new hadrosaurid dinosaur from the Late Campanian Williams Fork Formation (~75–72 Myr [Fowler, 2017; Ogg & Hinnov, 2012; Walker et al., 2021]) of northwestern Colorado. The specimen (CNFM-001) was recovered from a sand-rich environment, with localized sections that range from loosely compacted sand grains to hardened concretions and pebble-sized rip-up clasts.

The Williams Fork Formation preserves a diverse dinosaur fauna (Diem, 1999; Brand et al., 2022), including hadrosaurs, tyrannosaurs, neornithischians, ceratopsians, ankylosaurs, ornithomimosaurs, dromaeosaurs, and oviraptorosaurs. These taxa are known from microfossil sites (Archibald, 1987; Brand et al., 2018, 2022; Sanchez et al., 2020), trackways (Lockley et al., 2011), and fragmentary body fossils (Archibald, 1987; Hunt-Foster & Foster,

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2015; Yun, 2023). However, only one dinosaur referrable to genus level has been formally described in peer-reviewed literature, a ceratopsid usually assigned to *Pentaceratops* (Diem, 1999; Fowler & Freedman-Fowler, 2020; Lucas et al., 2006). Williams Fork hadrosaurids are represented by teeth (Brand et al., 2022) and partial unidentified body fossils (Carpenter, 1992), but no identifiable hadrosaurid fossils have yet been described. The new taxon therefore represents the first identifiable hadrosaur from this formation.

CNFM-001 preserves a partial disarticulated skull and postcranial skeleton. The preparation of this specimen is ongoing, therefore skeletal completeness is currently unknown. CNFM-001 is referable to Kritosaurini based on a nasal arch that rises above the orbits, infratemporal fenestra wider than the orbit at the dorsal margin, and strong concavity along the ventral margin of the jugal between the rostral process and the caudoventral flange (Prieto-Márquez, 2014). Preliminary observations of the skull roof and braincase indicate that CNFM-001 is a non-gryposaur kritosaurin. This referral is supported by the complete osseous enclosure of the ophthalmic ramus of the trigeminal nerve (CN-V1) opening and the dorsoventrally flattened nasal arch. The osseous enclosure of CN-V1 foramen is rare in Saurolophinae, observed only in a specimen referred to *Kritosaurus navajovius* (USNM 8629), and was tentatively proposed as a possible diagnostic trait of the aforementioned species by Prieto-Márquez (2014), and thus may be more widespread across kritosaurs. CNFM-001 is strongly distinguished from the earlier-diverging taxon *Naashoibitosaurus ostromi* by the inclusion of the frontal in the orbital margin and a straight quadrate. The novel Williams Fork taxon can be differentiated from *Kritosaurus horneri* by the placement of the nasal arch apex, which is decidedly rostral to the orbits, and from *K. navajovius* by the deep recession of the metotic foramen into the basioccipital-exoccipital suture, among other traits. CNFM-001 is unlike all known kritosaurins in exhibiting a frontonasal suture that is grossly flat and mediolaterally oriented mesially; *Gryposaurus* generally displays a medial insertion of the nasals between the frontals in this region (although there can be contralateral variation in this feature, e.g., CMN 2278; Gates & Sampson, 2007), whereas *Kritosaurus* possesses a medial insertion of the frontals between the nasals with the caudal expansion of two laterally placed nasal 'wings' over the frontals. Critically, CNFM-001 may represent the most complete non-gryposaur specimen referable to Kritosaurini. All specimens of *K. navajovius*, *K. horneri*, and *N. ostromi* are represented only by partial skulls and few postcranial elements.

Preliminary Bayesian phylogenetic analyses were conducted to discern the approximate placement of CNFM-001 within Hadrosauridae using the matrix of Ramírez-Velasco (2022), retaining the ordering of characters. The matrix was coded for only those CNFM-001 elements that were prepared and available for study. Analyses were performed in MrBayes (version 3.2.7a) (Ronquist et al., 2012) using the Mkv model, gamma rate distribution divided into k=8 rate categories, and independent partitioning of cranial and postcranial characters. The analysis ran for 15 million generations sampling every 1000 generations. The resulting Maximum Clade Credibility topology (not figured) tentatively places CNFM-001 as the sister taxon to '*Kritosaurus* IGM-6685'. IGM-6685 was referred to *K. navajovius* by Prieto-Márquez (2014) but was reclassified as an independent taxon by Ramírez-Velasco (2022). The consensus tree (Figure 1) unambiguously places CNFM-001 basal to the clade containing *Gryposaurus* and *Rhinorex*. However, the remaining relationships within Kritosaurini remain poorly supported; nodes external to the *Gryposaurus* clade produced node probability lower than 0.5. These analyses also produced a paraphyletic Saurolophinae in which Brachylophosaurini diverges basal to the most recent common ancestor of *Parasaurolophus* and *Edmontosaurus* in a subset of the posterior tree sample. Formations of the WIB are not uniformly sampled for fossils, leaving gaps in the known biotic record that limit hypothesis testing of faunal change on continental scales. A series of studies have convincingly demonstrated that faunas and floras of the WIB were divided into northern and southern biomes (Burgener et al., 2021; Gates et al., 2010, 2012; Lehman, 1987; Sampson et al., 2010). Fossils from the Williams Fork Formation both fill in one of these faunal voids and are located at the boundary of the dual biomes. At 74 Ma, the northern hadrosaurid fauna consisted of species most closely related to *Prosaurolophus* (to the Almond Formation of southern Wyoming [Gates & Farke, 2009]), whereas the southern hadrosaurid faunas were most closely related to *Kritosaurus*. Recovery of CNFM-001 as a possible kritosaurin means that the southern hadrosaurid faunas extended from northern Mexico through at least northern Colorado.

References

Archibald, J. D. (1987). Late Cretaceous (Judithian and Edmontonian) vertebrates and geology of the Williams Fork Formation, NW Colorado. *Occasional Papers of the Tyrrell Museum of Palaeontology*, *3*, 7-11.

Brand, N. A., Heckert, A. B., Hunt-Foster, R. K., & Foster, J. R. (2018). On the banks of the Western Interior Seaway: Possible marine influence at the J&M site of the Williams Fork Formation (Upper Cretaceous, Campanian) in

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Colorado based on a newly described microvertebrate fossil assemblage. *Journal of Vertebrate Paleontology*, *Program and Abstracts, 2018*, 95-96

Brand, N. A., Heckert, A. B., Sanchez, I., Foster, J. R., Hunt-Foster, R. K., & Eberle, J. J. (2022). New Late Cretaceous microvertebrate assemblage from the Campanian–Maastrichtian Williams Fork Formation, northwestern Colorado, USA, and its paleoenvironmental implications. *Acta Palaeontologica Polonica*, *67*(3), 579-600.

Burgener, L., Hyland, E., Griffith, E., Mitášová, H., Zanno, L. E., & Gates, T. A. (2021). An extreme climate gradient-induced ecological regionalization in the Upper Cretaceous Western Interior Basin of North America. *Geological Society of America Bulletin*, *133*(9-10), 2125-2136.

Carpenter, K. (1992). Behavior of hadrosaurs as interpreted from footprints in the "Mesaverde" Group (Campanian) of Colorado, Utah, and Wyoming. *Rocky Mountain Geology*, *29*(2), 81-96.

Diem, S. (1999). *Vertebrate faunal analysis of the Upper Cretaceous Williams Fork Formation, Rio Blanco County, Colorado* [Master's Thesis, San Diego State University].

Fowler, D. W. (2017). Revised geochronology, correlation, and dinosaur stratigraphic ranges of the Santonian-Maastrichtian (Late Cretaceous) formations of the Western Interior of North America. *PLoS One*, *12*(11), e0188426.

Fowler, D. W., & Freedman-Fowler, E. A. (2020). Transitional evolutionary forms in chasmosaurine ceratopsid dinosaurs: evidence from the Campanian of New Mexico. *PeerJ*, *8*, e9251.

Gates, T. A., & Farke, A. A. (2009). Biostratigraphic and biogeographic implications of a hadrosaurid (Ornithopoda: Dinosauria) from the Upper Cretaceous Almond Formation of Wyoming, USA. *Cretaceous Research*, *30*(5), 1157-1163.

Gates, T. A., Prieto-Marquez, A., & Zanno, L. E. (2012). Mountain building triggered Late Cretaceous North American megaherbivore dinosaur radiation. *PLoS One*, 7(8), e42135.

Gates, T. A., & Sampson, S. D. (2007). A new species of *Gryposaurus* (Dinosauria: Hadrosauridae) from the late Campanian Kaiparowits Formation, southern Utah, USA. *Zoological Journal of the Linnean Society*, *151*(2), 351-376.

Hunt-Foster, R. K. & Foster, J. R. (2015). First occurrence of an oviraptorosaur (Theropoda: Maniraptora) from the Mesaverde Group (Williams Fork Formation) of Northwestern Colorado. *Journal of Vertebrate Paleontology*, *Program and Abstracts, 2015*, 148.

Lehman, T. M. (1987). Late Maastrichtian paleoenvironments and dinosaur biogeography in the western interior of North America. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *60*, 189-217.

Lockley, M. G., Cart, K., Martin, J., & Milner, A. R. C. (2011). New theropod tracksites from the Upper Cretaceous "Mesaverde" Group, western Colorado: implications for ornithomimosaur track morphology. *New Mexico Museum of Natural History and Science Bulletin*, *53*, 321-329.

Lucas, S. G., Sullivan, R. M., & Hunt, A. P. (2006). Re-evaluation of *Pentaceratops* and *Chasmosaurus* (Ornithischia: Ceratopsidae) in the Upper Cretaceous of the Western Interior. *New Mexico Museum of Natural History and Science Bulletin*, *35*, 367-370.

Ogg J. G., & Hinnov L. A. (2012). Cretaceous. In F. M. Gradstein, J. G. Ogg, M. D. Schmitz, & G. Ogg (Eds.), *The geologic time scale* (pp. 793-853). Elsevier.

Prieto-Márquez, A. (2012). The skull and appendicular skeleton of *Gryposaurus latidens*, a saurolophine hadrosaurid (Dinosauria: Ornithopoda) from the early Campanian (Cretaceous) of Montana, USA. *Canadian Journal of Earth Sciences*, *49*(3), 510-532.

Prieto-Márquez, A. (2014). Skeletal morphology of *Kritosaurus navajovius* (Dinosauria: Hadrosauridae) from the Late Cretaceous of the North American south-west, with an evaluation of the phylogenetic systematics and biogeography of Kritosaurini. *Journal of Systematic Palaeontology*, *12*(2), 133-175.

Ramírez-Velasco, A. A. (2022). Phylogenetic and biogeography analysis of Mexican hadrosauroids. *Cretaceous Research*, *138*, e105267.

Ronquist, F., Teslenko, M., van der Mark, P., Ayres, D. L., Darling, A., Höhna, S., Larget, B., Liu, L., Suchard, M. A., & Huelsenbeck, J. P. (2012). MrBayes 3.2: Efficient Bayesian phylogenetic inference and model choice across a large model space. *Systematic Biology*, *61* (3), 539-542.

Sampson, S. D., Loewen, M. A., Farke, A. A., Roberts, E. M., Forster, C. A., Smith, J. A., & Titus, A. L. (2010). New horned dinosaurs from Utah provide evidence for intracontinental dinosaur endemism. *PLoS One*, *5*(9), e12292.

Sanchez, I., Heckert, A. B., Foster, J. R., Brand, N., & Hunt-Foster, R. K. (2020). Geology and Microvertebrate paleontology of the J&M Site (Upper Cretaceous; ?Campanian), Williams Fork Formation, Northwestern Colorado. *Geological Society of America Abstracts with Programs, 52*(2). doi: 10.1130/abs/2020SE-344181

Walker, J. T., Aslan, A., Cole, R. D., & Heizler, M. T. (2021). New age constraints on the Late Cretaceous lower Williams Fork Formation, Coal Canyon, Colorado. *The Mountain Geologist, 58*(1), 5-26.

Yun, C. G. (2023). A tyrannosaurid pedal ungual from the Williams Fork Formation (Campanian) of Colorado and its implications for the biogeography of Laramidian dinosaurs. *Acta Geologica Polonica, 73*, 63-72.

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Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 4:25 PM)

RECOVERY OF AN EXCEPTIONAL PERMINERALIZED TREE TRUNK FROM THE SALT WASH MEMBER OF THE MORRISON FORMATION OF NE UTAH: THE MANWELL LOG

Bennis, Mary Beth[1], Gee, Carole T.[2], Gray, Dale E.[3], Love, Renee[1]

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The Morrison Formation of northeast Utah remains puzzling regarding the climate regime and potential to support forests of large trees (Parrish et al., 2004; but see Gee, 2020). Growing evidence based on paleobotanical data indicates that the fluvially deposited Salt Wash Member in Rainbow Draw supported large trees. There are at least four permineralized logs that measure up to 11 meters long and 1.3 meters in diameter plus seven more occurrences of fossil wood along a 460 linear meter traverse in Rainbow Draw, suggesting the possibility of a conifer forest ecosystem that was not water limited or stressed (Gee et al., 2019). The wood anatomy of the 152-million-year-old trees indicate a monospecific stand of *Agathoxylon hoodii* of the family Araucariaceae (Gee et al., 2019). Geological mapping shows that the logs and wood identified in this area occur in the same stratigraphic interval within the Salt Wash Member (Sprinkel, et al., 2019). The traceable unit containing the logs is approximately 11 meters thick and consists of exceptionally fine to fine-grained sandstone and siltstone, with no distinct bedding or discernible sedimentary features indicative of a distributive fluvial system (Sprinkel et al., 2019). Growth rings from the trees implies a mesic environment where conditions were suitable for even, year-round growth (Gee et al., 2019). This contrasts with evidence of aridity in the sedimentation reported by previous workers (Parrish et al., 2004).

As is often the case, a fossil may give the appearance of being uncommon owing more to insufficient inspection of potential areas or a bias on behalf of the surveyor, which appears to be the case with the ever-growing sites of Morrison Wood. However, intact logs are rare due to their vulnerability to weathering processes, therefore, when an exceptional fossil specimen was discovered 19 kilometers to the southwest of the initial study area, the opportunity was seized to extract it in July 2021 for future research and museum exhibition (Figure 1a). Therefore, when an exceptional fossil specimen was discovered 19 kilometers to the southeast of the initial study area, the opportunity was seized to extract it in July 2021 for future research and museum exhibition. The fossil tree trunk, referred to informally as the "Manwell Log," named for the museum visitor who initially discovered it, is approximately 4 meters long, with a diameter of over 1 meter, and an estimated weight of 8 short tons (Gee, unpubl. data, 2020). Preliminary analysis suggests that the fossil does not pertain to the species *Agathoxylon hoodii*, which further strengthened the resolve for its collection. Reassessment of the quarry site at a later time unearthed the upper portion of the trunk which shows the splitting of the lower trunk into several smaller upright trunks, which is characteristic of trees among living Araucariaceae.

Although the road was only 0.4 kilometers away from the fossil site, getting to it required navigation through a steep gully, making recovery efforts exceptionally challenging. Planning the excavation, transportation, and placement of the log encompassed 18 months, in large part due to the precise coordination of three companies that would perform all but the excavation portion of the recovery, the procurement of two permits through the BLM, as well as the recruitment of enough volunteers to perform an exhaustive nine-day excavation operation (Figure 1b).

The Manwell Log is now on display at the Utah Field House of Natural History State Park Museum, still mounted on the custom-built wooden "cradle" used to transport it from the fossil site into the museum. The extremely heavy fossil log is oriented horizontally to spread out its weight on the floor, but an image-scanning method called photogrammetry has helped to lift the log into a vertical position. Photogrammetry uses two-dimensional data, in this case, multiple photographs from different angles of the log's surface taken with an iPad on iOS 13.0, and turns the photos into a photorealistic 3D model using an application called Trnio. This software has several scanning options including the importation of manual photographs, automated photographs, as well as ARKIT and Lidar scans. The data is uploaded to remote servers for processing, then the 3D model is returned to the application for viewing and minimal editing.

Using this state-of-the-art image processing, the fossil log optically becomes an ancient, upright tree trunk, complete with the wood texture of the trunk and the scars of massive branches. Furthermore, because the top portion of the Manwell log had broken off during transport, a photogrammetry scan of this top portion was joined to the scan of the main part of the trunk using Meshmixer

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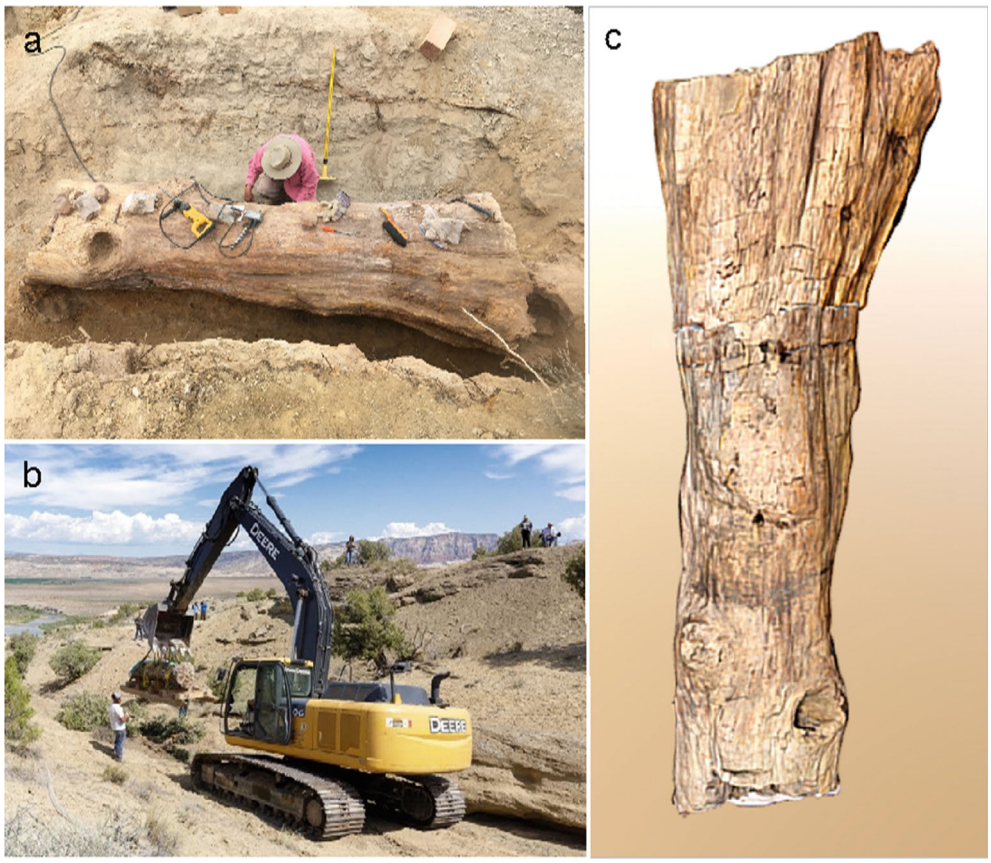


Figure 1. (a) Excavating the Manwell Log in the field. Photo: Mary Beth Bennis. **(b)** Supported by its custom-built cradle, the 8-ton log of solid silica is first transported by heavy machinery to the Field House in Vernal, Utah. Photo courtesy of Tom Howells. **(c)** 3D reconstruction joining the two portions of the log using photogrammetry shows it as an upright tree trunk with wood texture and branch scars, as well as with a top at the point of branching upwards into three trunks. Reconstruction by Dale E. Gray.

on an iMac, which created a seamless, 3D digital image (Figure 1c). The resulting photogrammetry model now represents a tree trunk of 3.88 m length.

Perhaps the old quote "you can't see the forest for the tree," will be paradoxically twisted, as future research will surely reveal that you can see the (Morrison) forests, because of the trees.

References

Gee, C. T. (2020). The conifer forests of the "Jurassic Park" in western North America, Section 6.5. In C. T. Gee (chapter editor and coordinator), Unit 6, Postcards from the Mesozoic: Forest landscapes with giant flowering trees, enigmatic seed ferns, and other naked-seed plants. In E. Martinetto, E. Tschanz, & R. A. Gastaldo (Eds.), *Nature through Time: Virtual Field Trips Through the Nature of the Past* (pp. 165-169). Springer Nature.

Gee, C. T., Sprinkel, D. A., Bennis, M. B., & Gray, D. E. (2019). Silicified logs of *Agathoxylon hoodii* (Tidwell et Medlyn) comb. nov. from Rainbow Draw, near Vernal, Utah, and their implications for conifer forests in the Late Jurassic Morrison Formation. *Geology of the Intermountain West*, *6*, 77-92.

Parrish, J. T., Peterson, F., & Turner, C. E. (2004). Jurassic "savannah"–plant taphonomy and climate of the Morrison Formation (Upper Jurassic, Western USA). *Sedimentary Geology*, *167*, 137-162.

Sprinkel, D. A., Bennis, M. B., Gray, D. E., & Gee, C. T. (2019). Stratigraphic setting of Morrison Formation (Upper Jurassic) permineralized wood sites near Dinosaur National Monument, Uintah County, Utah. *Geology of the Intermountain West*, *6*, 61-76, A1-A5.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 11:45 AM)

SQUAMATES, MAMMALS, SALAMANDERS AND OTHER SMALL TETRAPODS FROM THE MIDDLE JURASSIC KILMALUAG FORMATION, ISLE OF SKYE, SCOTLAND

Benson, Roger B. J.[1*], Butler, Richard J.[2], Evans, Susan E.[3], Jones, Marc E.H.[4], Panciroli, Elsa [5,6], Tałanda, Mateusz[7], Walsh, Stig[6]

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The Middle Jurassic was a transitional time in the evolution of land vertebrates, especially among small-bodied groups such as squamates, amphibians and crown mammals, which became abundant as components of microvertebrate fossil assemblages for the first time. However, the fossil record of Middle Jurassic land vertebrates, and especially of small-bodied taxa, is poorly sampled, obscuring aspects of the anatomy and ecology of the early members of these groups. Few localities yield significant remains globally, and fewer still yield associated skeletal material. Here, we give a progress report of fieldwork on rocks of the Kilmaluag Formation at the Elgol Coast Site of Special Scientific Interest (Elgol Coast SSSI), Isle of Skye, Scotland. We propose to call this the 'Elgol Lagerstätte' due to the high abundance of small-bodied tetrapod remains, preservation of relatively complete and associated skeletons, wide range of taxa represented, and generally uncrushed preservation of most specimens. We provide a summary of scientifically important specimens recovered during joint field expeditions of the University of Oxford, National Museums of Scotland and University of Birmingham since 2014, including unreported material.

The Elgol Lagerstätte has yielded some of the most complete fossil skeletons of small vertebrates from the Middle Jurassic (Bathonian *c.*166 mya), including stem-members of turtles, squamates, therian mammals and salamanders, as well as other groups such as docodontan mammaliaforms and tritylodontids (e.g., Evans et al., 2006; Panciroli et al., 2020). The fossils are found in well-lithified carbonate rocks, with generally fine-grained lithologies deposited in a marginal marine lagoonal setting with predominantly freshwater influence. The first fossils from the Elgol Lagerstätte were discovered between 1971–1982, by Michael Waldman (Stowe School) and Robert Savage (University of Bristol), including partial skeletons of the docodontan *Borealestes* and the stem lepidosaur *Marmoretta* (e.g., Waldman & Evans, 1994). Further fieldwork was undertaken in the early 2000s, led by Paul Barrett (Natural History Museum, London) and Susan Evans (University College London), resulting in a substantial expansion of the faunal list and discovery of the stem-turtle *Eileanchelys waldmani* (Anquetin et al., 2009; Evans et al., 2006).

Our recent fieldwork has dramatically increased the number of skeletons and partial skeletons known from the site. These include two partial pterosaur skeletons, approximately 15 new stem-salamander specimens belonging to two species (the undescribed taxon 'Salamander A', and *Marmorerpeton wakei*; Figure 1a-b; Jones et al. 2022), fossil squamates or crownward stem-squamates including an unreported *Parviraptor*-like form and a near-complete skeleton of the stem squamate *Bellairsia gracilis* (Figure 1c; Tałanda et al., 2022), five new docodontan specimens belonging to two genera (*Borealestes* and *Krusatodon*; e.g., Figure 1d-e; Panciroli et al., 2021) and including unreported young juveniles, and three species of stem-therian mammals including an new triconodont and the amphitheriid *Palaeoxonodon ooliticus*.

The species assemblage of the Elgol Lagerstätte is similar to that of Kirtlington Quarry and other Bathonian microvertebrate assemblages in England (Panciroli et al., 2020), but differs in that relatively complete skeletons are present, in contrast to the disarticulated remains picked through after bulk processing at sites like Kirtlington. Skeletons from the Elgol Lagerstätte are typically disarticulated, are rarely confined to a single bedding plane, and generally represent small animals. These factors make both mechanical preparation and acid preparation very difficult. Instead, specimens are discovered from millimetre-scale cross-sections of a few bones visible at outcrop, and then visualized using an iterative process of lossless block-splitting and micro-CT or synchrotron scanning, with minimal exposure or damage of the physical specimen. This approach allows high-resolution digital visualization of generally every bone preserved in each specimen, including the original distribution and positioning of bones within the rock (Figure 1).

Scientifically important findings from the research so far include: new three-dimensionally preserved skeletons of the stem-salamander *Marmorerpeton* that substantially extend knowledge of the detailed anatomy of karaurid stem salamanders (Figure 1a-b; Jones et al., 2022); the near-complete skeleton of a stem squamate, *Bellairsia gracilis*, which provides new insights relevant to the ancestral morphology preceding the origin of the squamate crown-group (Figure 1c; Tałanda et al., 2022); arboreal ecology, based on hand anatomy, in the stem-lepidosaur *Marmoretta*; and 3D morphometric evidence for an unspecialized, terrestrial ecology in early docodonts, from the high subsequent ecological diversity of the group then arose (Figure 1d-e; Panciroli et al., 2021). Ongoing research on a wide range of other specimens will continue to yield new insights to the early evolution of speciose present-day groups of land vertebrates.

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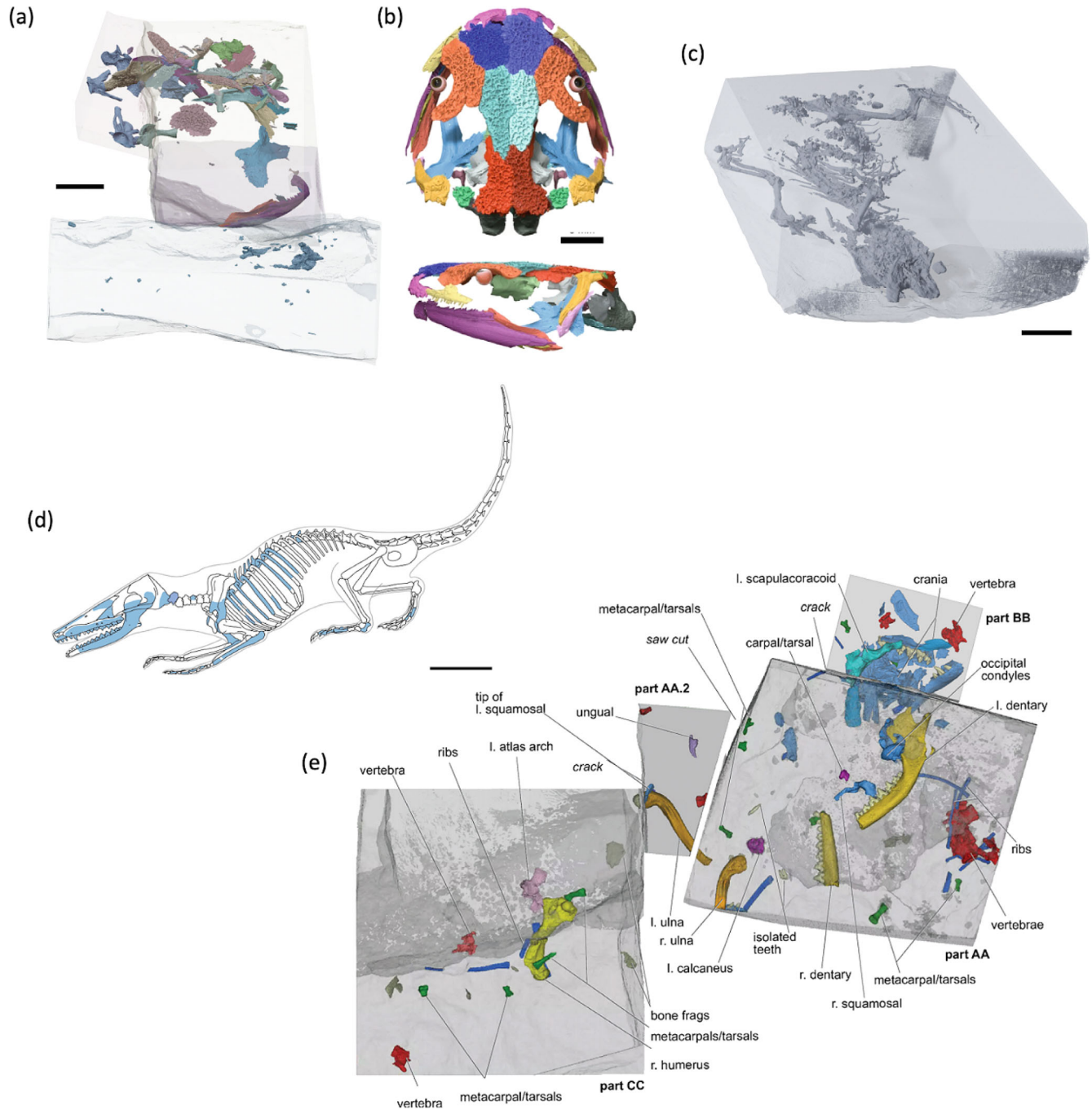


Figure 1. Fossils from the Kilmaluag Formation of the Elgol Largerstätte. (a-b) The stem salamander *Marmorerpeton wakei* (modified from Jones et al., 2022), (a) digital rendering of the most complete cranial specimen (National Museums of Scotland (NMS) G.2021.4.2) showing disarticulated skull bones in rock and (b) skull reconstruction in dorsal (upper) and left lateral (lower) views. (c) Digital rendering of stem squamate *Bellairsia gracilis* in rock (NMS G.2022.1.1; modified from Tałanda et al., 2022). (d-e) The docodontan mammal *Borealestes cuillinensis* (NMS G.2020.4.1.1; modified from Panciroli et al., 2021), (a) skeletal reconstruction with preserved bones highlighted in blue and (b) digital rendering of the bones in rock. Scale bars equal 10 mm.

References

Anquetin, J., Barrett, P. M., Jones, M. E. H., Moore-Fay, S., & Evans, S. E. (2009). A new stem turtle from the Middle Jurassic of Scotland: New insights into the evolution and palaeoecology of basal turtles. *Proceedings of the Royal Society of London B, 276*(1658), 879-886.

Evans, S. E., Barrett, P. M., Hilton, J., Butler, R. J., Jones, M. E. H., Liang, M.-M., Parish, J. C., Rayfield, E. J., Sigogneau-Russell, D., & Underwood, C. J. (2006). The Middle Jurassic vertebrate assemblage of Skye, Scotland. In P. M. Barrett, & S. E. Evans (Eds.). *Ninth International Symposium on Mesozoic Terrestrial Ecosystems and Biota,*

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Abstract and Proceedings (pp. 36-39). The Natural History Museum London.
Jones, M. E., Benson, R. B. J., Skutschas, P., Hill, L., Panciroli, E., Schmitt, A. D., Walsh, S. A., & Evans, S. E. (2022). Middle Jurassic fossils document an early stage in salamander evolution. *Proceedings of the National Academy of Sciences, 119*(30), e2114100119.
Panciroli, E., Benson, R. B. J., Walsh, S., Butler, R. J., Castro, T. A., Jones, M. E., & Evans, S. E. (2020). Diverse vertebrate assemblage of the Kilmaluag Formation (Bathonian, Middle Jurassic) of Skye, Scotland. *Earth and Environmental Science Transactions of the Royal Society of Edinburgh, 111*(3), 135-156.
Panciroli, E., Benson, R. B. J., Fernandez, V., Humpage, M., Martín-Serra, A., Walsh, S., Luo, Z. X., & Fraser, N. C. (2022). Postcrania of *Borealestes* (Mammaliformes, Docodonta) and the emergence of ecomorphological diversity in early mammals. *Palaeontology, 65*(1), e12577.
Tałanda, M., Fernandez, V., Panciroli, E., Evans, S. E., & Benson, R. B. J. (2022). Synchrotron tomography of a stem lizard elucidates early squamate anatomy. *Nature, 611* (7934), 99-104.
Waldman, M., & Evans, S. E. (1994). Lepidosauromorph reptiles from the Middle Jurassic of Skye. *Zoological Journal of the Linnean Society, 112*(1-2), 135-150.

Poster Session 2 associated with the Theme Session: Laramidia to Asia: biota and biogeography of interconnected iconic Late Cretaceous ecosystems (Friday, June 9, 2023)

PRECISE BENTONITE CHRONOSTRATIGRAPHY FOR FOSSILIFEROUS CAMPANIAN STRATA ACROSS WESTERN NORTH AMERICA

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Some of the richest and most diverse terrestrial fossil records in the world are preserved in the Upper Cretaceous strata of western North America. These rocks are exposed in a belt that covers a broad latitudinal range from Alaska to Mexico, which facilitates detailed spatio-temporal comparisons of palaeo-ecosystems across a north-south transect of the continent. Growing fossil collections illustrate an increasingly comprehensive portrayal of Late Cretaceous ecosystems and the focus of many investigations has now shifted to understanding continental scale biotic patterns such as latitudinal endemism vs cosmopolitanism, rates of biotic turnover, and diversity decline preceding the Cretaceous-Palaeogene extinction event. At their core, these concepts are founded on large compilations of spatially and temporally resolved fossil locality data, with the precision of this data determining the robustness of the broader concepts they support.
Work presented here synthesizes several recent contributions to the refinement of litho- and chronostratigraphic correlation of fossiliferous Campanian rocks across the Western Interior (Beveridge, 2022; Beveridge et al., 2020, 2022; Ramezani et al., 2022; and more). Weathered volcanic ash beds (bentonites) interbedded with targeted strata were used to construct a high precision temporal framework using U-Pb geochronology of phenocrystic zircon via chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-ID-TIMS). The present work focuses on the Campanian strata of southern Utah, namely the Wahweap and Kaiparowits formations, and how these units compare to strata from Alberta, Montana, and New Mexico.
The new high-precision age data were used to construct Bayesian age-stratigraphic models for stratotype sections. These provide decisively robust ages with appropriately propagated uncertainties for any stratigraphic level at one-meter increments throughout the modeled units. Thus, stratigraphically calibrated fossil localities can now be assigned calculated ages with robust uncertainty, which facilitates reliable and precise comparison across North America and beyond. These robust ages can be used to refine first and last appearance datums, which can be implemented in time-calibrated phylogenetic analyses and investigation of biotic turnover rates.
Lithostratigraphic refinement included in these works consisted of formal recognition and naming of seven previously described informal subdivisions of the Wahweap and Kaiparowits formations, and discovery and description of an entirely new member capping the Kaiparowits Formation. The new member names are, in ascending order, the Last Chance Creek, Reynolds Point, Coyote Point, and Pardner Canyon members of the Wahweap Formation, and the Tommy Canyon, The Blues, Powell Point, and Upper Valley members of the Kaiparowits Formation. Stratigraphic correlation of measured sections within the Kaiparowits Formation were refined by comparing high-precision type section bentonite ages with those from isolated sections using the new age models. Through this process, six bentonite beds were defined; the Star Seep, Horse Mountain, Death Ridge, Paria Hollow, Deadmans Corner, and Overlook bentonite beds.
Temporal refinement presented throughout our series of work indicates that stratigraphic diachroneity is

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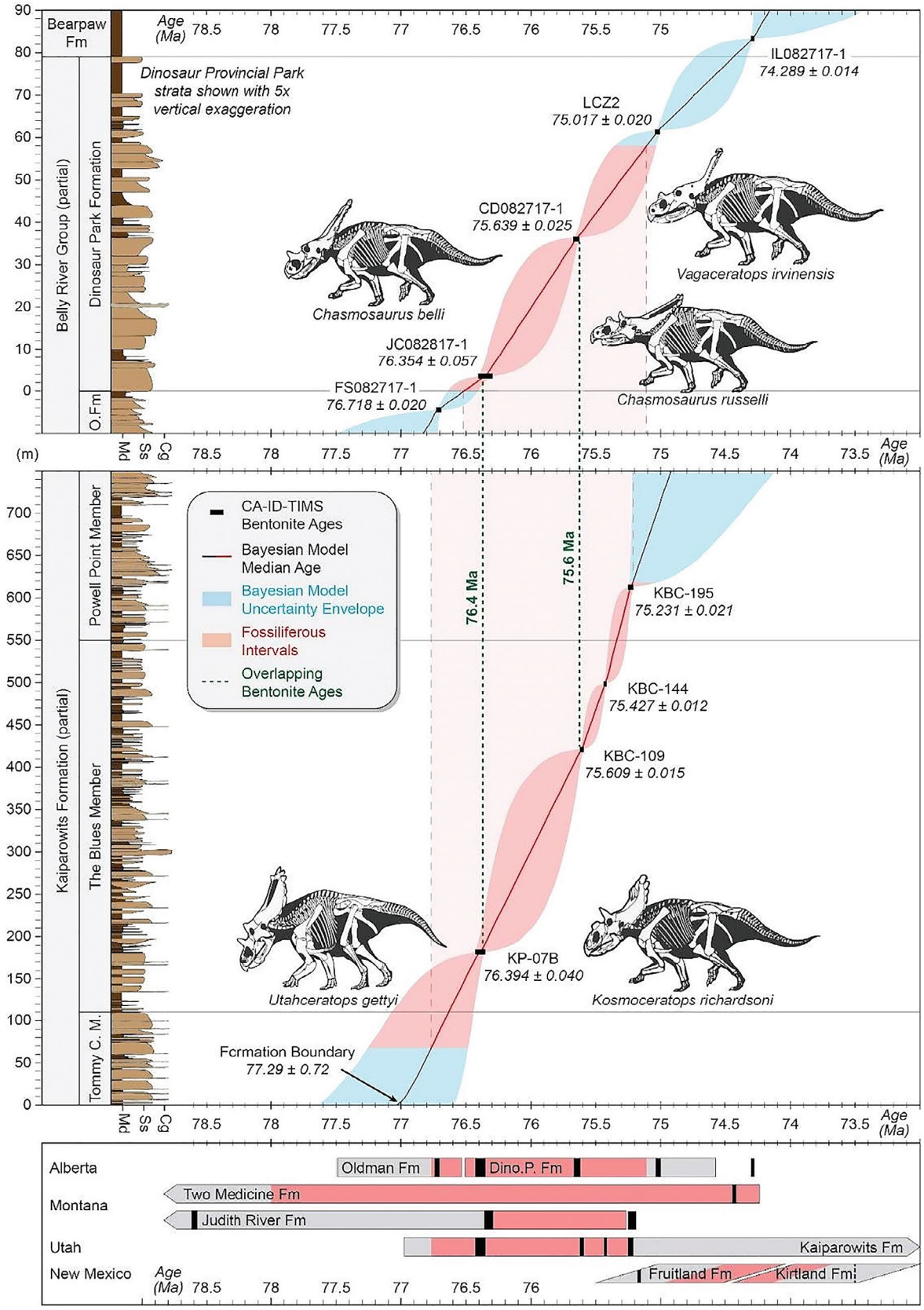


Figure 1. Comparison of age stratigraphic models for the Dinosaur Park and Kaiparowits formations in Alberta and Utah, respectively. Adapted from Ramezani et al. (2022) and Beveridge (2022). This new temporal refinement facilitates precise comparison of faunas (e.g., ft. chasmosaurian ceratopsids; Sampson et al., 2010; Mallon et al., 2012) across the Western Interior.

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most likely not the cause of apparent biogeographic patterns of endemism across Laramidia during the late Campanian. Synchronicity of key fossiliferous intervals between suspected northern and southern endemic centers is most explicitly demonstrated by comparing age-stratigraphic models for the Dinosaur Park and Kaiparowits formations from Alberta and Utah, respectively (see also Ramezani et al., 2022). The most fossiliferous intervals of these units are near-perfectly aligned (within error) and there are also two instances of synchronous bentonite ages. Discrete faunal zones within each formation can now be compared to one another with greater resolution to more precisely examine spatio-temporal relationships of closely coeval taxa across western North America.

Although the results clearly demonstrate synchronicity of several key localities, the most fossiliferous late Campanian strata in the San Juan Basin were shown to be distinguishably younger than those of the Dinosaur Park, Judith River, and Kaiparowits formations. This finding is consistent with published Campanian endemism counterarguments dominantly founded on observations from the San Juan succession (i.e., faunal diachroneity evident from the San Juan perspective is also validated by the new high-precision ages). This means that the addition of data from the Kaiparowits Formation has provided a critical southern representative, without which there is less clear evidence for a southern endemic center synchronous with northern equivalents. Inclusion of additional southern areas (e.g., Aguja Formation, West Texas) may further elucidate late Campanian biogeographic trends and facilitate investigation of proposed faunal gradients versus defined endemic centers. The overall outcome is the validation of many perspectives, which demonstrates the complexity of the latitudinal endemism hypothesis and how refinement of foundational datasets is critical for the advancement of palaeoecological hypotheses. With this new temporal framework in place, other avenues for refinement (e.g., efforts towards equal sampling, investigation of taphonomic influences) become the forefront of paleoecological investigations.

References

Beveridge, T. L. (2022a). *Bentonite geochronology and tephrostratigraphy for litho- and chronostratigraphic refinement of fossiliferous Campanian strata in western North America* [Doctoral Dissertation, James Cook University]. doi.org/10.25903/293r-4g58

Beveridge, T. L., Roberts, E. M., Ramezani, J., Titus, A. L., Eaton, J. G., Irmis, R. B., & Sertich, J. J. W. (2022b). Refined geochronology and revised stratigraphic nomenclature of the Upper Cretaceous Wahweap Formation, Utah, USA and the age of early Campanian vertebrates from southern Laramidia. *Palaeogeography, Palaeoclimatology, Palaeoecology, 591*, 110876. doi.org/10.1016/j.palaeo.2022.110876

Mallon, J. C., Evans, D. C., Ryan, M. J., & Anderson, J. S. (2012). Megaherbivorous dinosaur turnover in the Dinosaur Park Formation (upper Campanian) of Alberta, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology, 350-352*, 124-138. doi.org/10.1016/j.palaeo.2012.06.024

Ramezani, J., Beveridge, T. L., Rogers, R. R., Eberth, D. A., & Roberts, E. A. (2022) Calibrating the zenith of dinosaur diversity in the Campanian of the Western Interior Basin by CA-ID-TIMS U–Pb geochronology. *Scientific Reports, 12*, 16026. doi.org/10.1038/s41598-022-19896-w

Sampson, S. D., Loewen, M. A., Farke, A. A., Roberts, E. M., Forster, C. A., Smith, J. A., & Titus, A. L. (2010). New horned dinosaurs from Utah provide evidence for intracontinental dinosaur endemism. *PLoS ONE, 5*(9), e12292. doi.org/10.1371/journal.pone.0012292

Poster Session 1 (Thursday, June 8, 2023)

ON THE TERRESTRIAL EDGE - CRETACEOUS SEA TURTLE NESTS: ECOLOGY, PALEOECOLOGY, AND ICHNOLOGY

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All known sea turtles nest in the terrestrial sandy sediment fringing oceans in which they spend most of their lives; defining boundary of the terrestrial and marine ecosystems. Recent work on St. Catherines Island, Georgia by a team of paleontologists, has documented the ecology of sea turtle nesting on the fluctuating sandy shorelines of the modern and ancient seas; including the Mesozoic (Bishop et al., 2007; Blakey, 2006; Kržič & Bishop, 2021; Kržič et al., 2022). Cretaceous shorelines are represented by 62 black sand deposits of heavy mineral placers (Houston & Murphy, 1962; 1977; Force, 2000) throughout the Western Interior Seaway where the first fossilized sea turtle nest, representing a nearly complete nesting

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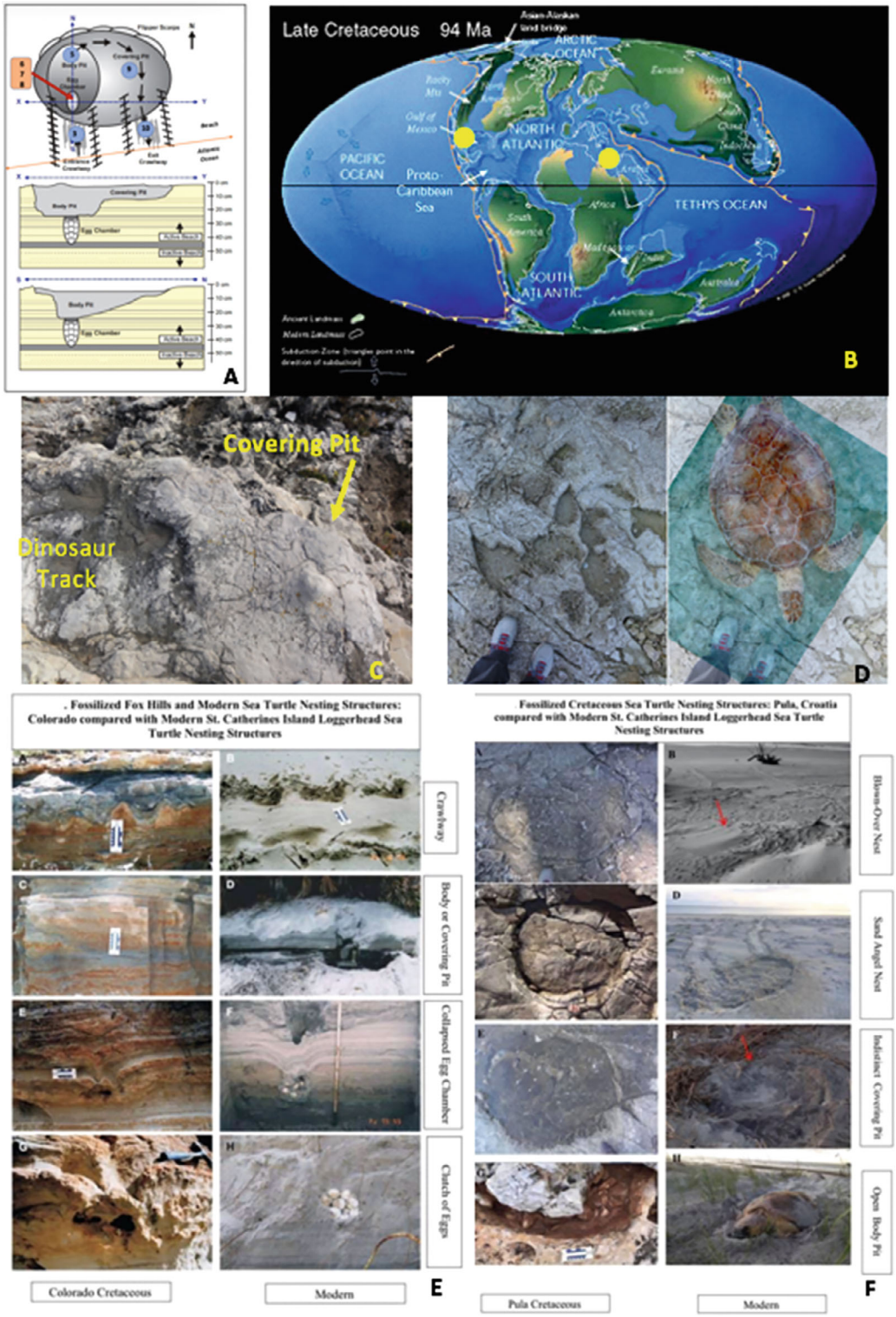


Figure 1 A). Map and cross section depiction of *C. caretta* sea turtle Ethogram; B). Cretaceous Paleogeography (after Scotese, from Blakey, 2006); C). Croatian Covering Pit with a Hadrosaur Track (from Kržič & Bishop, 2021); D). Impression of sea turtle on Croatian Limestones (from Kržič, et al., 2012); D). Comparison of 94 Ma Fox Hills Colorado nest with analogs from SCI (from Kržič, et al., 2012); E). Comparison of fossilized 110 Ma Croatian sea turtle nests with analogs from SCI.

ethogram, was discovered and documented (Bishop et al., 2000, 2008, 2011; Hailman & Elowson, 1992; Pirkle et al., 2012, 2000). This presentation documents the back-beach boundary of the terrestrial marine ecosystem in Colorado and Croatia, and provides impetus for additional research on the nesting ecology, morphology, and paleoecology of

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sea turtles' utilization of the edge of the terrestrial environment.

The first described sea turtle nesting fossilized suite of trace fossils of sea turtle nesting was discovered in the Fox Hills Sandstone 80 mi (130 km) ESE of Denver Colorado in 1997 in a heavy-mineral deposit about 1.6 kilometers in length, three meters in thickness exposed along Interstate 70, in Elbert County, near Limon, Colorado, on "Titanium Ridge;" a 74 million-year old shoreline of the Western Interior Seaway. The heavy mineral deposit appears in a series of visually interpretable facies that are stacked vertically and represent (bottom to top) subtidal, forebeach, back-beach, wash-over fan, and aeolian depositional environments. These facies are specifically analogous to depositional environments represented by a modern heavy-mineral bearing facies tract on St. Catherines Island, Georgia (Bishop et al., 2000, 2011; Pirkle et al., 2012). The Fox Hills Nest, with approximately 17 egg molds in its bottom, was collected with permission of the landowner and is reposited at the South Dakota School of Mines and Technology's Museum of Geology and Paleontology (SDSM 149144).

On the shore of the modern Adriatic Sea at Pula, Croatia, the world's second ethogram-based suite of trace fossils of sea turtle nesting has been described (Bishop et al., 2007; Kržič & Bishop, 2021, 2022, 2023; Kržič et al., 2021). Three impressions of sea turtles, 41 covering pits, two egg chambers, and other sea turtle nesting traces have been described, along with traces of crocodilians, pterosaurs, and fish in a dinosaur "highway" of bioturbation beds containing theropods, sauropods, and ankylosaurs. Two sea turtle nests have dinosaur tracks on top of their covering pits, two probable egg chambers have been photographed, and a depredated nest has been documented. All data were taken without collecting any specimens, using only photography, leaving the trace fossil evidence to remain in those beaches as voucher specimens (Dalton 2007). Unfortunately, this unique resource is now being partly lost as hotels respond to tourists' demands for smooth, cemented, and flagstone-covered beaches.

Frey and Pemberton (1987) defined the *Psilonichnus* Ichnocoenose; the "*ecotone between marine and nonmarine facies, typically corresponding to the beach backshore and dunes or to washover fans and supratidal flats. lchnologically, this quasi-marine ecotone yields distinctive mixtures of marine and nonmarine lebensspuren* ...," including sea turtle nesting traces and defines the edge of the terrestrial ecosystem. Similar facies in Croatia exhibit those coastal trace fossils as well as dinosaur track beds that define the very edge of the terrestrial ecosystem at ~ 105 to 110 million years ago, where at least 41 sea turtle nesting trace fossils overlap dinosaur bioturbations; making it the world's first described sea turtle rookery with sea turtle traces truncating dinosaur tracks and with at least two dinosaur tracks on top of covering pits of sea turtle nests. The dinosaur tracks on the top of "intertidal and shallowing-upward successions during ephemeral subaerial exposure of the fine-grained carbonate sediment in Croatia" have been described by Mezga et al. (2015:113) as part of a terrestrial *Brontopodus* Ichnocoenose (Lockley et al., 1994), which overlaps the *Psilonichnus* Ichnocoenose by having dinosaur tracks on top of sea turtle nests. All known sea turtles nest in the terrestrial sediment fringing the oceans in which they spend most of their lives; bridging the terrestrial and marine ecosystems between the *Brontopodus* Ichnocoenose and the *Psilonichnus* Ichnocoenose. The ramifications of naming sea turtle nesting ichnofossils from complete nesting ethograms is imperative (Bertling et al., 2006; Gaillard et al., 2003).

Both trace fossil suites represent nearly complete sequences of nesting traces of sea turtle ethograms at 74 Ma and 110 Ma ago and both suites include covering pits, evidence of camouflaging activity of sea turtles to protect their clutches of incubating eggs (Brannen & Bishop, 1993). Data from Recent loggerhead sea turtle nests (*Caretta caretta* Linneaus, 1758) on St. Catherines Island, Georgia (USA), of analogous size and morphology, indicate an average covering pit size of 3.72 m^2 with egg chamber necks 1.01% of the area of the covering pits. The search continues for additional fossilized sea turtle nests around the world (Cadena et al., 2018; Lockly et al., 2019).

References

Bertling, M., Braddy S. J., Bromley, G. R., Demathieu, J., Genise, R., Mikula´sˇ, J. K., Nielsen K. S. S., Rindsberg, A. K., Schlirf, R. G., & Uchman. A. (2006). Names for trace fossils: a uniform approach. *Lethaia, 39*, 265-286. https://doi.org/10.1080/00241160600787890

Bishop, G. A., Marsh, N. A. B., & Pirkle, F. L. (2000). Fossilized Cretaceous Sea Turtle Nest from Colorado. *Proceedings of the Nineteenth Annual Symposium on Sea Turtle Conservation and Biology*, *NOAA Technical Memorandum NMFS-SEFSC-443*, 101-103.

Bishop, G. A., Hayes, R. H., Meyer, B. K., Rollins, H. E., Rich, F. J., Thomas, D. H., & Vance, R. K. (2007). Transgressive Barrier Island Features of St. Catherines Island, Georgia. In F. J. Rich (Ed.), *Fieldtrips of the 2007 annual meeting, Southeastern Section, Geological Society of America* (pp. 39-85). Georgia Southern University.

Bishop, G. A., Marsh, N. B., & Pirkle. F. L. (2000). Fossilized Cretaceous Sea Turtle Nest from Colorado. In H. J. Kalb, & T. Wibbels (Eds.). *Proceedings of the Nineteenth Annual Symposium (1999) on Sea Turtle Biology and Conservation, U.S. Department of Commerce NOAA Technical Memorandum NMFS-SEFSC-443*, 101-104.

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Bishop, G. A., Pirkle, F. L., Meyer, B. K., & Pirkle, W. A. (2011). The foundation for sea turtle geoarchaeology and zooarchaeology: Morphology of recent and ancient sea turtle nests, St. Catherines Island, Georgia, and Cretaceous Fox Hills Sandstone, Elbert County, Colorado, Chapter 13. In G. A. Bishop, H. B. Rollins, & D. H. Thomas (Eds), *Geoarchaeology of St. Catherines Island, Georgia*. (pp. 247-269). American Museum of Natural History, Anthropological Papers 94.

Blakey, R. C. (2006). Cretaceous paleogeography, southwestern US: accessed March 10, via the internet at http://paleoportal.org/index.php?globalnav=time_space&sectionnav=period&period_id=18

Brannen, N. A., & Bishop, G. A. (1993). Nesting traces of the Loggerhead Sea Turtle (Caretta caretta (Linné), St. Catherines Island, Georgia: Implications for the fossil record. In K. M. Farrell, C. W. Hoffman, & V. J. Henry, Jr. (Eds.), *Geomorphology and facies relationships of Quaternary barrier island complexes near St. Marys, Georgia. Georgia Geological Society Guidebook 13*, 30-36.

Cadena, E.-A., Parra-Ruge, M. L, Parra-Ruge, J. D. D., & Padilla-Bernal, S. (2018). A gravid fossil turtle from the early Cretaceous reveals a different egg development strategy to that of extant marine turtles. *Palaeontology, 62*, 533-545. doi: 10.1111/pala.12413.

Dalton, R. (2007). Dinosaur prints lead to crediting row. *Nature, 446*(12), 708.
https://www.nature.com/articles/446708a.

Force, E. R. (2000) Titanium mineral resources of the western US - an update. *U.S. Geological Survey Open File Report, 00-442*, 1-37.

Frey, R. W., & Pemberton, S. G. (1987). The Psilonichnus Ichnocoenose, and its relationships to adjacent marine and nonmarine icnocoenoses along the Georgia coast. *Bulletin of Canadian Petroleum Geology, 35*(3), 333-357.

Gaillard, C., Bernier, P., Barale, G., Bourseau, J.-P., Buffetaut, E., Ezquerra, R., Gall, J.-C., Lapparent de Broin, F., Renous, S., & Went, S. (2003). A giant Upper Jurassic turtle revealed by its trackways. *Lethaia, 36*, 315-322. DOl10.1080/00241160310004611.

Hailman, J. P., & Elowson, A. M. (1992). Ethogram of the nesting female Loggerhead (*Caretta caretta*). *Herpetologica, 48*, 1-30.

Houston, R. S., & Murphy, J. F. (1962). *Titaniferous black sandstone deposits of Wyoming. Geological Society of Wyoming Bulletin, 49*, 1-120.

Houston, R. S., & Murphy, J. F. (1977) Depositional environment of Upper Cretaceous black sandstones of the western interior. *U.S. Geological Survey Professional Paper, 994A*, 1-29.

Kržič, B., & Bishop, G. A. (2021). Želvja Jajca V Mivki – Že110 Milijonov Let!. "Zivljenje and Tehnika," 04 leto 2021, *letnik* LXXII, 24-33.

Kržič, B., Bishop, G. A., Samms, M. J., Rindsberg, A. K., & Meyer, B. K. (2021). Ancient Sea Turtle Nests! ... from around the World! *Academia Letters*, Article 3082. https://doi.org/10.20935/AL3082.

Kržič, B., & Bishop, G. A. (2022). Fosilne Sledi in Odtisi Krokodilov iz Zgodeje Kriede. Zivljenje and Tehnika, *Letnik, LXIII*, 51-65.

Kržič, B., & Bishop, G. A. (2023). Orjaški Tetropodi Istre. Zivljenje and Tehnika, 04, *Letnik, LXXIV*, 56-65.

Lockley, M. G., Hunt, A., & Meyer, C. A. (1994). Vertebrate tracks and the ichnofacies concept: Implication for paleoecology and palichnostratigraphy. In S. Donovan (Ed.), *The paleobiology of trace fossils* (pp. 241-268). Wiley & Sons.

Lockley, M. G., Cawthra, H. C., De Vynck, J. C., Helm, C. W., McCrea, R. T., & Nel, R. (2019). New fossil sea turtle trackway morphotypes from the Pleistocene of South Africa highlight role of ichnology in turtle paleobiology. *Quaternary Research, 92*, 626-640. https://doi.org/10.1017/qua.2019.40.

Mezga, A., Tesovic, B. C., Pretovic, V., Jovanovic, N., & Bajraktarevic, Z. (2015). Dinosaur footprints in the lower Hauterivian deposits of Palud Cove in Istria, Croatia. *Geologica Croatica, 68*, 113-122.

Pirkle, F. L., Bishop, G. A., Pirkle, W. A., & Stouffer, N. W. (2012). Heavy mineral deposits of the Fox Hills Formation located near Limon, CO. *Mining Engineering, 64*(3), 34-44.

Scotese, C. R. (2014). Atlas of Early Cretaceous Paleogeographic Maps, PALEOMAP *Atlas for ArcGIS, volume 2, The Cretaceous, Maps 23-31, Mollweide Projection*. PALEOMAP Project. DOI:10.13140/2.1.4099.4560

Theme Session: Global Perspectives on Mesozoic Lacustrine Ecosystems (Thursday, June 8, 2023, 2:45 PM)

NOTES FROM THE UNDERGROUND—A GLOBAL PERSPECTIVE ON THE ESSENTIAL ROLE OF GROUNDWATER AND CONTINGENCIES IN FORMING AND PRESERVING PALEOENVIRONMENTAL INDICATORS AND CLIMATE PROXIES IN CONTINENTAL SETTINGS

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The stratigraphic record of continental depositional environments (river-floodplain, mire, lake, aeolian) indicates that they respond to extrinsic controls in an integrated, self-organized way that results in characteristic lithofacies, stratal architectures, and infaunal activity (Bohacs et al., 2000; 2003). These characteristics are a function of proximate, derivative controls (e.g., accommodation, sediment supply, groundwater hydrology, and fluvial discharge) that are complex and convergent combinations of first-order ultimate controls such as tectonics and climate (Bohacs, 2022). Thus, the effects of climate and climate change on continental environments and their resulting deposits and fossil content are non-unique, being contingent on the pre-existing state of the system, direction and magnitude of change, and other factors that affect the system's sensitivity to change. For example, the formation and preservation of many 'climate-sensitive' lithologies (coals, evaporites, red beds) and proxies (palynomorphs, stable isotopes) upon which we base paleoclimate interpretations are most sensitive to local paleohydrologic conditions and may not accurately depict regional or global atmospheric conditions. Thus, one can find coals and not find evaporites in dry climates or not find coals in wet climates due to local conditions. The hydrographic-hydrologic complexity of some continental interior basins can also obviate confident quantitative estimates of paleotemperature from oxygen isotopes. Such challenges can be addressed by thorough integration of paleogeography, stratigraphy, sedimentology, paleontology, paleoichnology, mineralogy, and stable isotope data of lacustrine and pedogenic carbonates within a framework that accounts for the many, convoluted, and contingent controls on continental depositional systems.

Contingent factors that affect all continental systems include biological evolution, basin phase, upstream and downstream conditions, lake-water salinity, landscape development, and immediately antecedent conditions (e.g., topography, substrate composition [Bohacs, 2022]). The relative importance of each of these factors vary among continental systems.

For fluvial-floodplain strata, additional contingent factors include grain-size distribution and sorting of sediment available to the system, along-stream location in the basin, interchange with groundwater systems, local sediment sources, and tectonically imposed gradients (Schumm 1977). Key proximate controls are spatial distribution of sedimentation (due to interaction of rates of sediment supply and accommodation) along with water supply and channel avulsion rates. Key paleoclimate parameters are the spatial distribution of precipitation and its seasonality, precipitation/evaporation (P/E) range, minimum and maximum surface temperatures, and glaciation potential, with due regard for the potential of differing paleoclimate conditions in reaches upstream of a study section.

For mires and their coal-bearing strata, important additional contingencies are groundwater table hydrologic history, location along the groundwater profile, floral community control on the compaction component of accommodation, aeolian input of nutrients, and time available for plant colonization (Bohacs & Suter, 1997). Coals are observed to accumulate both in areas of high primary plant production and in areas of high plant preservation (persistently high groundwater tables or seasonally freezing temperatures). Thus, coals are not only found in tropical areas and mid to high latitudes, but also in zonally dry areas with long-traveled rivers and local subsidence leading to high groundwater (e.g., the papyrus peats of the Okavango delta in the Kalahari desert). Key proximate controls are the rates of production of plant material relative to rates of accommodation change. Paleoclimatic conditions favorable for coal accumulation are: abundant rainfall during the growing season, high and consistent P/E to maintain high groundwater, or very low temperatures during the non-growing season.

For lacustrine strata, additional influential factors include rates of uplift or geomorphic evolution of a lake's sill, basin-floor subsidence, and along-stream position of depositional site within a chain of lakes, as well as the route of water supply (overland, direct precipitation, or groundwater). Present-day observations demonstrate no significant relation between any measure of lake size or character or any independent climatic factor (Bohacs et al., 2003). In the ancient record, climate alone does not correlate strongly with lake occurrence, character, size, or lithofacies. Key proximate controls are the rates of potential accommodation change relative to supply of sediment+water. These governing variables are not, however, simple functions of climate and tectonics, but nonlinear combinations of them with other equally important variables. Sediment+water supply rate is not a simple function of precipitation due to multiple mechanisms of sediment transport, strong memory in the watershed system, and significant hysteresis and sensitivity to the direction of change. For instance, a very dry climate may have abundant mechanically weathered sediment, but insufficient precipitation to provide persistent transport. Thus, it would yield little clastic sediment. The presence and abundance of evaporites in a dry climate is a very strong function of groundwater flow paths (Rosen, 1994): significant bedded evaporites are preserved only where

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persistent discharge occurs. Moderate intrastratal evaporites occur where groundwater is through-flowing, and minimal evaporites are preserved in groundwater recharge areas. Groundwater paths are influenced by aquifer stratigraphy, groundwater salinity, underlying tectonic structure, lake-basin type, and the position of a particular lake basin in a hydrologically connected chain of lakes, as well as climate. Certain combinations of these controls can lead to apparently conflicting climatic indicators: freshwater spring deposits characteristically form near and landward of the shoreline in saline and hypersaline lakes because the fresher groundwater flows atop the more saline groundwater wedge (Freeze & Cherry, 1979; Jagnieki et al., 2021). These paths can be deciphered using stable carbonate and oxygen isotope composition of primary authigenic carbonates, detailed sedimentology, and mineralogy (Baddouh et al., 2021; Benavente et al., 2019; Jagnieki et al., 2021). Distinguishing water-supply paths provides additional insights into continental systems and occurrence and character of evaporites and carbonates. Associated trace fossils (burrows, trails, etc.) also provide information about many aspects of their depositional environment (groundwater and oxygen levels, substrate consistency, food availability, and ecosystem trophic structure). Key paleoclimate parameters are the temporal and spatial distribution of precipitation, P/E range, minimum and maximum surface temperatures, and wind fields. Climates with relatively low precipitation/evaporation host the most areally extensive lakes whereas intermittently high precipitation favors the development of extensive clastic shorelines.

These many processes and contingencies make reconstructing continental paleo-environmental conditions quite challenging. It is essential to interpret paleoenvironmental proxies within a context that includes physical, biogenic, and chemical data at scales from paleogeography to isotopes and that considers the influence of contingencies.

References

Baddouh, M., Carroll, A. R., Jagniecki, E. A., Beard, B. L., Lowenstein, T. K., & Johnson, C. M. (2021). Groundwater mixing in an alkaline paleolake: Eocene Green River Formation, Wyoming, *Palaeogeography, Palaeoclimatology, Palaeoecology, 561*, 110038.

Benavente, C. A., Mancuso, A. C., & Bohacs, K. M. (2019), Paleohydrogeologic reconstruction of Triassic carbonate paleolakes from stable isotopes: Encompassing two lacustrine models. *Journal of South American Earth Sciences, 95*, 102292.

Bohacs, K. M. (2022). Chapter 16: Controls on stratal record: mechanisms and contingencies affecting sediment supply and accommodation. In K. M. Bohacs & O. R. Lazar (Eds.), *Sequence stratigraphy—applications to fine-grained rocks. American Association of Petroleum Geologists Memoir 126* (pp. 642-686).

Bohacs, K. M., Carroll, A. R., & Neal, J. E. (2003). Lessons from large lake systems—Thresholds, nonlinearity, and strange attractors, In M. A. Chan & A. W. Archer (Eds.), *Extreme depositional environments: Mega end members in geologic time. Geological Society of America Special Paper, 370* (pp. 75-90).

Bohacs, K. M., Carroll, A. R., Neal, J. E., & Mankiewicz, P. J. (2000). Lake-basin type, source potential, and hydrocarbon character: An integrated sequence-stratigraphic–geochemical framework. In E. Gierlowski-Kordesch & K. Kelts (Eds.), *Lake basins through space and time: American Association of Petroleum Geologists Studies in Geology, 46* (pp. 3-37).

Bohacs, K. M., & Suter, J. (1997). Sequence stratigraphic distribution of coaly rocks; fundamental controls and paralic examples. *American Association of Petroleum Geologists Bulletin, 81*, 1612-1639.

Freeze, R. A., & Cherry, J. A. (1979). *Groundwater*. Prentice-Hall.

Jagniecki, E. A., Lowenstein, T. K., Demicco, R. V., Baddouh, M., Carroll, A. R., Beard, B. L., & Johnson, C. M. (2021), Spring origin of Eocene carbonate mounds in the Green River Formation, Northern Bridger Basin, Wyoming, USA. *Sedimentology, 68*, 2334-2364.

Rosen, M. R. (1994). The importance of groundwater in playas: A review of playa classifications and the sedimentology and hydrology of playas, In M. R. Rosen (Ed.), *Paleoclimate and basin evolution of playa systems*: *Geological Society of America Special Paper, 289* (pp. 1-18).

Schumm, S. A. (1977). *The fluvial system*. John Wiley & Sons.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 10:30 AM)

KAROO FOOTPRINTS MADE DURING THE CARNIAN PLUVIAL EVENT IN SW GONDWANA

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A major shift in the early Late Triassic climate, referred to as the Carnian Pluvial Event (CPE), has emerged as

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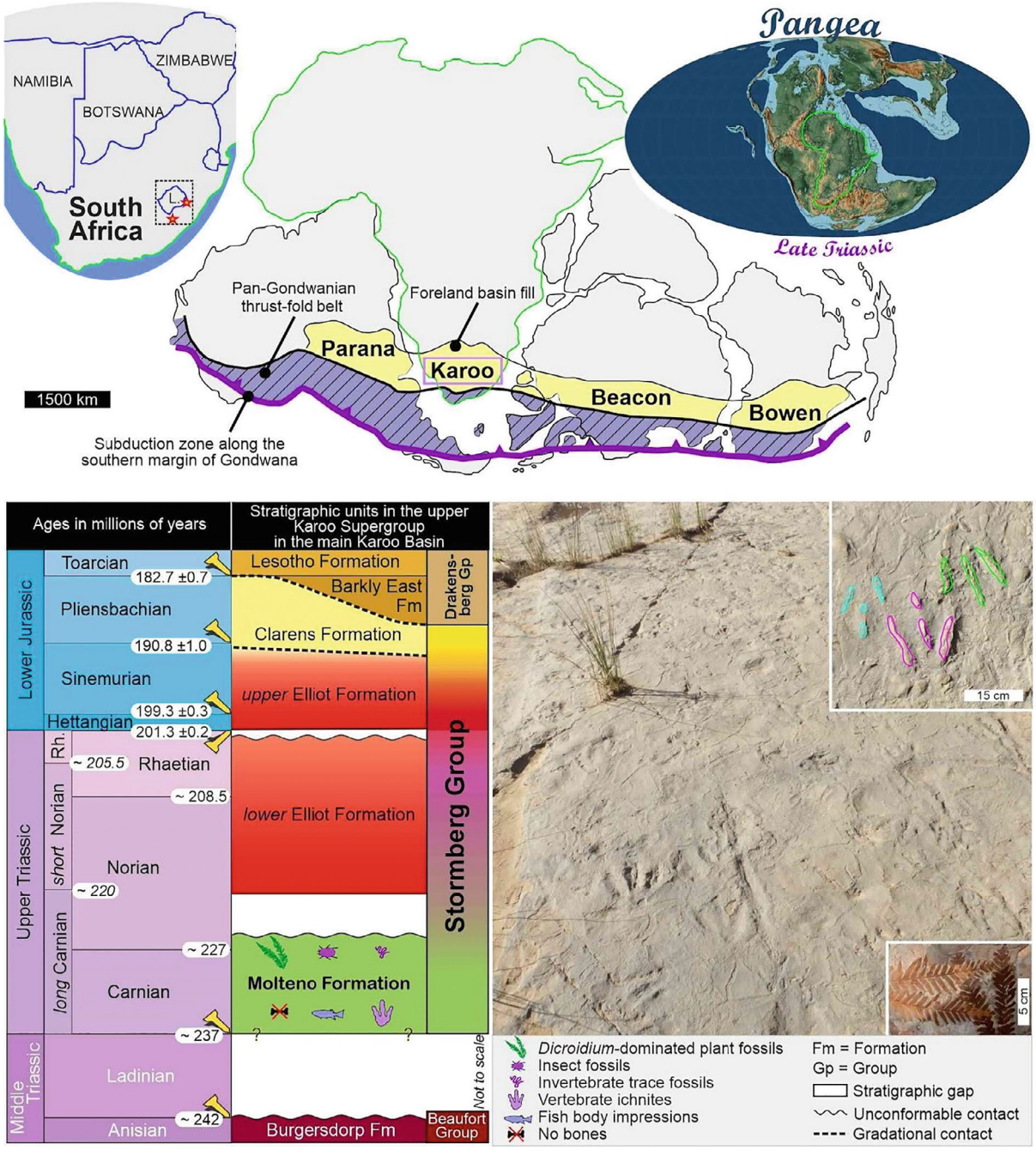


Figure 1. Stratigraphic and geological context of the Carnian–?lowermost Norian Molteno Formation within the upper Karoo Supergroup. The six footprint sites reported herein are all in the south-eastern part of South Africa. Regional palaeogeographic maps show the position of Africa within SW Gondwana as well as Pangea in the Late Triassic (Pangea map source: PALEOMAP Project – Scotese, 2014).

the trigger of an extraordinary interval of continental landscape and biotic evolutionary history in Pangea, however, the impact of the CPE remains unknown in the Karoo region of the supercontinent (Figure 1). The physicochemical origin of this environmental change and the magnitude of the ensuing ecological turnover in the Late Triassic remain the focus of ongoing international investigations (Dal Corso et al., 2020; Simms & Ruffell, 2018).

The only southern African stratigraphic unit of Carnian age is the coal-bearing fluvio-lacustrine Molteno Formation that is sandwiched between Triassic red beds of the Burgersdorp and Elliot Formations (Figure 1). Being the oldest upper Karoo unit, the Molteno Formation diachronously and unconformably overlies older Karoo rocks along the 'Ladinian Gap' of Veevers et al. (1994), which is the largest single stratigraphic gap in the Karoo Supergroup (Figure 1; Hancox & Rubidge, 2023). Arranged into

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repeated, erosively based, upward-fining successions of a few metres in thickness, the characteristic Molteno assemblage is dominated by feldspathic, quartz-rich sandstones that are laterally extensive (average > 150 m), sheet-like, multi-storey bodies. The depositional environment of the Molteno Formation was reconstructed as high-energy alluvial plain in the Karoo foreland basin (Figure 1). This northward draining system hosted crevasse-splays, sheet-flood deposits, lakes and swamps, and was occupied by various peat-forming habitats: riparian forests, woodlands, thickets, marshes, and fern meadows (Cairncross et al., 1995).

The unit's firm global geoscientific status is due to its palaeontological significance as it is richly fossiliferous and marks a major shift in vertebrate life by a faunal turnover from cynodont- to dinosaur-dominated fossil biota in SW Gondwana. Given the Carnian age, this turnover likely occurred during the brief but severe environmental change of the CPE that resulted in episodes of significant rainfall increase globally. Indeed, the Molteno Formation shows ample evidence for increased humidity by preserving abundant and diverse fossil plant and insect species in its carbonaceous rocks. More specifically, the remarkably rich *Dicroidium*-dominated Molteno flora contains over 200 fossil plant species and marks the peak of gymnosperm biodiversity in Gondwana (e.g., Anderson & Anderson, 1985; Anderson et al., 1998). The Formation also contains the oldest reported fossil amber in Africa (Ansorge, 2007) and an abundant and diverse insect fauna with several hundred species with an associated plethora of insect-plant interactions (e.g., leaf-mining activities; Labandeira et al., 2018). Juxtaposing the exceptional wealth of macroplant and insect fossils, the formation, however, lacks evidence for animal life, the exception being some rare freshwater molluscs, branchiopod crustaceans, spiders, and body impressions of fossil ray-finned fish, and to-date, a single South African site with tetrapod footprints that is one of the oldest records of putative dinosaur footprints in the world (Raath et al., 1990).

Here, we report the discovery of five additional Molteno footprint sites that preserve abundant and diverse tetrapod tracks and trackways (Figure 1) in the SE part of South Africa. Using standard and modern ichnological methods, we documented these tridactyl and tetradactyl ichnites at the newly documented track sites as well as at the previously reported site of Raath et al. (1990). Moreover, we resolved the stratigraphic context of these track-bearing surfaces and examined the sedimentology of the host rocks. Our results show that the tracks belong to various bipedal and quadrupedal tetrapods ranging from amphibious/aquatic tetrapods to pseudosuchians and dinosaurs, including basal sauropodomorphs. Detrital zircon ages, extracted from the host sandstones and analysed via U-Pb radioisotopic dating methods, show that these track-bearing surfaces host the oldest dinosaur tracks in SW Gondwana to-date. Furthermore, some of the dinosaurian tracks are being reported herein for the first time from this part of Pangea.

Constraining the paleoecology of the Molteno Formation is critical for refining the biostratigraphy of the Late Triassic globally. In the more regional context of SW Gondwana, the Molteno paleoecology is also key for determining the interwoven factors driving Triassic palaeo-climatic change from semi-arid pre- and post-Molteno times as well as the Carnian habitat of the main Karoo Basin. Because stratigraphy, in all of its manifestations (e.g., litho-, chrono-, biostratigraphy), is at the heart of local and regional correlations, our new discovery of numerous and diverse footprint sites in the richly fossiliferous Molteno Formation will benefit comparisons with other Carnian units in Africa and across Pangea, from Australia in the SE to China in the NE. Moreover, because the deposition of the Molteno Formation overlapped with the dawn of the dinosaur and modern terrestrial vertebrates, our study is valuable not only for deciphering improved macroevolutionary trends in Late Triassic continental biota globally but also for contextualizing how the iconic CPE unfolded and caused palaeobiotic changes and a potentially substantial ecological perturbation in Pangea.

References

Anderson, J. M., & Anderson, H. M. (1985). *Palaeoflora of southern Africa. Prodromus of South African megafloras, Devonian to Lower Cretaceous*. A. A. Balkema.

Anderson, J. M., Anderson, H. M., & Cruickshank, A. R. I. (1998). Late Triassic ecosystems of the Molteno/Lower Elliot biome of Southern Africa. *Palaeontology, 41*, 387-421.

Ansorge, J. (2007). Upper Triassic insects and amber from Lesotho. *4th International Conference on Fossil Insects, Arthropods and Amber, Pretoria, South Africa*, *Abstract book*, 52-54.

Cairncross, B., Anderson, J. M., & Anderson, H. M. (1995). Palaeoecology of the Triassic Molteno Formation, Karoo Basin, South Africa - sedimentological and palaeontological evidence. *South African Journal of Geology, 98*, 452-478.

Dal Corso, J., Bernardi, M., Sun, Y., Song, H., Seyfullah, L. J., Preto, N., Gianolla, P., Ruffell, A., Kustatscher, E., Roghi, G., Merico, A., Hohn, S., Schmidt, A. R., Marzoli A., Newton, R. J., Wignall, P. B., & Benton, M. J. (2020). Extinction and dawn of the modern world in the Carnian (Late Triassic). *Science Advances, 6*, eaba0099.

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Hancox, P. J., & Rubidge, B. S. (2023). The Beaufort-Stormberg Group contact – Implications for Karoo Basin development in the Triassic. *Journal of African Earth Sciences, 198*, 104767. https://doi.org/10.1016/j.jafrearsci.2022.104767

Labandeira, C. C., Anderson, J. M., & Anderson, H. M. (2018). Expansion of arthropod herbivory in Late Triassic South Africa: The Molteno Biota, Aasvoëlberg 411 site and developmental biology of a gall. In L. H. Tanner (Ed.), *The Late Triassic world: Earth in a time of transition* (pp. 623-719). Springer.

Raath, M. A., Kitching, J. W., Shone, R. W., & Rossouw, G. W. (1990). Dinosaur tracks in Triassic Molteno sediments: the earliest evidence of dinosaurs in South Africa? *Palaeontologica Africana, 27*, 89-95.

Scotese, C. R. (2014). Atlas of Permo–Triassic Paleogeographic Maps (Mollweide Projection), Map 42, *Volume 3 of the PALEOMAP Atlas for ArcGIS*. PALEOMAP Project.

Simms, M. J., & Ruffell, A. H. (2018). The Carnian Pluvial Episode: from discovery, through obscurity, to acceptance. *Journal of the Geological Society, 175*, 989-992.

Veevers, J. J., Cole, D. I., & Cowan, E. J. (1994). Southern Africa: Karoo Basin and Cape Fold Belt. In J. J. Veevers & C. M. Powel (Eds.), *Permian–Triassic Pangean Basins and foldbelts along the Panthalassan Margin of Gondwanaland*. *Geological Society of America Memoirs, 184* (pp. 223-278).

Theme Session: Global Perspectives on Mesozoic Lacustrine Ecosystems (Thursday, June 8, 2023, 3:00 PM)

'THE LAKE AS A MICROCOSM': LACUSTRINE ECOSYSTEMS FROM THE EARLY JURASSIC OF SOUTHERN PANGEA

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The rock record of lakes is a collage of petrified but incomplete signals resulting from the intricate interactions between physical, chemical, and biological processes that occurred in each of these microcosms. Teasing apart the geo- and biological changes recorded in ancient lake sediments is difficult, not only because every lake is a "little world within itself" (Forbes, 1887), but also because lake studies that are transferable in time and space* are lacking (* "a lake is not just a mini ocean" – Bohacs et al., 2001). Another limitation arises from the disparate focus on temperate-climate lakes in lake-rich areas, leaving many questions unanswered, for example, on palaeo-ecological changes in shallow "little worlds" in arid zones compared to deep "little worlds" of temperate or even tropical zones. This also poses a contemporary problem, because decoding the ancient, natural, lacustrine depositional record can serve as a baseline for ecological changes in recent and future lake systems. However, without a robust handle on the pre-human depositional record, our understanding of the anthropogenic influence on lacustrine ecosystems across all climatic conditions, remains incomplete.

To fill these knowledge gaps and to refine current multiproxy lake facies models (e.g., Bohacs et al., 2000; Scott et al., 2012) additional interdisciplinary case studies are needed from all corners of the Earth and across geological time. Facies models are powerful tools that can simplify and synthesise complex processes, and make some predictions, but without the expectation to perfectly capture the uniqueness of each "little world". Herein, I present a Sinemurian case study to narrate the sedimentological and palaeo-ecological processes in some early Mesozoic lake systems preserved in the upper Karoo Supergroup of southern Africa (Figure 1).

The Lower Jurassic of southern Africa represents the final events in the depositional history of the iconic main Karoo Basin of southern Pangea/Gondwana (Figure 1). This highly fossiliferous succession records evidence for extensive alluvial floodplains with calcic vertisols, ephemeral rivers, streams, and lakes in a semi-arid setting that eventually gave way to a vast sand sea before the return of more humid conditions at the end-Pliensbachian (Figure 1; Bordy et al., 2020; Head & Bordy, 2022). The upper Karoo is key to refining palaeo-ecological reconstructions not only during the biotic recovery after the end-Triassic extinction, but also prior to the extrusion of continental flood basalts that led to the end-Pliensbachian extinction. By providing detailed sedimentological, palaeontological and geochemical descriptions of the fossiliferous lacustrine beds, this study utilizes some of these Lower Jurassic rocks as multiproxy evidence to refine the traditional palaeo-climatic narrative of a gradual drying to a punctuated aridification trend from the Hettangian to the late Pliensbachian of southern Pangaea.

The most striking Lower Jurassic lacustrine beds are those rhythmites that locally yield high organic-matter content, fossil clam shrimps, ostracods and insects (Figure 1) and contain a diverse suite of sedimentary structures in both sandstones and mudstones. Collectively, this collage of petrified but incomplete palaeo-lake signals reveals insights into the controls on the cyclic arrangements of sedimentary facies and the rate of clastic sediment versus organic matter supply to the lake floor. They show that the lakes were episodically anoxic and

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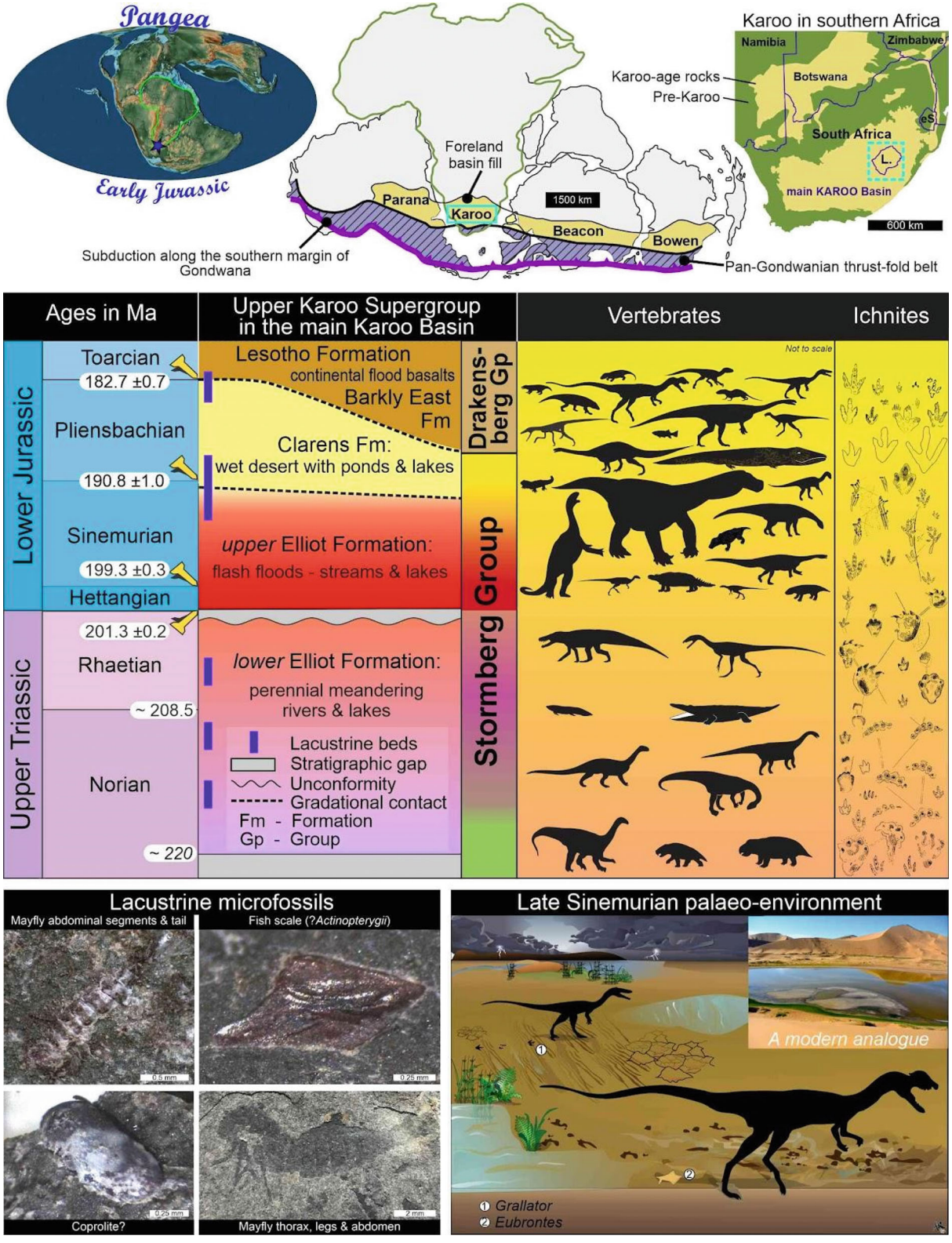


Figure 1. Stratigraphic and geological context of the highly fossiliferous upper Karoo Supergroup in southern Africa. Regional palaeogeographic maps show the distribution of Karoo-age rocks, the position of Africa within south-western Gondwana as well as Pangea in the Early Jurassic (Pangea map source: PALEOMAP Project – Scotese, 2014). Lacustrine deposits are marked in the lithostratigraphic column. Late Sinemurian lake environment in a dryland setting as summarized in the artwork by Akhil Rampersadh and EM Bordy.

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occasionally endured severe storms, triggering combined oscillatory and unidirectional flow. However, several key palaeo-environmental parameters still need to be extracted from this rock record, and these include the mean lake depth and area (including fetch), the lake-bed gradient, wind- versus storm-generated wave regimes (length/velocity, duration, direction, periodicity), lateral and vertical facies trends from littoral to profundal zones, the morphodynamics of associated landforms (beach ridges, aeolian dunes, deltas) as well as the longevity of these Early Jurassic lakes in southern Pangea.

References

Bohacs, K. M., Carroll, A. R., Neal, J. E., & Mankiewicz, P. J. (2000). Lake-basin type, source potential, and hydrocarbon character: an integrated sequence-stratigraphic–geochemical framework. *Lake basins through space and time: American Association of Petroleum Geologists Studies in Geology, 46*, 3-34. https://doi.org/10.1306/St46706C1

Bordy, E. M., Abrahams, M., Sharman, G. R., Viglietti, P. A., Benson, R. B. J., McPhee, B. W., Barrett, P. M., Sciscio, L., Condon, D., Mundil, R., Rademan, Z., Jinnah, Z., Clark, J. M., Suarez, C. A., Chapelle, K. E. J., & Choiniere, J. N. (2020). A chronostratigraphic framework for the upper Stromberg Group: implications for the Triassic–Jurassic boundary in southern Africa. *Earth-Science Reviews, 203*, 103120.
https://doi.org/10.1016/j.earscirev.2020.103120

Forbes, S. A. (1887). The lake as a microcosm. *Bulletin of the Peoria Science Association, 1887*, 77-87.

Head, H., & Bordy, E. M (2022). Lake dynamics in an Early Jurassic desert: Evidence from the Clarens Formation in southern Africa. *Sedimentology*, 1-30. https://doi.org/10.1111/sed.13066

Scott, J. J., Buatois, L. A., & Mangano, M. G. (2012). Lacustrine environments. *Developmental Sedimentology, 64*, 379-417. http://dx.doi.org/10.1016/B978-0-444-53813-0.00013-7

Scotese, C. R. (2014). Atlas of Jurassic Paleogeographic Maps (Mollweide Projection), Maps 32-42. *Volume 3 of the PALEOMAP Atlas for ArcGIS*. PALEOMAP Project. http://dx.doi.org/10.13140/2.1.4850.4321

Poster Session 3 (Saturday, June 10, 2023)

USING PHOTOGRAMMETRY FOR LONG-TERM PRESERVATION AND MANAGEMENT OF IN SITU MESOZOIC PALEONTOLOGICAL RESOURCES: PRESERVING ANCIENT ECOSYSTEMS

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Fossil vertebrate tracksites provide a wealth of valuable scientific information, not only about the characteristics of the trackmakers, but also insights into behavioral and community dynamics. As such, track-bearing surfaces are often stripped of their protective sedimentary coverings to be mapped, studied, and hopefully photogrammetrically documented. Often these surfaces are left exposed to natural weathering and human degradation (e.g., vandalism, carelessness, negligence). Due to remote locations, expansive size, and land status, it is often not feasible to provide these sites with the level of protection warranted by their scientific, educational, and interpretive values. With the discovery of the Red Gulch Dinosaur Tracksite (RGDT) in 1997, a new era in ichnological documentation and tracksite management began (Breithaupt et al., 2001), as photogrammetry became a well-established technique in the documentation of paleontological resources. Although rarely used in paleontology prior to 1997, currently photogrammetry is considered state-of-the art and best practice in the noninvasive, 3D digital data collection of in situ paleontological resources, especially vertebrate trace fossils. It is a technique that is employed worldwide today.

Although the literature is filled with examples of the use of photogrammetry in research, little has been done illustrating its obvious utility for the proper management of fossil sites. Unlike most body fossils (which are collected), vertebrate trace fossils are routinely left in place to preserve their context, frequently resulting in challenging management decisions. However, photogrammetric data is increasingly being used in the assessment, monitoring, and decision making of in situ paleontological resources. Bureau of Land Management (BLM) staff spearheaded the use of photogrammetry at the RGDT and have pioneered many techniques in photogrammetric ichnology in use today (Breithaupt et al., 2004; Matthews et al., 2016). They remain on the forefront utilizing this technology for resource management. This is possible because episodic imagery sets from various platforms (e.g., handheld, ground-based monopods, tethered blimps, unmanned aircraft systems, etc.) have been collected that incorporate proper photogrammetric techniques (such as good quality images taken with high resolution cameras with wide angle lenses, capturing

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proper 66% overlap, and additional images to support a robust camera calibration). These techniques produce high-quality 3D data sets that can be coaligned into the same coordinate space to support direct visual and quantitative analysis of tracks and overall site impacts and degradation. Not only is this level of documentation important for research purposes, but first alert digital documentation (photogrammetry shortly after the sites are exposed) provides baseline data that can be used for condition assessment and future monitoring.

Episodic photogrammetric documentation has been conducted by BLM staff at numerous dinosaur tracksites throughout the western United States over the past 25 years. These imagery and 3D data sets have regularly proven invaluable for understanding natural morphological degradation of the tracks themselves, as well as impacts to the track-bearing surface due to wrongful impact. The importance of well photogrammetrically documented tracks was exemplified recently at the Early Cretaceous Mill Canyon Dinosaur Tracksite (MCDT) (Cedar Mountain Formation) in Utah. Comparative photogrammetric analysis from over 10 years of documentation allowed for high-resolution, millimeter-level comparison and assessment of natural and human caused degradation of the track-bearing surface, where fractures and breaks on and around the delicate impact rims of the tracksite's ichnotaxa (e.g., *Hatcherichnus*, *Irenosauripus*, *Caririchnium*, *Brontopodus*, *Dromaeosauripus*, *Tetrapodosaurus*, *Carmelopodus* were studied. At the Middle Jurassic Red Gulch Dinosaur Tracksite (Sundance Formation) in Wyoming, natural weathering, impacts of visitor foot traffic, and occasional plaster molding of the *Carmelopodus* tracks preserved at that site have been monitored and repeatedly photogrammetrically assessed over the past 25 years. The RGDT and MCDT are two of the most extensively and intensively documented dinosaur tracksites in the world and preserve the unique community dynamics of two ancient ecosystems. Studies at these sites epitomize the advances in photogrammetric ichnology. Other Jurassic sites in Utah, such as the Hell's Revenge Tracksite (Navajo Sandstone) and the Twentymile Wash Dinosaur Tracksite (Entrada Sandstone) have also benefitted from having photogrammetric documentation in light of serious vandalization.

Episodic 3D data collection not only helps with the management of tracksites, but also can shed light on the morphological changes that may come with normal weathering, which might impact scientific interpretations. In addition, people often perceive an ichnological surface as a snapshot in time, as opposed to an accumulation of events that have been preserved over time (i.e., time averaging). Likewise, many may also have the misconception that documentation should take place only once for a tracksite. However, thorough ichnocartographic and photogrammetric documentation should be conducted initially as a baseline and then repeated over time for monitoring, scientific comparisons, and a better understanding of the changes that occur to the track-bearing surface. Photogrammetry has proven to be a powerful documentation and research tool, which allows public land managers to inventory, monitor, manage, and protect in situ paleontological resources using scientific principles and expertise (as per the Paleontological Resources Preservation Act), and make scientific-based management decisions to preserve these invaluable parts of America's Natural Heritage.

References

Breithaupt, B. H., Southwell, E. H, Adams, T. L., & Matthews, N. A. (2001). Innovative documentation methodologies in the study of the most extensive dinosaur tracksite in Wyoming. In V. L. Santucci, & L. McClelland (Eds.), *Proceedings of the 6th Fossil Resources Conference* (pp 113-122). United States Department of Interior National Park Services Geological Resources Division.

Breithaupt, B. H., Matthews, N. A., & Noble, T. A. (2004). An integrated approach to three-dimensional data collection at dinosaur tracksites in the Rocky Mountain West. *Ichnos, 11*, 11-26.

Matthews, N. A., Noble, T. A., & Breithaupt, B. H. (2016). Close-range photogrammetry for 3D ichnology: the basics of photogrammetric ichnology. In P. Falkingham, D. Marty, & A. Richter (Eds.), *Dinosaur tracks: The next steps* (pp. 29-55). Indiana University Press.

Technical Session 3: Terrestrial Ecosystems – Late Cretaceous (Saturday, June 10, 2023, 1:45 PM)

EARLY CAMPANIAN FOOTPRINTS FROM THE EAST COAST OF MID-LARAMIDIA: STEPS FROM THE ORNITHOPOD HARBINGERS OF THE "CAMPANIAN EXPLOSION"

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Ever since F. V. Hayden's discovery of "huge bird" tracks in 1868 (Deibert & Breithaupt, 2006), Wyoming's geologic formations of Campanian age have been known to contain unique vertebrate fossils. Currently, dozens of

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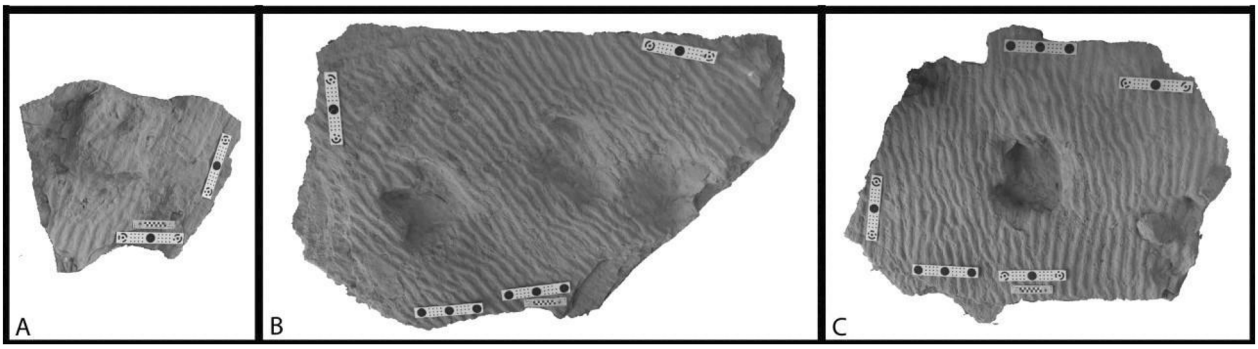


Figure 1. Photogrammetrically derived images of ornithopod tracks (Iguanodontipodidae) in wave-rippled sandstone blocks of the Late Santonian/Early Campanian Adaville Formation from BLM-administered, coal mine, western Wyoming. Coded target scale bars are visible and were used for increased accuracy (distance between center of coded targets is 24.81 cm). A) Track preserved as a natural cast (convex hyporelief) with angiosperm leaf impressions preserved. B) Tracks preserved as natural impressions (concave epirelief). C) Tracks preserved as natural impressions (concave epirelief).

localities preserve diverse faunas of geographic intermediatory ecosystems between northern and southern Campanian communities along the eastern shore of Laramidia (DeMar & Breithaupt, 2008). Over the past two decades, large blocks containing dinosaur tracks and partial trackways have been recovered from a coal mine outside of Kemmerer, Wyoming on BLM-administered land. The tracks were found in the lower Adaville Formation, associated with the Lazeart Sandstone. This unit represents a wave-dominated deltaic complex of a shallow to intermittently emergent coastline along the western shore of the Western Interior Seaway, associated with the eastward progradation of the Adaville Clastic Wedge (Lawrence, 1992; Minor et al., 2021). Although dinosaur footprints have been occasionally noted from other coal-bearing geologic units (e.g., Mesaverde Group) in the western part of the state, these new tracks represent some of the oldest (i.e., Late Santonian/Early Campanian, approximately 83-84 mya) and are the first vertebrate fossils from the Adaville Formation. These tracks are preserved in a heavily rippled sandstone, both as natural impressions (concave epirelief), as well as natural casts (convex hyporelief), and represent a Biped Grade 2 level of track preservation. In addition, angiosperm leaf impressions and marine invertebrate trace fossils are preserved on the track-bearing surfaces, which were stabilized by microbial activity. The tracks are mesaxonic, subsymmetrical, tridactyl pes impressions, with blunt toes, widths equal to (if not wider than) lengths, and with short steps exhibiting slight inward rotation. To document and preserve the features of these paleontological resources, close-range photogrammetry (Matthews et al., 2016) was done, providing permanent 3D record of the surfaces. The footprints are all approximately 35 cm in length and range in width from 35-40 cm with a maximum depth of 10 cm. Track and trackway morphologies suggest that these footprints were made by intermediate-sized, ornithopod dinosaurs, ranging from 3.5-4 m long with a hip height of 140 cm. Step and stride measurements (70 cm and 140 cm respectively) represent a bipedal, walking gait. The tracks are assigned to the ichnotaxon Iguanodontipodidae (Díaz-Martínez et al., 2015; Lockley et al., 2014). Although other Campanian tracks from Wyoming are assigned to the large, robust ichnogenera *Hadrosauropodus* and *Caririchnium*, these intermediate-sized tracks resemble the ichnogenera *Amblydactylus* and *Iguanodontipus*, based on the more gracile, laterally divergent digit impressions. Most likely the footprints were made by hadrosaurids or nonhadrosaurid iguanodontids, as they ambled across the shores of the warm temperate epicontinental seaway. These tracks will compliment fossils from other areas of the Western Interior and may assist in understanding ornithopod diversification at the beginning of the "Campanian Explosion" (see Weishampel et al., 2004). As tracks are often harbingers for the discoveries of other vertebrate fossils, it is anticipated that future work on the Adaville Formation and contemporaneous units will lead to a better understanding of the biogeographic distribution of biotas throughout Laramidia.

References

Deibert, J. E, & Breithaupt, B. H. (2006). Ferdinand V. Hayden's 1868 "huge bird" tracks in the Upper Cretaceous Almond Formation: field evidence for the first dinosaur fossil discovered in Wyoming. In S. G. Lucas & R. M. Sullivan (Eds.). *Late Cretaceous Vertebrates from the Western Interior. New Mexico Museum of Natural History and Science Bulletin, 35*, 69-78.

DeMar, D. G. Jr, & Breithaupt, B. H. (2008). Terrestrial and aquatic vertebrate paleocommunities of the Mesaverde Formation (Upper Cretaceous, Campanian) of the

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Wind River and Bighorn basins, Wyoming, USA. In J. Sankey, & S. Baszio (Eds.), *Vertebrate microfossil assemblages* (pp. 78-103). Indiana University Press.

Díaz-Martínez, I., Pereda-Suberbiola, X., Pérez-Lorente, F., & Canudo, J. I. (2015). Ichnotaxonomic review of large ornithopod dinosaur tracks: Temporal and geographic implications. *PLoS One, 10*(2), e0115477.

Lawrence, D. T. (1992). Primary controls on total reserves, thickness, geometry, and distribution of coal seams: Upper Cretaceous Adaville Formation, southwestern Wyoming. In P. J. McCabe & J. T. Parrish (Eds.), *Controls on the distribution and quality of Cretaceous coals*. *Geological Society of America Special Papers, 267*, 69-100.

Lockley, M. G., Xing, L., Lockwood, J. A. F., & Pond, S. (2014). A review of large Cretaceous ornithopod tracks, with special reference to their ichnotaxonomy. *Biological Journal of the Linnean Society, 113*(3), 721-736.

Matthews, N. A., Noble, T. A., & Breithaupt, B. H. (2016). Close-range photogrammetry for 3D ichnology: the basics of photogrammetric ichnology. In P. Falkingham, D. Marty, A. Richter (Eds.). *Dinosaur tracks: The next steps* (pp. 29-55). Indiana University Press.

Minor, K. P., Steel, R. J., & Olariu, C. (2021). Tectonic and eustatic control of Mesaverde Group (Campanian–Maastrichtian) architecture, Wyoming-Utah-Colorado region, USA. *Geological Society of America Bulletin, 134* (1-2), 419-445.

Weishampel, D. B., Barrett, P. M., Coria, R. A., Le Loueff, J., Xu, X., Zhao, X., Sahni, A., Gomani, E. M. P., & Noto, C. N. (2004). Dinosaur distribution. In D. B. Weishampel, P. Dodson, & H. Osmólska (Eds.), *The Dinosauria* (pp. 517-606). University of California Press.

Theme Session: Laramidia to Asia: Biota and Biogeography of Interconnected Iconic Late Cretaceous Ecosystems (Saturday, June 10, 2023, 5:05 PM)

LATITUDINAL VARIATION OF EARLY CAMPANIAN MAMMALIAN FAUNAS FROM THE LOWER SHALE MEMBER OF THE AGUJA FORMATION IN WEST TEXAS, THE WAHWEAP FORMATION IN UTAH, AND THE MENEFEE FORMATION IN NEW MEXICO

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The lower shale member of the Aguja Formation in the Big Bend region of Texas is one of very few early Campanian terrestrial units in Laramidia. The diverse microvertebrate assemblage from Texas, the Lowerverse Local Fauna, includes chondrichthyan and osteichthyan fishes, amphibians, lizards, dinosaurs, birds, and mammals. Mammals are represented by more than 325 teeth and tooth fragments forming a diverse assemblage, including several spalacotheriid "symmetrodonts", and at least ten species of multituberculates including ?*Janumys*, *Paracimexomys*, *Cedaromys*, *Dakotamys*, *Cimolodon*, and *Meniscoessus*. Seven species of marsupials are also present, including new species of *Eoalphadon* and *Turgidodon*, as well as representatives of *Albertatherium*, *Varalphadon*, and the pediomyid *Aquiladelphis*. Eutherians are represented by *Paranyctoides* and a new species of *Gallolestes*. A single unusual Ferugiotheriidae tooth fragment is also present. This taxon has not previously been reported in North America.

Unique aspects of the Lowerverse mammalian assemblage may reflect its southern paleolatitude, but it also includes endemic taxa. Although North American late Santonian (Aquilan) and middle Campanian (Judithian) mammalian faunas are well known, only two localities have thus far yielded probable early Campanian mammals: the lower Wahweap Formation of Utah, and Menefee Formation of New Mexico. The Lowerverse fauna represents a third assemblage from this intermediate time frame.

Poster Session 1 (Thursday, June 8, 2023)

NEW LATE CRETACEOUS MAMMALS FROM APPALACHIA: ADDITIONS FROM MISSISSIPPI

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Late Cretaceous mammals, particularly from sediments deposited during the Santonian- Campanian, are well-

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known from Laurentia (e.g., Cifelli, 1990; Eaton, 1991, etc.) but very few specimens are known from Appalachia. From Mississippi, only one has been reported: a single therian premolar (Emry et al., 1981). The tooth is from the Tombigbee Sand Member of the Eutaw Formation on the Vinton Bluff meander of the Tombigbee River near Columbus, Mississippi. The concentrate from which that tooth was discovered, as well as concentrate from an earlier expedition, is housed at the Mississippi Museum of Natural Science.

Three additional teeth were picked from that concentrate but have not been published. They are much better preserved and can be identified as therian tooth, and two multituberculate teeth representing Rp4 and LM2. The remaining unpicked concentrate was loaned to the Brink Lab at USM, and although much has been picked, resulting in many fish, sharks, etc. (Kennedy & Brink, 2022), no mammal teeth have yet been found.

In the 1980s, the Vinton Bluff locality was well-exposed and easily accessible, however, with excavation of the Tennessee-Tombigbee Waterway by the Army Corps of Engineers, the Vinton Bluff meander of the river was deemed inaccessible due to slumping and vegetation overgrowth. Recently, Tim Brooks, Wildlife Biologist with the Army Corps of Engineers, helped with access to the Vinton Bluff site. From several localities along that meander, over 273 kg of matrix was collected and is in the process of being wet sieved, in hopes of finding additional mammal teeth. Recently, another mammal tooth specimen has been recovered from a second locality: Luxapallila Creek in Lowndes County. This tooth comes from the Eutaw Formation rather than the Tombigbee Sand.

The main locality producing Appalachian mammal teeth is from New Jersey's Marshalltown Formation at Ellisdale. The age of these materials is very similar to the teeth from the Tombigbee Sand Member and Eutaw Formation. R. Denton and colleagues have recovered many mammal teeth from this site (personal communication, R. Denton) in addition to previously published material (Denton & O'Neill, 2010; Grandstaff et al., 1992; Krause & Baird, 1978). With additional specimens from Mississippi, there will be a more meaningful comparison between these localities, a better understanding of the general diversity of Appalachian mammals, and the potential to unravel questions about the origins of mammals on the North American continent.

References

Cifelli, R. L (1990). Cretaceous mammals of southern Utah II. Marsupials and marsupial-like mammals from the Wahweap Formation. *Journal of Vertebrate Paleontology, 10*(3), 320-331.

Denton Jr., R., & O'Neill, R. (2010). A new stagodontid metatherian from the Campanian of New Jersey, and its implications for a lack of east–west dispersal routes in the Late Cretaceous of North America. *Journal of Vertebrate Paleontology, 30*(3), 81A.

Emry, R. J., Archibald, J. D., & Smith, C. C. (1982). A mammalian molar from the Late Cretaceous of Mississippi. *Journal of Paleontology, 55*(5), 953-956.

Grandstaff, B. S., Parris, D. C., Denton, Jr., R, & Gallagher, W. B. (1992) *Alphadon* (Marsupialia) and Multituberculata (Allotheria) in the Cretaceous of eastern North America. *Journal of Vertebrate Paleontology, 12*(2), 217-222.

Kennedy, S., & Brink, A. A. (2022). Biodiversity changes in batoids from the Cretaceous onward in the Mississippi Embayment. *Abstracts from the Mississippi Academy of Sciences Annual Meeting, 67*(3), 90.

Krause, D. W., & Baird, D. (1978). Cretaceous Mammals east of the North American Western Interior Seaway. *Journal of Paleontology, 53*(3), 562-565.

Theme Session: Laramidia to Asia: Biota and Biogeography of Interconnected Iconic Late Cretaceous Ecosystems (Saturday, June 10, 2023, 3:25 PM)

FISHES FROM THE LATE CRETACEOUS PRINCE CREEK FORMATION, NORTH SLOPE OF ALASKA AND THEIR IMPLICATIONS FOR INTERCHANGE BETWEEN ASIA AND NORTH AMERICA

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Interchange between Laramidia and Asia during the Late Cretaceous was via a high-latitude connection of these regions. Thus, the Prince Creek Formation of northern Alaska, which was deposited at a paleolatitude of 80-85°N (Hay & Al, 1999; Spicer & Herman, 2010), is of particular interest with respect to patterns of interchange between Laramidia and Asia because it provides insight into terrestrial high latitude ecosystems of the late Cretaceous. Based on TIMS dates recently acquired by one of us (PD) we consider the age of the localities to be late Campanian. Taxa described from this formation include non-avian and avian dinosaurs as well as eutherian, metatherian, and multituberculate mammals (Clemens & Nelms, 1993; Druckenmiller et al., 2021, and references therein; Gangloff, 1998;). Notably, terrestrialized ectotherms (e.g., lissamphibians, testudines, choristodires, squamates, and crocodilians) that are commonplace in warmer, contemporaneous lower latitude formations are absent (Clemens & Nelms, 1993). In contrast, a diverse assemblage of fishes is present. Here we present a taxonomic assessment of fish remains in the Prince Creek Formation and consider the significance of the assemblage to questions of interchange between Asia and North America.

The fish assemblage of the Prince Creek Formation includes a minimum of 12 taxa. An elasmobranch is represented only by two dermal denticles. These differ from non-marine elasmobranch denticles from southern localities in North America. As such, they likely represent an endemic taxon whose relationships are currently unknown. Chondrosteans are represented by both sturgeons and paddlefishes. In addition to macro-remains, such as skull elements and fin spines, denticles of both groups are present in microfossil assemblages.

Clemens and Nelms (1993) recognized that the fish assemblage of the Prince Creek Formation was unusual in the absence of lepisosteids. The much larger samples that are now available demonstrate that basal neopterygians as a group are exceptionally rare. Only a single enamel-covered scale, likely from *Belonostomus*, has been recovered. Lepisosteids and amiids, which have long been considered the hallmark of Late Cretaceous vertebrate microfossil assemblages, are notably absent. Similarly, the semionotiforms referred to as Holostean A and Holostean B, which are represented by scales from vertebrate microfossil localities in Alberta and are interpreted as being more northern in their distribution (Brinkman, 1990; Sinha et al., 2021), are absent.

In contrast with the rarity of basal neopterygians, teleosts are abundant in Prince Creek vertebrate microfossil localities. Two genera previously recognized in the Late Cretaceous of Laramidia, the esocid *Oldmanesox* and the clupeomorph *Horseshoeichthys* (Newbrey et al., 2010; Wilson et al., 1992), can be recognized based on dentaries. Dentaries and other tooth-bearing elements indicate that a minimum of six additional teleosts are present in the assemblage. One of these can be ascribed to Esocidae based on its distinctive tooth implantation. One is tentatively included in the Salmonidae based on comparison of the lower jaw, maxillae, and basioccipitals with extant members of the group. Fin spines document the presence of at least one kind of acanthomorph. Two teleosts of unknown relationships are represented by dentaries. One of these is small and gracile and has a tooth implantation like that of salmonids and thus may be a member of that group. The second is large and robust and bears multiple rows of teeth. These features suggest it may be a member of Osteoglossomorpha, although it is unlike any of the osteoglossomorphs previously recognized from the Late Cretaceous of Laramidia. Three distinct morphotypes of branchial teeth indicate the presence of minimally one, and possibly three, additional fish of uncertain relationships. One of these branchial tooth morphotypes is similar to that of pycnodonts. Nevertheless, it also bears similarities to those of some teleosts such as cyprinids and some Late Cretaceous acanthomorphs, so the possibility that they are from one of these cannot be excluded at this time.

The rarity of elasmobranchs and the presence of acipenseriforms in the fish assemblage from the Prince Creek Formation are consistent with proposed latitudinal patterns based on the distribution of fish from more southern localities in North America (Brinkman et al., 2013; Cook et al., 2014). The abundance and diversity of esocids and the probable presence of a salmonid is consistent with dominance of these groups in extant high-latitude fish assemblages and suggests that this latitudinal pattern extended into the Late Cretaceous. The rarity of basal neopterygian fish is surprising since at least three taxa, a lepisosteid, an amiid, and the presumed semionotiform referred to as Holostean B, are present in both Asia and North America during the Late Cretaceous (Nesov, 1997; Sinha et al., 2021). Two of these, an amiid and Holostean B are also present in a high latitude North American assemblage of Turonian age, a time of high global temperatures (Friedman et al., 2003; Sinha et al., 2021). Thus, it appears that the high latitude connection between Asia and Laramidia acted as a filter, allowing some taxa to disperse between these regions only at times when the climatic conditions in high latitude regions were more favorable.

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References

Brinkman, D. B. (1990). Paleoecology of the Judith River formation (Campanian) of dinosaur Provincial Park, Alberta, Canada: Evidence from vertebrate microfossil localities. *Palaeogeography, Palaeoclimatology, Palaeoecology, 78*, 37-54.

Brinkman, D. B., Newbrey, M. G., Neuman, A. G., Eaton, J. G., & Titus, A. L. (2013). Freshwater Osteichthyes from the Cenomanian to late Campanian of Grand Staircase-Escalante National Monument, Utah. In G. P. Wilson, W. A. Clemens, J. R. Horner, & J. H. Hartman (Eds.), *Through the end of the Cretaceous in the type locality of the Hell Creek Formation in Montana and adjacent areas. Geological Society of America Special Paper, 503* (pp. 195-236).

Clemens, W. A., & Nelms, L. G. (1993). Paleoecological implications of Alaskan terrestrial vertebrate fauna in latest Cretaceous time at high paleolatitudes. *Geology, 21*, 503-506.

Cook, T. D., Newbrey, M. G., Brinkman, D. B., & Kirkland, J. I. (2014). Euselachians from the freshwater deposits of the Hell Creek Formation of Montana. In G. P. Wilson, W. A. Clemens, J. R. Horner, & J. H. Hartman (Eds.), *Through the end of the Cretaceous in the type locality of the Hell Creek Formation in Montana and adjacent areas. Geological Society of America Special Paper, 503* (pp. 229-246).

Druckenmiller, P. S., Erickson, G. M., Brinkman, D. B., Brown, C. M., & Eberle, J. J. (2021). Nesting at extreme polar latitudes by non-avian dinosaurs. *Current Biology, 31*, 3469-3478.

Friedman, M., Tarduno, J. A., & Brinkman, D. B. (2003). Fossil fishes from the high Canadian Arctic: further palaeobiological evidence for extreme climatic warmth during the Late Cretaceous (Turonian–Coniacian). *Cretaceous Research, 24*, 615-632.

Hay, W. W., & Al, E. (1999). Alternative global Cretaceous paleogeography. In E. Barrera & C. Johnson (Eds.), *The evolution of the Cretaceous ocean/climate system. Geological Society of America Special Paper, 332* (pp. 1-47).

Gangloff, R. A. (1998). Arctic dinosaurs with emphasis on the Cretaceous record of Alaska and the Eurasian-North American connection. Lower and Middle Cretaceous Terrestrial Ecosystems. *New Mexico Museum of Natural History and Science Bulletin, 14*, 211-220.

Nesov, L. A. (1997). *Nemorskie pozvonochnye melovogo perioda severnoy Evrazii* [Cretaceous nonmarine vertebrates of Northern Eurasia]. Saint Petersburg State University, Institute of Earth Crust. [In Russian]

Newbrey, M. G., Murray, A. M., Brinkman, D. B., Wilson, M. V., & Neuman, A. G. (2010). A new articulated freshwater fish (Clupeomorpha, Ellimmichthyiformes) from the Horseshoe Canyon Formation, Maastrichtian, of Alberta, Canada. *Canadian Journal of Earth Sciences, 47*, 1183-1196.

Sinha, S., Brinkman, D. B., Murray, A. M., & Krause, D. W. (2021). Late Paleocene Fishes of the Ravenscrag Formation, Roche Percée Area, Southeastern Saskatchewan, Canada. *Journal of Vertebrate Paleontology, 41*, e1957907.

Spicer, R. A., & Herman, A. B. (2010). The Late Cretaceous environment of the Arctic: A quantitative reassessment based on plant fossils. *Palaeogeography, Palaeoclimatology, Palaeoecology, 295*, 423-442.

Wilson, M. V., Brinkman, D. B., & Neuman, A. G. (1992). Cretaceous Esocoidei (Teleostei): early radiation of the pikes in North American fresh waters. *Journal of Paleontology, 66*, 839-846.

Poster Session 3 associated with the Theme Session: Laramidia to Asia: Biota and Biogeography of Interconnected Iconic Late Cretaceous Ecosystems (Saturday, June 10, 2023)

NON-MARINE FISH FROM THE TURONIAN BISSEKTY FORMATION OF UZBEKISTAN PROVIDE EVIDENCE FOR INTERCHANGE IN THE FISH ASSEMBLAGES OF ASIA AND NORTH AMERICA

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The Turonian Bissekty Formation of Uzbekistan preserves an assemblage of vertebrates that is taphonomically and paleoenvironmentally similar to assemblages preserved in the Late Cretaceous of North America (Sues & Averianov, 2009, 2016 and references therein). Thus, it is of particular interest with respect to patterns of interchange between Laramidia and Asia. Here we present taxonomic assessment of acanthopterygian fish remains from the Bissekty Formation and consider their

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significance to questions of interchange between Asia and North America.

Fish from the Bissekty Formation are largely preserved as isolated elements. Many of these were illustrated by Nesov (1997). Subsequently the ichtyodecitform *Aidachar paludalis* was described by Mkhitaryan and Averianov (2011). Also, Sinha et al (2022) demonstrated that an unnamed basal neopterygian from the Late Cretaceous and Paleocene of North America that has been referred to as Holostean B, is also present in the Bissekty Formation. Recent expeditions to the Bissekty Formation undertaken by the joint Slovak-Uzbek Exploration Program led by Martin Kundrat have led to the collections of additional specimens of fish from the formation. This material, along with specimens housed in the Royal Ontario Museum that were collected by the Uzbek / Russian / British / American / Canadian Joint Paleontological Expedition led by Alexander Averianov, David Archibald, and Hans-Dieter Sues, allow the assemblage to be described in more detail. Based on initial reports of Nesov (1997) and the material collected by subsequent expeditions, the assemblage includes a minimum of thirteen taxa: a sturgeon, a lepisosteid, an amiid, the aspidorhynchiform *Belonostomus*, a basal neopterygian represented by scales referred to as Holostean B, an elopomorph, an osteoglossomorph, the ichthyodectiform *Aidachar paludalis*, a clupeomorph, a gonorynchiform, an acanthomorph, and two teleosts of uncertain relationships represented by distinctive centra. All but the ichthyodectiform *Aidachar paludalis* have close relatives in the Late Cretaceous assemblages of Laramidia. The shared presence of these taxa indicates extensive interchange in fish assemblages between Laramidia and Asia during the Late Cretaceous. However, the timing and direction of interchange between these regions remains unknown and invites further research.

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References

Nesov, L. A. (1997). *Nemorskie pozvonochnye melovogo perioda severnoy Evrazii* [Cretaceous nonmarine vertebrates of Northern Eurasia]. Saint Petersburg State University, Institute of Earth Crust. [In Russian]

Mkhitaryan, T. G., & Averianov, A. O. (2011). New material and phylogenetic position of *Aidachar paludalis* Nesov, 1981 (Actinopterygii, Ichthyodectiformes) from the Late Cretaceous of Uzbekistan. *Proceedings of the Zoological Institute RAS, 315*, 181-192.

Sinha, S., Brinkman, D. B., Murray, A. M., & Krause, D. W. (2021). Late Paleocene fishes of the Ravenscrag Formation, Roche Percée Area, Southeastern Saskatchewan, Canada. *Journal of Vertebrate Paleontology, 41*, e1957907.

Sues, H. D., & Averianov, A. (2009). A new basal hadrosauroid dinosaur from the Late Cretaceous of Uzbekistan and the early radiation of duck-billed dinosaurs. *Proceedings of the Royal Society B: Biological Sciences, 276*, 2549-2555.

Sues, H. D., & Averianov, A. (2016). Ornithomimidae (Dinosauria: Theropoda) from the Bissekty Formation (Upper Cretaceous: Turonian) of Uzbekistan. *Cretaceous Research, 57*, 90-110.

Technical Session 1: Paleoclimatology and Paleogeography (Thursday, June 8, 2023, 8:45 AM)

PROXY-BASED RECONSTRUCTIONS OF CRETACEOUS CLIMATE EXTREMES

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The Cretaceous Period (145-66 Ma) was a prolonged greenhouse period characterized by relatively cool early (Berriasian to Aptian, ~145-113 Ma) and late (Campanian to Maastrichtian, ~84-66 Ma) phases that were separated by a hothouse phase known as the "Cretaceous super greenhouse" (Albian to Santonian, ~113-84 Ma). Extensive research has focused on the spatial and temporal evolution of Cretaceous paleoclimate conditions, due to its influence on the evolution and biogeography of major faunal and floral clades (e.g., dinosaurs: Burgener et al., 2021; birds: Bono et al., 2016; mammals: Woodburne & Case, 1996; and flowering plants: Zhang et al., 2018), and its utility as a natural laboratory for understanding the earth climate system under high atmospheric CO_2 conditions (Burgener et al., 2023). However, questions remain regarding the nature and extent of Cretaceous glacial conditions; and the timing and spatial extent of excess (photosynthesis-limiting) mean annual and monthly temperatures during the Cretaceous.

To address these questions, we build on the work of Burgener et al. (2023) and employ newly-developed, proxy-based global maps of mean annual temperature (MAT), warmest mean monthly temperature (WMMT), and mean annual precipitation (MAP) from nine Cretaceous time slices in order to 1) constrain the occurrence and duration of glacial conditions across the Cretaceous; 2)

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estimate maximum and minimum ice volumes and areas for each Cretaceous analysis window; and 3) describe the occurrence of excess mean annual and monthly temperatures over the course of the Cretaceous. For the purposes of this study, we define "excess temperatures" as the temperature beyond which photosynthesis in terrestrial plants is impeded (temperatures >35 °C; Hüve et al., 2011).

With regard to Cretaceous glacial conditions, we use the global maps of mean MAT and WMMT and their associated uncertainties to reconstruct daily temperature curves on a 1°x1° global grid, from which we derive global maps of positive degree day sums for each of the nine analysis windows. These positive degree day maps are then paired with the global MAP maps to produce estimates of total, net, and year-on-year snow accumulation maps for three different precipitation seasonality scenarios (winter wet, summer wet, and evenly distributed).

Our analyses of proxy-based winter temperatures and three precipitation seasonality scenarios suggest that even during the coldest periods of the Cretaceous (e.g., the Hauterivian, Barremian, and Aptian) snowpack build-up was less than 1 meter water equivalent—even at high latitudes—and that even during these cold phases, no snow survived the summer melt season at elevations <2000 meters above sea level (masl). However, our results suggest that alpine glaciers could have accumulated at high latitudes on isolated peaks at minimum elevations ranging from 2000 masl during the Hauterivian-Barremian to 3500 masl during the Turonian.

Regarding excess temperatures, our interpolated temperature maps suggest that unlike the modern climate, where even equatorial warmest mean monthly temperatures are largely restricted to <35 °C, there was a relatively high probability (>40%) of mean annual temperatures > 35 °C near the equator during the mid-Cretaceous supergreenhouse (Albian to Turonian). Additionally, we find that tropical WMMT values >35 °C were relatively common throughout the Cretaceous, except during the coldest phases (Hauterivian-Barremian, Aptian and Maastrichtian). We note that these excess temperature probabilities are conservative, because Burgener et al. (2023) imposed a 40 °C and 50 °C limit on the semi-quantitative MAT and WMMT samples used to construct their interpolated temperature maps; thus, the actual probability of excess temperatures during the Cretaceous may be even higher. Importantly, the co-occurrence of plant macrofossils with high excess temperature probabilities in the tropics during the Cenomanian, Turonian and Coniacian-Santonian suggest that tropical Cretaceous plant taxa likely employed novel strategies for coping with extremely high temperatures (e.g., Adole et al., 2019; summer dormancy as discussed in Laude, 1953).

Our findings regarding Cretaceous glacial conditions are consistent with previous proxy-based studies and suggest that even during the coolest phases of the Cretaceous, high-latitude temperatures were warm enough to prevent the build-up of permanent ice masses except at elevations >2000 masl. These findings disagree with recent Cretaceous climate model simulations, which predict significantly colder high-latitude conditions (Valdes et al., 2021). Future work should focus on these proxy-model discrepancies. Additionally, our results suggest that excess temperatures were commonplace during the summer months in the tropics during the middle Cretaceous supergreenhouse, and that MAT >35 °C may even have occurred in restricted areas. The strategies that Cretaceous plants employed to survive these high temperature conditions is a ripe field for future research.

References

Adole, T., Dash, J., Rodriguez-Galiano, V., & Atkinson, P. M. (2019). Photoperiod controls vegetation phenology across Africa. *Communications Biology, 2*(1), 391. doi: 10.1038/s42003-019-0636-7

Bono, R. K., Clarke, J., Tarduno, J. A., & Brinkman, D. (2016). A large ornithurine bird (*Tingmiatornis arctica*) from the Turonian High Arctic: climatic and evolutionary implications. *Scientific Reports, 6*, 38876. doi: 10.1038/srep38876

Burgener, L., Hyland, E., Reich, B., & Scotese, C. (2023). Cretaceous climates: mapping paleo-Köppen climatic zones using a bayesian statistical analysis of lithologic, paleontologic, and geochemical proxies. *Palaeogeography, Palaeoclimatology, Palaeoecology, 316*, 111373. https://www.sciencedirect.com/science/article/abs/pii/S0031018222005442

Burgener, L., Hyland, E., Griffith, E., Mitášová, H., Zanno, L. E., & Gates, T. A. (2021). An extreme climate gradient-induced ecological regionalization in the Upper Cretaceous Western Interior Basin of North America. *Bulletin of the Geological Society of America, 133*(9-10), 2125-2136. doi: 10.1130/B35904.1

Hüve, K., Bichele, I., Rasulov, B., & Niinemets, Ü. (2011). When it is too hot for photosynthesis: heat-induced instability of photosynthesis in relation to respiratory burst, cell permeability changes and H2O2 formation. *Plant, Cell and Environment, 34*(1), 113-126. doi: 10.1111/j.1365-3040.2010.02229.x

Laude, H. (1953). The nature of summer dormancy in perennial grasses. *Botanical Gazette, 114*(3), 284-292.

Valdes, P. J., Scotese, C. R., & Lunt, D. J. (2021). Deep ocean temperatures through time. *Climate of the Past, 17*(4), 1483-1506. doi: 10.5194/cp-17-1483-2021

Woodburne, M., & Case, J. (1996). Dispersal, vicariance, and the Late Cretaceous to early Tertiary land mammal biogeography from South America to Australia. *Journal of Mammalian Evolution, 3*(2), 121-161.

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Zhang, M., Dai, S., Baoxia, D. U., Liming, J. I., & Shusheng, H. U. (2018). Mid-Cretaceous hothouse climate and the expansion of early angiosperms. *Acta Geologica Sinica* (English Edition), *92*(5), 2004-2025. doi: 10.1111/1755-6724.13692

Technical Session 1: Paleoclimatology and Paleogeography (Thursday, June 8, 2023, 9:30 AM)

RECONSTRUCTING THE FLOODPLAIN PALEOGEOGRAPHY ASSOCIATED WITH THE QUARRY RIVER, DINOSAUR NATIONAL MONUMENT, UTAH, USA.

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A summary is presented of ongoing studies of the renowned Carnegie Quarry at Dinosaur National Monument in northeastern Utah, USA (Carpenter 2013), with emphasis on the adjacent overbank facies. The Quarry lies in the middle of the Brushy Basin Member of the Morrison Formation.

Channel Facies (CF)
The channel facies is the bone-bearing unit in the Quarry Exhibit Hall (QEH). This facies overlies thin heterolithic sandstone wedges that become progressively coarser-grained up-section with matrix supported angular to subrounded grayish black and gray chert pebbles and pale green mudstone clasts. The sandstone wedges are interpreted as crevasse splay deposits that preceded the avulsion creating the Quarry River. The CF consists of three or four stacked sandstone bodies composed of volcanically derived silica cementing medium to coarse-grained sandstones and pebble conglomerates of angular to subrounded dark cherts and mudstone clasts (Figure 1a). The large grain size, coupled with large (>1 m) megabedforms, trough cross-stratification, high angled inclined planar strata, large clasts (=transported dinosaur bones) greater than boulder-size (>25.6 cm), and scarcity of lateral accretionary taken together are interpreted as muti-threaded (i.e., braided river) deposits. Clay drapes between sandstone bodies represent deposition during wanning flow. Paleocurrents are towards the southeast.

Proximal Overbank Facies (POF)
The overbank sediments adjacent to the channel sandstone facies are muddy sandstones that grade distally to silty mudstones of the distal overbank facies. The transition between the relatively clean CF and the POF is gradational, lacking a sharp channel boundary. Rapidly coarsening upward units (Figure1b) are interpreted as prograding crevasse splay deposits. These are commonly white to pale gray and cemented with calcite. Other muddy sandstone beds are interpreted as levee deposits, although some may also be internally structureless crevasse splays. Dinosaur bones occur but decrease in quantity distally.

Distal Overbank Facies (DOF)
The transition between POF and DOF is gradual and is marked by a decrease in the relative percentage and grain-size of the sand fraction. The sandy and silty mudstones are gray, grayish purple, or light brown, and may show redoximorphic pedogenic mottling of light bluish gray or light greenish gray, or streaks of dusky yellow to very light gray along root channels (Figure 1c). Micritic nodules commonly occur in this facies, and have either diffuse or sharp boundaries of in situ growth or transport respectively. Some nodules in thin section show microcrustaceans (diplostracan branchiopods and ostracods) and charophytes, indicating formation in palustrine sediments. Some nodules also show internal pedogenic brecciation and mottling (Figure 1d). Two thin (~10 cm thick) orange-weathering gray limestone beds containing whole and fragmented microcrustaceans and charophytes are interpreted as small waterbodies that developed distal to crevasse splays to which they can be traced. Even further distally, the silty mudstones of the DOF weather light- to medium gray and have a frothy or popcorn texture of weathered montmorillonite from volcanic ash; unweathered, the mudstone is grayish black. Schudack et al. (1998; Schudack, unpublished) report ostracods (three taxa) and charophytes (seven taxa) along a measured section through the DOF. However, taxon diversity and specimen richness from each stratigraphic sample were low, consisting of one or two taxa of one or two identifiable specimens (Schudack, unpublished data). Finally, Litwin et al. (1998) reported a low diversity palynomorph assemblage from the gray mudstones, including a bryophyte (1 taxon), lycopsids (3 taxa), pteriodophytes (3 taxa), araucariaceans (2 taxa), and podocarpaceans (3 taxa). Compression fossils of the ginkgophyte *Czekanowskia* is also known.

Reconstructing the Floodplain Paleoenvironment
The above information is used to reconstruct a hypothetical paleoenvironmental cross-section from channel to floodplain (Figure 1e); the principle of nearest living relative is used to reconstruct the vegetation.

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Figure 1 (a) channel facies, CF. (b) coarsening upwards prograding crevasse splay over a Protosol, proximal overbank facies, POF. (c) pedogenic distal overbank facies, DOF. (d) brecciated carbonate nodule. (e) reconstructed cross-section from channel to distal floodplain with inferred vegetation distribution; no scale implied.

The CF is interpreted as a braided river. It is not well differentiated laterally from the POF reflecting the rapid flow deceleration of overbank flow and deposition of coarse-grained sediment. The absence of interbedded paleosols in the POF suggests that flood disturbance and sediment deposition were frequent enough to maintain a nearly continuously disturbed habitat colonized by pteriodophytes (ferns), which are known pioneer species today. Any slower growth tree seedlings attempting to establish themselves would undoubtedly be smothered by sediment, as might older established trees as the crevasse splays prograded; this is implied by the dead trees in Figure 1e. The coarseness and white color of the sediments suggests well drained, oxidizing soil, with limited organic carbon build up. More distally (DOF), sediments become finer grained and immature paleosols and rhizoliths indicating sedimentation hiatus and pedogenic modification of a B soil horizon. Vegetation consisted of a mixed riverine forest of two species of araucariacean, three species of podocarpacean and the ginkgophyte *Czekanowskia*, with an understory of shade tolerant ferns. Such trees today inhabit moist, well drained soils in humid climates. Cycads were also present based on fossil wood from the CF.

In the flood basin were small waterbodies, which received most of their water sporadically from overland flow (crevasse splay drainage, floods, rain). Longer lasting waterbodies probably also received groundwater seepage flowing though the coarser sediments of crevasse splays. Fragmentary or single microcrustacean valves, some at angle relative to the bedding plane of oriented rock samples, suggests some allochthonous assemblages.

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Furthermore, the low species diversity suggests similarity to that seen in modern stressed ecosystems. Brecciation of some lacustrine carbonates indicate pedogenetic episodes of the flood basin.

Acknowledgments

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References

Carpenter, K. (2013). History, sedimentology, and taphonomy of the Carnegie Quarry, Dinosaur National Monument. *Annals of the Carnegie Museum, 81*, 153-232.

Litwin, R. J., Turner, C. E., & Peterson, F. (1998). Palynological evidence on the age of the Morrison Formation, Western Interior US. *Modern Geology, 22*, 297-319.

Schudack, M.E., Turner, C.E., & Peterson, F. (1998). Biostratigraphy, paleoecology and biogeography of charophytes and ostracodes from the Upper Jurassic Morrison Formation, Western Interior, USA. *Modern Geology, 22*, 379-414.

Poster Session 2 (Friday, June 9, 2023)

CHIROTHERES: CINDERELLA AND THE ADVENT OF ARCHOSAURIAN LOCOMOTOR INNOVATIONS–A PICTORIAL GUIDE

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Chirotheres, the pentadactyl footprints of some early Mesozoic archosauromorphs, are key to understanding the early evolution of archosaur posture, locomotion and gait. However, convergent locomotor developments in crocodilian and dinosaurian lineages present challenges when correlating chirotheres with known archosaur skeletons. We present a visual guide to potential trackmakers of different chirothere ichnotaxa in an attempt to reconcile the body and trace fossil records of Triassic archosauromorphs. The primary footprint characters and parameters used are: digit proportions and pad configurations of pes and manus imprints, pace, stride, pace angulation, trackway width, rotation of imprints, and gleno-acetabular distance based on preserved longer step cycles. More interpretive characters derived from body fossils include the length of the tail and neck or features of the skull. Footprints frequently do not reflect an exact mold of foot anatomy, but are modified by substrate-related factors and foot dynamics. Extramorphological influences were minimized by including only footprints of high anatomical fidelity (the ichnological "slipper" for archosaurian "Cinderellas").

Over the course of the Triassic, trackways document different trends of archosaur locomotor evolution. In some cases they can be correlated with skeletons, however, complete osteological records of archosaurian autopods are rare and some chirothere morphotypes still have no convincing skeletal counterpart. We have correlated typical chirotheres with known foot skeletons and proposed their phylogenetic position based on digit proportions and synapomorphies of footprints and skeletons. For some ichnotaxa alternative positions are indicated and it is probable that different archosaur clades with similar foot anatomy were able to leave morphologically identical tracks.

Synaptichnium and *Protochirotherium* are conservative chirothere morphotypes, with the pes showing relatively long digits IV and V and a strong outward rotation. These ichnotaxa coarsely match the foot skeletons of basal pseudosuchians such as *Ticinosuchus* and *Batrachotomus* from the Middle Triassic of Switzerland and Germany. One of the best studied chirotheres, *Chirotherium barthii*, known from abundant trackways from all over Pangea, has a more "modern" appearance characterized by a functionally tridactyl pes with dominating digits II–IV and digit III longest, while digit I is short and slightly posteriorly shifted. Trackways are narrow with large pace angulation and minor outward rotation of the pes prints. *C. barthii* probably correlates with multiple taxa, including: 1) *Euparkeria*, a basal archosauriform from the Middle Triassic of South Africa; and 2) hypothetical basal avemetatarsalians, based on the functionally tridactyl pes and the "dinosaurian" manus with reduced digits IV and V. Avemetatarsalians are well-documented from both ichnological and osteological evidence with *Atreipus*, *Grallator* and *Evazoum* attributed to dinosauriform silesaurids, theropods and sauropodomorphs, respectively. However, grallatorid footprints might also have been left by pseudosuchians such as *Poposaurus* from North America, and *Evazoum* tracks may have been made by poposauroids like *Shuvosaurus* from the Norian of Texas. Several different attributions are also considered for the characteristic Late Triassic *Brachychirotherium*. While a correlation with the typical aetosaurian pes is reasonable

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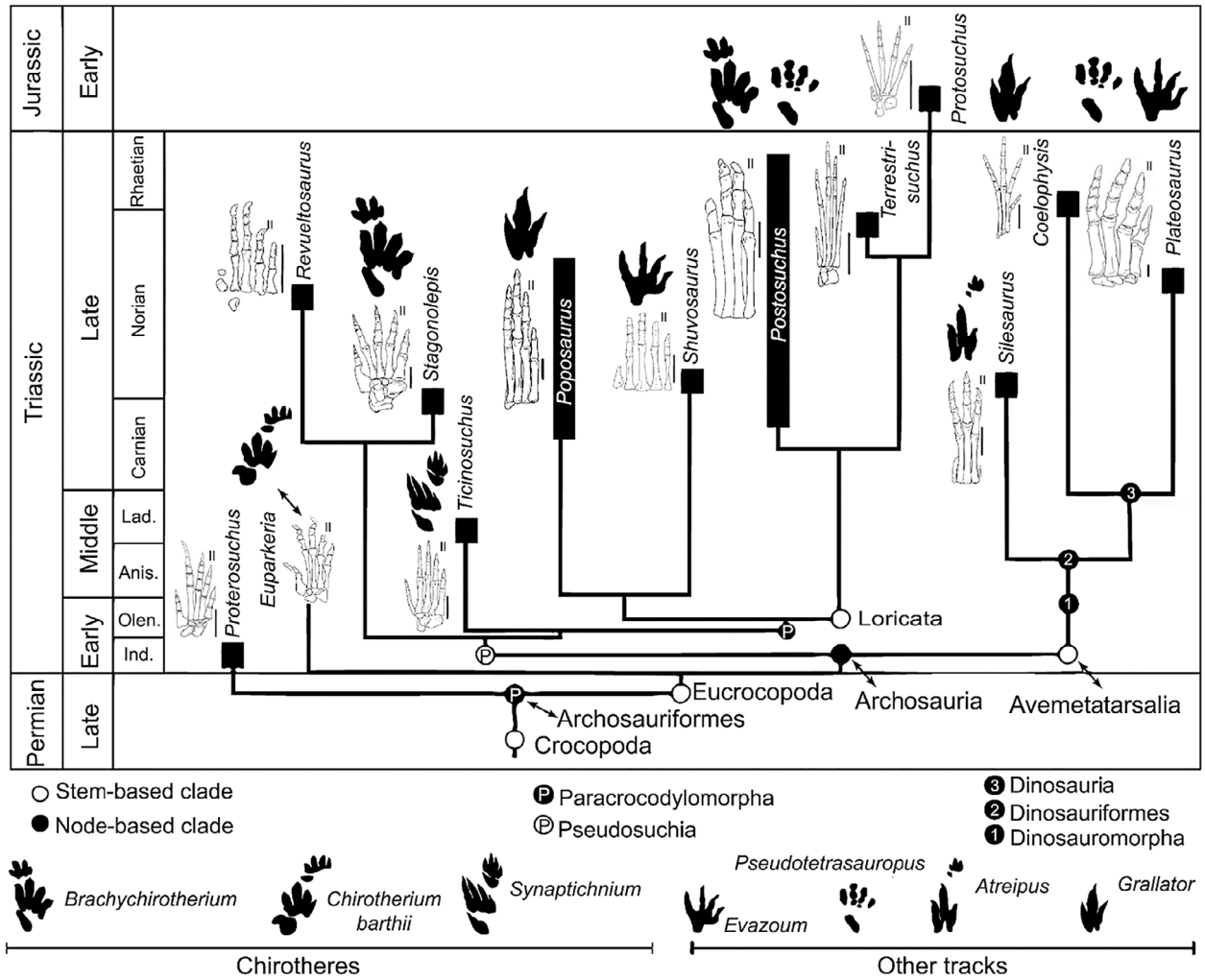


Figure 1. Simplified cladogram of Triassic archosauromorphs from which the foot skeleton is reasonably well known compared to tracks of chirotheres and related ichnotaxa. II = digit II. Footprint skeletons modified from Farlow et al. (2014, Figure 2) except for *Euparkeria*, which is based on Bernardi et al. (2015, Figure 5). Note alternative position of some footprint taxa, indicating multiple possible producers.

and has been widely accepted, some loricatans, such as *Postosuchus*, well-known from nearly complete skeletons from North America, cannot be excluded. Because a distinct footprint morphotype can represent convergent developments of the autopodia, it is possible that *Brachychirotherium* was left by both aetosaurs and loricatans.

Data from trackways and footprints are precise indicators of the trackmaker's gait, behavior and general habitus, however, they are less reliable with respect to their biotaxonomic attribution. Therefore, our reconstructions and lifestyle models should be considered generalized, essentially based on footprints, but supported by skeletal data. Nevertheless, footprints reflect distinct evolutionary developments of the archosaur locomotory apparatus. Because these occur in specific intervals of geological time, they leave characteristic footprint morphotypes and assemblages with a restricted temporal distribution. Footprints are abundant and often have a wide geographical distribution, making them important as biostratigraphic markers. Chirothere-based footprint biochrons are 1) *Protochirotherium* (Early Triassic, Olenekian), 2) *Chirotherium barthii* (Middle Triassic, Anisian) and 3) *Brachychirotherium* (Late Triassic, Carnian–Rhaetian). Index ichnotaxa cooccur in assemblages with *Synaptichnium* (1–2), *Isochirotherium* and *Rotodactylus* (2), *Atreipus–Grallator* and *Apatopus* (3). Finally, the paleobiogeographic distribution of chirotheres is important for outlining the origin and dispersal of different archosaur groups in the Triassic.

References

Bernardi, M., Klein, H., Petti, F. M., & Ezcurra, M. D. (2015). The origin and early radiation of archosauriforms: integrating the skeletal and footprint record. *PLoS One, 10*(6), e0128449.

Farlow, J. O., Schachner, E. R., Sarrazin, J. C., Klein, H. K., & Currie, P. J. (2014). Pedal proportions of

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Poposaurus gracilis: convergence and divergence in the feet of archosaurs. *The Anatomical Record, 297*, 1022-1046.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 11:30 AM)

INDICATORS OF AN ACTIVE HYDROLOGY IN THE EOLIAN ECOSYSTEM OF THE JURASSIC NAVAJO SANDSTONE, SOUTHERN UTAH

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The thick, prominent Jurassic Navajo Sandstone of stacked, eolian-crossbed sets is typically assumed to represent a vast, dry desert in the trade-wind belt that covered much of the Western Interior during the Early Jurassic. However, across much of southern Utah, four distinctive features of the Jurassic Navajo Sandstone eolianite indicate an active hydrologic system that would have sustained life. First, prevalence of soft-sediment deformation (SSD) structures in overlapping hierarchies across local to regional scales indicate near-surface, fluctuating water tables and overpressurized water. Second, carbonate lithofacies reflect standing water and springs fed by groundwater. Third, a wide spectrum of trace fossils preserves habitat evidence for diverse ecosystems of plants and animals. Fourth, pedogenic modification and common rooted zones along many surfaces, sometimes with petrified wood, indicate periods of rainfall and infiltration. All of these features collectively show the dynamic nature of water in the eolian environment, and how life could thus be supported in multiple depositional settings of the erg.

The SSD in particular gives clues to episodic events that influenced near-surface waters, from autogenic (e.g., dune slumping) or allogenic (e.g., earthquake) triggers. In order of increasing hierarchies of deformation intensity, the smallest centimeter- to meter-scale features of SSD include wavy undulations and dish structures (SSD 1–2), related to dewatering in wind-blown porous sand. Disruptions across meter- and decameter-scales include synsedimentary faults, cylindrical pipes and tabular dikes, as well as contorted bedding (SSD 3). Clastic diapirs are commonly associated with extensive massive deposits (SSD 4) that can extend up to a kilometer scale and indicate liquefaction and fluidization, with possible sand volcanoes (Figure 1). More careful inspection of the sedimentary record shows that in addition to the common cross-bedded dune deposits, the erg preserves dynamic environments that were sensitive to rainfall, runoff from the ancestral Uncompahgre Uplift, springs, and episodic strong ground motion, which may have contributed to bringing water to the surface and altering the hydrology. At certain times, when sand supply and dune activity were limited, diverse biotas flourished wherever surface water was available.

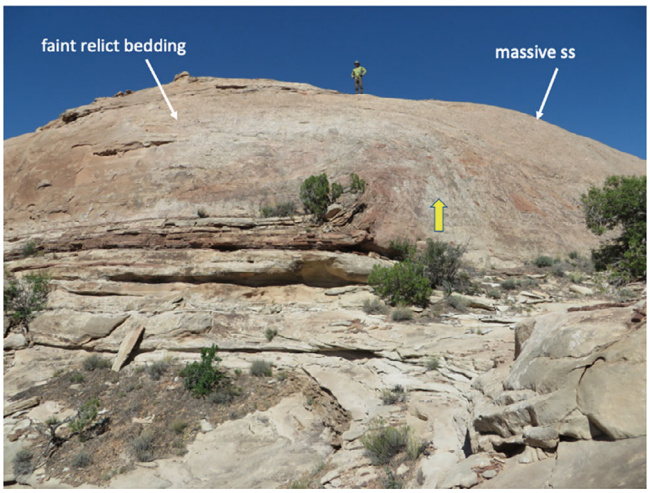


Figure 1. The active hydrology of the Navajo Sandstone is reflected in examples of the highest level of soft-sediment deformation features (SSD 4). A clastic diapir feature (directional yellow arrow) is flanked by deformed and upturned playa and lake beds (near the center bushes), as well as massive sandstone (ss) shown at the right. These features are attributed to overpressurized waters, possibly triggered by strong ground motion. Location: Trough Canyon East, west of Moab, Utah.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 11:15 AM)

THE SMALLEST ADULT JURASSIC SAUROPODOMORPH

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The earliest sauropodomorphs were small omnivores (<10kg) that first appeared in the Carnian (Benson et al., 2018). By the Hettangian, early branching sauropodomorphs (EBSMs) were globally distributed, had variable postures, and large body masses (>10 tonnes) (Chapelle et al., 2019; McPhee et al., 2018; Pol et al., 2021). This exceptionally rapid evolutionary increase in body mass has been extensively studied (e.g., Benson et al., 2014), and is potentially explained by a cascade model (Sander 2013), where many different evolutionary factors reinforced lineage-specific size increases. Small-bodied EBSMs like *Massospondylus* (<500kg) persist at least until the Pliensbachian at nearly all dinosaur-bearing localities worldwide but are comparatively low in alpha diversity (Barrett et al., 2019; Martínez, 2009; Pol et al., 2021). One potential reason for this is competition with other similarly sized amniote groups, including Late Triassic gomphodont cynodonts (e.g., *Scalenodontoides*), and early branching ornithischian dinosaurs (e.g., *Heterodontosaurus*) in the earliest Jurassic (Butler et al., 2010; Filippini et al., 2022; Radermacher et al., 2021). Today's herbivorous mammals show a wide range of body size classes (<10g to 7000kg), with smaller herbivorous mammal (<100kg) frequently cooccurring (Price & Hopkins, 2015). Comparatively, our understanding of the phylogenetic distribution of body mass in Early Jurassic strata, and its explanatory power for the lower thresholds of body mass in EBSMs, needs more data. We osteohistologically sectioned a small humerus, BP/1/4732, from the upper Elliot Formation of South Africa. Its comparative morphology and its osteohistology show that it represents a skeletally mature individual of a new sauropodomorph taxon with an adult body mass of 75.35kg. This makes it among the smallest-known sauropodomorph taxa to live on Earth, and the smallest ever reported from a Jurassic stratum.

References

Barrett, P. M., Chapelle, K. E. J., Staunton, C. K., Botha, J., & Choiniere, J. N. (2019). Postcranial osteology of the neotype specimen of *Massospondylus carinatus* Owen, 1854 (Dinosauria: Sauropodomorpha) from the upper Elliot Formation of South Africa. *Palaeontologia Africana, 53*, 114-178.

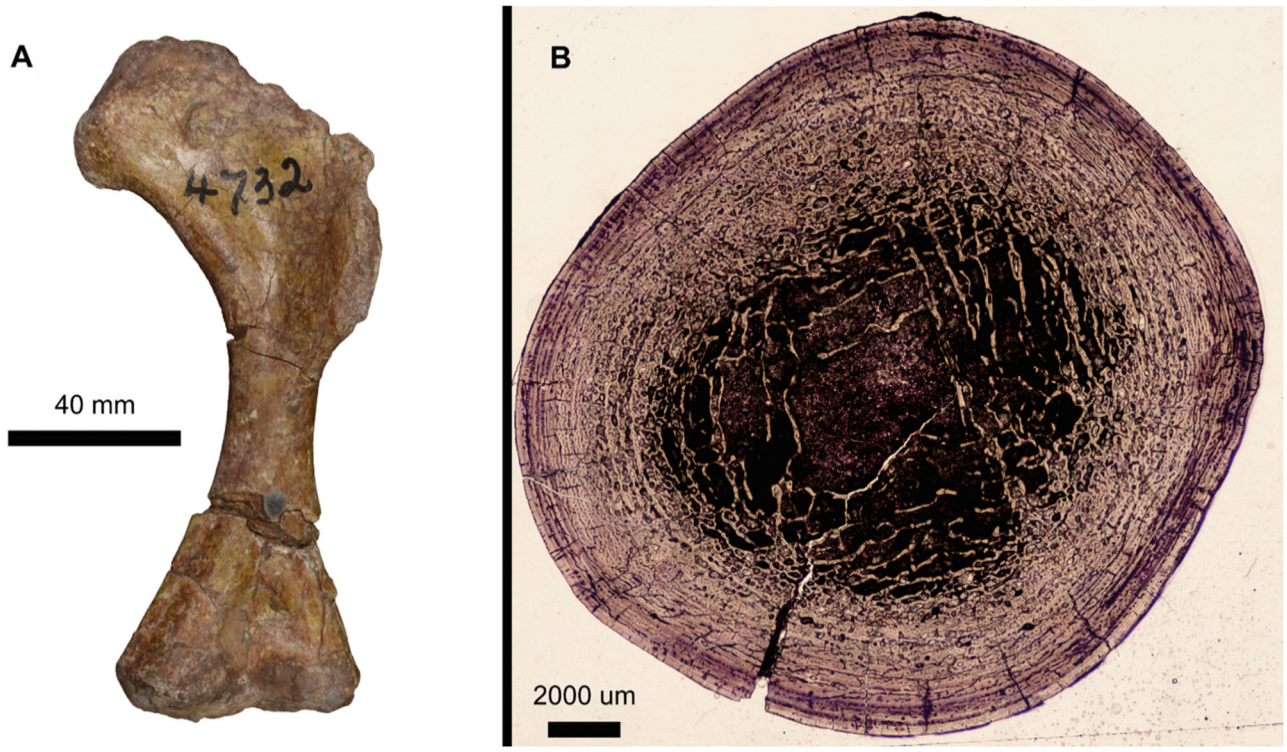


Figure 1. A, Left humerus of BP/1/4732 in anterior view. B, overall transverse osteohistological section of BP/1/4732 left humerus.

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Benson, R. B., Campione, N. E., Carrano, M. T., Mannion, P. D., Sullivan, C., Upchurch, P., & Evans, D. C. (2014). Rates of dinosaur body mass evolution indicate 170 million years of sustained ecological innovation on the avian stem lineage. *PLoS Biology, 12*, e1001853.

Benson, R. B., Hunt, G., Carrano, M. T., & Campione, N. (2018). Cope's rule and the adaptive landscape of dinosaur body size evolution. *Palaeontology, 61*, 13-48.

Butler, R. J., Galton, P. M., Porro, L. B., Chiappe, L. M., Henderson, D. M., & Erickson, G. M. (2010). Lower limits of ornithischian dinosaur body size inferred from a new Upper Jurassic heterodontosaurid from North America. *Proceedings of the Royal Society of London B: Biological Sciences, 277*, 375-381.

Chapelle, K. E., Barrett, P. M., Botha, J., & Choiniere, J. N. (2019). *Ngwevu intloko*: a new early sauropodomorph dinosaur from the Lower Jurassic Elliot Formation of South Africa and comments on cranial ontogeny in *Massospondylus carinatus*. *PeerJ, 7*, e7240.

Filippini, F. S., Abdala, N. F., & Cassini, G. H. (2022). Body mass estimation in Triassic cynodonts from Argentina based on limb variables. *Acta Palaeontologica Polonica, 67*(2), 543-557.

Martínez, R. N. (2009). *Adeopapposaurus mognai*, gen. et sp. nov. (Dinosauria: Sauropodomorpha), with comments on adaptations of basal Sauropodomorpha. *Journal of Vertebrate Paleontology, 29*, 142-164.

McPhee, B. W., Benson, R. B., Botha-Brink, J., Bordy, E. M., & Choiniere, J. N. (2018). A giant dinosaur from the earliest Jurassic of South Africa and the transition to quadrupedality in early sauropodomorphs. *Current Biology*, *28*(19), 3143-3151.

Pol, D., Otero, A., Apaldetti, C., & Martínez, R. N. (2021). Triassic sauropodomorph dinosaurs from South America: The origin and diversification of dinosaur dominated herbivorous faunas. *Journal of South American Earth Sciences, 107*, 103145.

Price, S. A., & Hopkins, S. S. (2015). The macroevolutionary relationship between diet and body mass across mammals. *Biological Journal of the Linnean Society, 115*, 173-184.

Radermacher, V. J., Fernandez, V., Schachner, E. R., Butler, R. J., Bordy, E. M., Hudgins, M. N., de Klerk, W. J., Chapelle, K. E., & Choiniere, J. N. (2021). A new Heterodontosaurus specimen elucidates the unique ventilatory macroevolution of ornithischian dinosaurs. *Elife, 10*, e66036.

Sander, P. M. (2013). An evolutionary cascade model for sauropod dinosaur gigantism--overview, update and tests. *PLoS ONE*, 8, e78573. 10.1371/journal.pone.0078573

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 11:00 AM)

ADVANCES IN OUR UNDERSTANDING OF THE GROWTH PATTERNS OF SAUROPODOMORPHA

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Derived members of the Sauropodomorpha are typified by the giant Mesozoic sauropods, while their basal members were more moderate in terms of body size. Understanding the evolution of gigantism in this lineage has been investigated using the microscopic structure of their bones. Until recently our understanding of the growth patterns of the basal sauropodomorph dinosaurs was based essentially on the Upper Triassic *Plateosaurus trossingensis* from Germany and Switzerland (Klein & Sander, 2007; Sander & Klein, 2005), and the Southern African Lower Jurassic *Massospondylus carinatus* (Barrett et al., 2019; Cerda et al., 2017; Chapelle et al., 2019, 2021; Chinsamy, 1991, 1993, 1994). However, in recent years, our histological data has been expanded and about 15 different basal sauropodomorph dinosaurs have been investigated to obtain a better understanding of how they grew (e.g., Apaldetti et al., 2018; Botha et al., 2022; Cerda et al., 2017; Krupandan et al., 2018).

It has become increasingly apparent that the notion of a dichotomous cyclical growth (Sander, 2004; Sander et al., 2011) for the basal forms and a noncyclical growth for the derived sauropods is not well supported (Cerda et al., 2017). It is apparent that although some basal sauropodomorph dinosaurs, such as *Massospondylus* and *Plateosaurus* have cyclical growth rates, others, like the sauropodiform *Antetonitrus, Ledumahardi and Sephapanosaurus* has a rapid early rate of growth that becomes cyclical during late stages of ontogeny (Krupandan et al., 2018; Botha et al., 2022). Indeed, although the large sauropods grow rapidly for most of their lives, towards the latter part of ontogeny they too develop growth rings in their bones. It is therefore an over-simplification that growth is continuously rapid and noncyclical in the sauropods. Osteohistological studies of the Lower Jurassic

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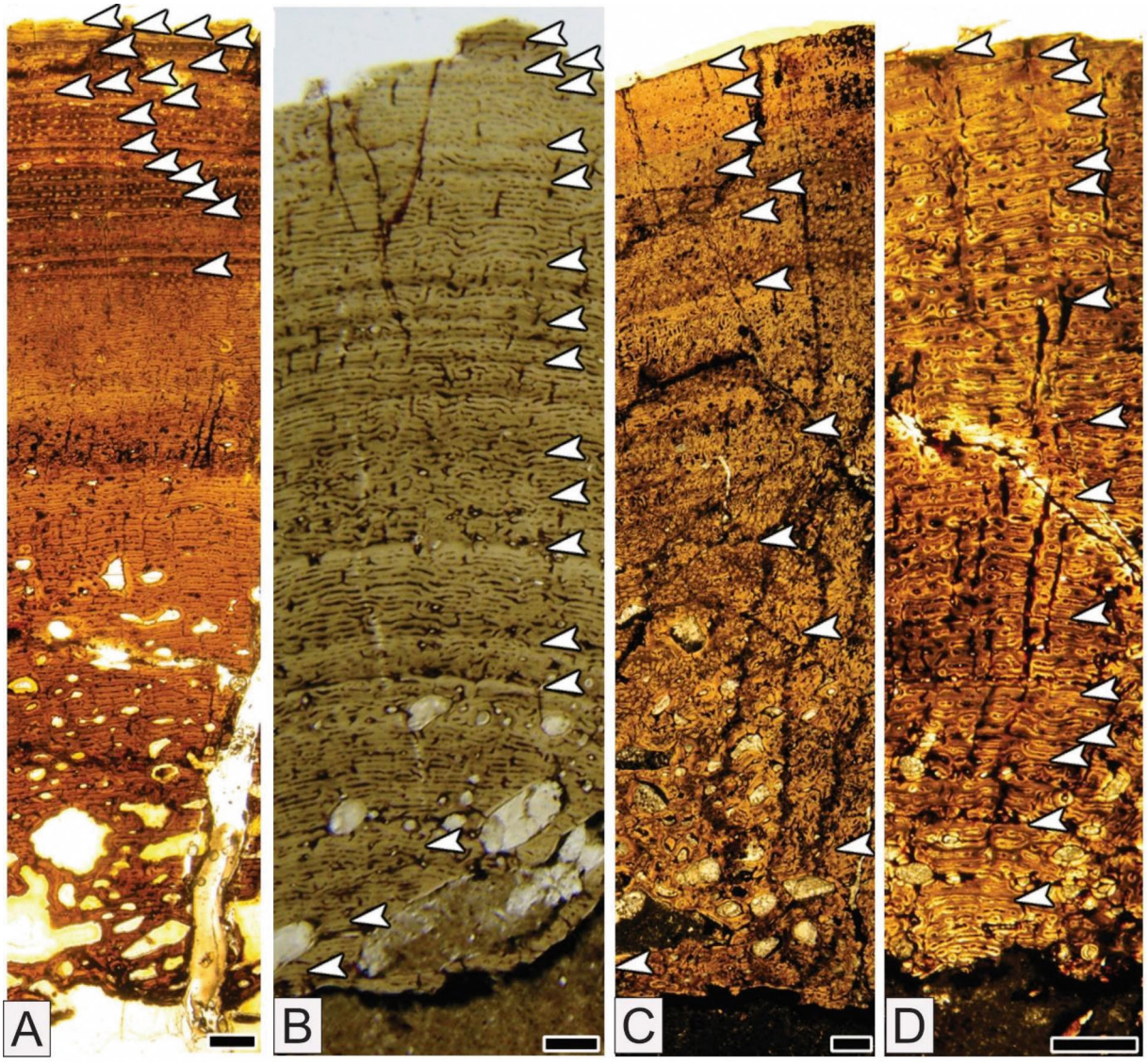


Figure 1. Distribution of growth marks (white arrowheads) in the cortical bone of *Mussaurus*. A) MLP 61-III-20, femur; B-D, MLP 68-II-27-1 humerus (B), femur (C) and fibula (D). Scale bars equal 1 mm.

sauropodiform *Mussaurus patagonicus* from Argentina has revealed that the situation is much more complex than previously envisioned (Cerda et al., 2017, 2022).

The osteohistology of twenty long bones from thirteen individuals of *Mussaurus patagonicus* representing a growth series was investigated. This represents the most comprehensive examination of an early sauropodiform dinosaur.

Based on the occurrence and distribution of growth marks and the abundance of parallel fibred bone and woven fibred bone, our results show that *Mussaurus* exhibits a huge amount of intraspecific variability. *Mussaurus* exhibits marked variation regarding relative growth rate, with some individuals growing much faster than others (Cerda et al., 2022). The variation in growth rates appears to influence the size at which adulthood (as indicated by the presence of an OCL and change in the type of bone tissue) was attained, which results in a poor correlation between the body size and the age/ontogenetic stage for this taxon The variability in the growth patterns could be the result of sexual dimorphism or may reflect plasticity in growth, and a variable response to prevailing environmental conditions. Intraspecific variation is also recorded in terms of the growth strategies, which can vary from cyclical, as in other early sauropodomorphs, to continuous, as reported in sauropods.

It is imperative that more individuals of different sauropodomorph taxa are studied to assess whether similar intraspecific growth patterns are the norm in this clade or perhaps novel in this taxon only. Irrespectively, our research on *Mussaurus* and other more basal sauropodomorph dinosaurs suggests that some Sauropodomorph

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dinosaurs were able to reach gigantic proportions through cyclical growth patterns, and it is therefore apparent that uninterrupted growth is not essential to attain giant size.

The implications of the intraspecific plasticity observed in *Mussaurus* is far reaching in terms of our understanding of the growth dynamics of the Sauropodomorpha. It reveals the occurrence of both cyclical and noncyclical growth dynamics (previously ascribed to basal and more derived sauropodomorpha respectively) in single Sauropodomorph taxon.

References

Apaldetti, C., Martínez, R. N., Cerda, I. A., Pol, D., & Alcober, O. (2018). An early trend towards gigantism in Triassic sauropodomorph dinosaurs. *Nature Ecology & Evolution, 2*, 1227.

Barrett, P. M, Chapelle, K. E., Staunton, C. K., Botha, J., & Choiniere, J. N. (2019). Postcranial osteology of the neotype specimen of *Massospondylus carinatus* Owen, 1854 (Dinosauria: Sauropodomorpha) from the upper Elliot formation of South Africa. *Palaeontologia Africana, 53*, 114-178.

Botha, J., Choiniere, J. N., & Benson, R. B. (2022). Rapid growth preceded gigantism in sauropodomorph evolution. *Current Biology, 32*, 4501-4507. e4502.

Cerda, I. A., Chinsamy, A., Pol, D., Apaldetti, C., Otero, A., Powell, J. E., & Martínez, R. N. (2017). Novel insight into the origin of the growth dynamics of sauropod dinosaurs. *PLoS One, 12*, e0179707.

Cerda, I. A., Pol, D., Otero, A., & Chinsamy, A. (2022). Palaeobiology of the early sauropodomorph *Mussaurus patagonicus* inferred from its long bone histology. *Palaeontology, 65*, e12614.

Chapelle, K. E., Barrett, P. M., Botha, J., & Choiniere, J. N. (2019). *Ngwevu intloko*: a new early sauropodomorph dinosaur from the Lower Jurassic Elliot Formation of South Africa and comments on cranial ontogeny in *Massospondylus carinatus*. *PeerJ, 7*, e7240.

Chapelle, K. E., Botha, J., & Choiniere, J. N. (2021). Extreme growth plasticity in the early branching sauropodomorph *Massospondylus carinatus*. *Biology Letters, 17*, 20200843.

Chinsamy, A. (1991). *The osteohistology of femoral growth within a clade: A comparison of the crocodile*, Crocodylus niloticus*, the dinosaurs*, Massospondylus *and* Syntarsus*, and the birds*, Struthio *and* Sagittarius [Doctoral dissertation, University of the Witwatersrand].

Chinsamy, A. (1993). Bone histology and growth trajectory of the Prosauropod dinosaur *Massospondylus carinatus* Owen. *Modern Geology, 18*, 319-329.

Chinsamy, A. (1994). Dinosaur bone histology: implications and inferences. In G. D. W. Rosenberg (Ed.), *Dino Fest*. *Paleontological Society Special Publication no. 7*. Cambridge University Press.

Krupandan, E., Chinsamy-Turan, A., & Pol, D. (2018). The long bone histology of the sauropodomorph, *Antetonitrus ingenipes*. *The Anatomical Record, 301*, 1506-1518.

Sander, P. (2004). Adaptive radiation in sauropod dinosaurs: bone histology indicates rapid evolution of giant body size through acceleration. *Organisms Diversity & Evolution, 4*, 165-173.

Sander, P. M., Christian, A., Clauss, M., Fechner, R., Gee, C. T., Griebeler, E. M., Gunga, H. C., Hummel, J., Mallison, H., & Perry, S. F. (2011). Biology of the sauropod dinosaurs: the evolution of gigantism. *Biological Reviews, 86*, 117-155.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 10:45 AM)

A NEW QUARRY IN THE UPPER TRIASSIC LOWER ELLIOT FORMATION PROVIDES EVIDENCE FOR CLASSICAL NORIAN FAUNAS IN THE MAIN KAROO BASIN OF SOUTHERN AFRICA

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The end-Triassic Extinction Event (ETE) marks major shifts in continental vertebrate faunas. In most Late Triassic continental ecosystems, tetrapods are represented by dicynodont and cynodont therapsids, a variety of pseudosuchian archosaur lineages, and more scarcely, members of the dinosaur clades Sauropodomorpha and Theropoda. Early Jurassic ecosystems, by contrast, are dominated by dinosaurs from all three major lineages whereas therapsid and pseudosuchian representation is restricted to late-branching cynodonts and crocodylomorphs.

Surprisingly few continental basins contain depositional records that span the Triassic–Jurassic transition, and classically studied units that do, such as the Newark Supergroup, have only sporadic body fossil preservation. These factors limit our ability to understand the dynamics of this mass extinction. The Stormberg Group of southern Africa is a sequence of sedimentary rocks deposited during the Carnian–Pliensbachian in the main Karoo Basin, a retroarc foreland basin in SW Gondwana (reviewed in Catuneanu et al., 2005). Its highly fossiliferous Elliot Formation contains Triassic–Jurassic fluviolacustrine deposits that bracket the ETE with very little depositional hiatus between them. A nearly 170-year history of paleontological, geologic, and stratigraphic investigations in the Elliot Formation makes it an ideal natural laboratory for studying the dynamics of this mass extinction.

Geological and paleontological subdivisions of the Elliot Formation were hypothesized by the early 1900s (Dunn, 1878; Haughton, 1924), and have been repeatedly refined, including recent comprehensive reviews of its litho-, magneto- and biostratigraphy (e.g., Bordy & Eriksson, 2015; Bordy et al., 2020; Ellenberger, 1972; Kitching & Raath, 1984; Knoll, 2004, 2005; Olsen & Galton, 1984; Sciscio et al., 2017; Viglietti et al., 2020a, 2020b). This body of work divides the Elliot Formation into distinct 'upper' and 'lower' lithostratigraphic sections, which in turn correspond closely to the biostratigraphic divisions of the *Scalenodontoides* and *Massospondylus* Assemblage Zones, respectively (hereafter SAZ and MAZ). Radiometric dating of detrital zircons, coupled with magnetostratigraphic work, supports a Late Triassic (Norian–Rhaetian) age for the lower Elliot Formation strata and the SAZ, and an Early Jurassic (Hettangian–Pliensbachian) age for the upper Elliot Formation and MAZ (reviewed in Bordy et al., 2020).

While fossils of vertebrates are abundant in the Elliot Formation, the SAZ fauna is poorly characterized relative to that from the MAZ. The SAZ currently provides less than one-quarter as many collections records as the MAZ (Bordy et al., 2020), and most of these records are partial postcranial skeletons of sauropodomorph dinosaurs that cannot be identified at the generic level (McPhee et al., 2017). Surprisingly, the SAZ has been almost completely lacking in fossils from lineages typical in other Norian deposits worldwide, such as dicynodonts (one poorly provenanced record (Kammerer, 2018), non-crocodylomorph pseudosuchians (a handful of highly fragmentary specimens (Tolchard et al., 2019), non-dinosaurian avemetatarsalians and early branching theropod dinosaurs (no body fossils for either). This paucity of specimens is a major limiting factor in using the South African fossil record to understand the ETE.

Our continuing fieldwork in the Elliot Formation has focused on expeditions to its Triassic outcrops with the aim of correcting this issue. We report here our preliminary findings from the 'Big Bridge Quarry' (BBQ), a fossiliferous lower Elliot locality situated near Qhemegha, a village in the Eastern Cape Province, South Africa. The BBQ was discovered in 2019 and excavations are ongoing at the site. Sedimentary rocks in the BBQ represent a debris flow that occurred after a prolonged period of drought, and they contain the articulated and disarticulated remains of at least nine tetrapod taxa. These include the cranial and postcranial remains of the following: an articulated, large-bodied pseudosuchian phylogenetically close to the crocodylomorph/rauisuchid split; large- and small-bodied representatives of at least two sauropodomorph species; large-and small-bodied representatives of at least three theropod species; and at least three distinctive femoral morphotypes that potentially represent non-dinosaurian avemetatarsalian lineages. Skeletal material in the BBQ is exceptionally well-preserved. It is particularly suitable for osteohistological analysis, and of the specimens we have so far sampled, we can infer a range of skeletal ages and growth strategies. Results from CA-TIMS dating of detrital zircons recovered from the BBQ and its under- and overlying strata firmly place these specimens in the late Norian ($\leq 213.84 \pm 0.14$ Ma).

The BBQ dramatically changes our knowledge of Late Triassic ecosystems in the Elliot Formation. Our findings reveal a more 'typical' Norian fauna than could be inferred from historical collections records, with much more abundant representation of previously undersampled groups, such as pseudosuchians and non-dinosaurian avemetatarsalians. As specimens are described and incorporated into phylogenetic analyses, this will undoubtedly improve biostratigraphic correlation between the Elliot Formation and penecontemporaneous strata in other parts of the world. When taken in conjunction with information from the rest of the main Karoo Basin, our results provide important evidence that typical Norian faunas persisted until within 12 million years of the Triassic–Jurassic boundary, lending support to hypotheses for the rapid reorganization of terrestrial vertebrate communities during the ETE.

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References

Bordy, E. M., Abrahams, M., Sharman, G. R., Viglietti, P. A., Benson, R. B., McPhee, B. W., Barrett, P. M., Sciscio, L., Condon, D., & Mundil, R. (2020). A chronostratigraphic framework for the upper Stormberg Group: Implications for the Triassic-Jurassic boundary in southern Africa. *Earth-Science Reviews, 203*, 103120.

Bordy, E. M., & Eriksson, P. G. (2015). Lithostratigraphy of the Elliot Formation (Karoo Supergroup), South Africa. *South African Journal of Geology, 118*, 311-316.

Catuneanu, O., Wopfner, H., Eriksson, P. G., Cairncross, B., Rubidge, B. S., Smith, R. M. H., & Hancox, P. J. (2005). The Karoo basins of south-central Africa. *Journal of African Earth Sciences, 43*, 211-253.

Dunn, E. (1878). Geological report on the Stormberg coal-fields. *Parlimentary Report* G 4.

Ellenberger, P. (1972). *Contribution á la vlassification des pistes de vertébrés du Trias: Les types du Stormberg d'Afrique du Sud* (I). Laboratoire de paléontologie des vertébrés.

Haughton, S. H. (1924). The fauna and stratigraphy of the Stormberg Series. *Annals of the South African Museum, 12*, 323-497.

Kammerer, C. F. (2018). The first skeletal evidence of a dicynodont from the lower Elliot Formation of South Africa. *Palaeontologia Africana, 52*, 102-128.

Kitching, J. W., & Raath, M. A. (1984). Fossils from the Elliot and Clarens Formations (Karoo sequence) of the northeastern Cape, Orange Free State, and Lesotho, and a suggested biozonation based on tetrapods. *Palaeontologia Africana, 25*, 111-125.

Knoll, F. (2004). Review of the tetrapod fauna of the "Lower Stormberg Group" of the main Karoo Basin (southern Africa): implication for the age of the Lower Elliot Formation. *Bulletin de la Société Géologique de France, 175*, 73-83.

Knoll, F. (2005). The tetrapod fauna of the Upper Elliot and Clarens formations in the main Karoo Basin (South Africa and Lesotho). *Bulletin de la Société Géologique de France, 176*, 81-91.

McPhee, B. W., Bordy, E. M., Sciscio, L., & Choiniere, J. N. (2017). The sauropodomorph biostratigraphy of the Elliot Formation of southern Africa: tracking the evolution of Sauropodomorpha across the Triassic-Jurassic boundary. *Acta Palaeontologica Polonica, 62*, 441-465.

Olsen, P. E., & Galton, P. M. (1984). A review of the reptile and amphibian assemblages from the Stormberg of southern Africa, with special emphasis on the footprints and the age of the Stormberg. *Palaeontologia Africana, 25*, 87-110.

Sciscio, L., de Kock, M., Bordy, E., & Knoll, F. (2017). Magnetostratigraphy across the Triassic-Jurassic boundary in the main Karoo Basin. *Gondwana Research, 51*, 177-192.

Tolchard, F., Nesbitt, S. J., Desojo, J. B., Viglietti, P., Butler, R. J., & Choiniere, J. N. (2019). 'Rauisuchian' material from the lower Elliot Formation of South Africa and Lesotho: Implications for Late Triassic biogeography and biostratigraphy. *Journal of African Earth Science, 160*, 103610.

Viglietti, P., McPhee, B., Bordy, E., Sciscio, L., Barrett, P., Benson, R., Wills, S., Chapelle, K., Dollman, K., & Mdekazi, C. (2020a). Biostratigraphy of the *Massospondylus* Assemblage Zone (Stormberg Group, Karoo Supergroup), South Africa. *South African Journal of Geology, 123*, 249-262.

Viglietti, P., McPhee, B., Bordy, E., Sciscio, L., Barrett, P., Benson, R., Wills, S., Tolchard, F., & Choiniere, J. (2020b). Biostratigraphy of the *Scalenodontoides* Assemblage Zone (Stormberg Group, Karoo Supergroup), South Africa. *South African Journal of Geology*, *123*, 239-248.

Technical Session 1: Paleoclimatology and Paleogeography (Thursday, June 8, 2023, 9:45 AM)

REAPPRAISAL OF THE MORENO HILL FORMATION, NEW MEXICO (USA)

Cilliers, Charl D.[1], Tucker, Ryan T.[1], Zanno, Lindsay E.[2,3]

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The mid-Cretaceous is demarcated by enigmatic yet globally significant tectonic and climatic processes (Huber et al., 2018). Although our understanding of the Cenomanian–Turonian is improving, geological and paleontological data immediately succeeding the Cretaceous Thermal Maximum remains fragmentary (Nesbitt et al., 2019; Cilliers, 2022). Fortunately, potential insights into the Turonian–Coniacian transition are preserved within the Moreno Hill Formation (MHF) of the Salt Lake Coal Field (SLCF) in west-central New Mexico (McLellan et al., 1983). Despite this importance, the MHF has hitherto undergone limited geohistorical interpretations.

Recently, we constructed new temporal, palaeoenvironmental, and stratigraphic frameworks for this globally important fossil-bearing sedimentary succession. We

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conducted U/Pb radiometric age dating of detrital zircons sampled from the historically defined lower, middle, and upper members of the MHF via LA-ICP-MS and CA-TIMS (Cilliers et al., 2021). Our study found that sediment transport and emplacement occurred during two non-coeval pulses of volcanism. The lower and middle members were emplaced after an eruption at 90.855 ± 0.040 Ma (late Turonian). A subsequent, younger pulse of volcanism at 88.632 ± 0.072 Ma (early Coniacian) is preserved in the upper MHF. Although sediment transport and emplacement were ongoing, the different zircon populations indicate the MHF to be diachronous. Based on geographic proximity, the Peninsular Ranges and Sierra Nevada Batholiths were likely source terranes for the above-mentioned youthful zircon grains and populations (Pecha et al., 2018).

With the additional assessment of co-occurring recycled zircon grains, we were able to strengthen tenuous linkages to key sediment source terranes and simultaneously construct a meaningful drainage history. By and large, most grains are derived from uplifted and eroded portions of the Yavapai/Mazatzal and Grenville to the west and south via the Sevier Fold and Thrust Belt and Mogollon Highlands (Pecha et al., 2018). Chiefly, this study identified the markedly different detrital histories of the lower and middle members when compared to the upper member to be a result of tectonically driven landscape modification. This difference is linked to the ongoing eastward migration of the forebulge, which gradually diverted westerly and north-westerly-lying feeder systems (e.g., Sierra Nevada Batholith and Sevier Highlands), synchronous with the development of the Maria Fold and Thrust Belt as a sediment source from the west to the southwest around 90–86 Ma (Cilliers et al., 2021; Szwarc et al., 2015).

We further assessed preserved Turonian–Coniacian climatic and environmental changes. Utilizing facies analysis and architectural reconstruction (Miall, 2016), we identified that the majority of lower member floodplain sediment was modified by pedogenic processes, with the most frequent facies comprising stacked gleyed vertisols, histosols, vertic histosols, and protosols (Tabor et al., 2017). These alternating paleosols indicate that groundwater fluctuated during a regional (southern Colorado Plateau) regression (R1) coincident with the latest Greenhorn Cyclothem which was followed by the New Mexico-specific T2–R2 transgressive-regressive sequence (Molenaar, 1983). Overall regression and base level fall within the lower member following the T2 is corroborated by the transition from relatively more-sulfurous coastal to less-sulfurous fluvial coals and by increasingly bedload-rich multi-story channel complexes (Hoffman, 1994; Cilliers, 2022). Transitioning to the upper member, sedimentary patterns and pedogenic development remain consistent with continued base level fall and slight aridification albeit with continuing groundwater flux. Whereas westerly feeder system diversion probably contributed to a return to single-story sandstones, more suspended-load-rich fluvial sediment and thin upper member coals are also linked to landward effects of another minor (T3) transgression (Elder & Kirkland, 1993). Therefore, MHF sediment modification occurred in a developing upper delta floodplain during punctuated regression of the Western Interior Seaway coincident with the latest Greenhorn through early Niobrara Cyclothems (Blakey, 2014; Miall & Catuneanu, 2019). We consider the Rufiji (Tanzania) or Godavari Rivers (India) as useful modern analogs.

Bolstered by shifting provenance, slight facies-based differences between the lower and upper MHF support a revised subdivision from three to two informal members. Using this two-member subdivision as a foundation for stratigraphic reappraisal we first resolved the stratigraphy of field sites in the southern SLCF where the MHF is mostly mapped as undivided. By including sedimentary, paleocurrent, structural, and existing spatial data within a parsimonious progradational geomorphologic model three sites were assigned to the lower MMF and one site to the upper member. Correlations to the seaward Gallup Delta (Molenaar et al., 2002) and contemporaneous Kaiparowits, Notom, Last Chance, Vernal, Frontier, and Cardium fluvio-deltaic systems (Bhattacharya & MacEachern, 2009) were then reassessed and strengthened. The lower member correlates to the Tres Hermanos Formation (Carthage and Ramah members), the uppermost Gallup Sandstone, and the Crevasse Canyon Formation (Torrivio Sandstone Member) and regionally to the middle–upper Toreva, Straight Cliffs (Tibbet Canyon and Smoky Hollow members), lower Funk Valley, upper Ferron Sandstone, Frontier (Dry Hollow Member), and Cardium formations. The upper member correlates to the Crevasse Canyon Formation (Dilco Coal Member) and regionally to the lower Wepo and Straight Cliffs (John Henry Member) formations. Ongoing progradation of the Gallup Delta system in response to the Greenhorn Regression likely resulted in continued maturation of the Moreno Hill floodplain and the biological communities therein (Cilliers, 2022).

References

Blakey, R. C. (2014). Paleogeography and paleotectonics of the Western Interior Seaway, Jurassic–Cretaceous of North America. *Search and Discovery, 30392*.

Bhattacharya, J. P., & MacEachern, J. A. (2009). Hyperpycnal rivers and prodeltaic shelves in the Cretaceous seaway of North America. *Journal of Sedimentary Research, 79*(4), 184-209.

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Cilliers, C. D., Tucker, R. T., Crowley, J. L., & Zanno L. E. (2021). Age constraint for the Moreno Hill Formation (Zuni Basin) by CA-TIMS and LA-ICP-MS detrital zircon geochronology. *PeerJ, 9*, e10948.

Cilliers, C. D. (2022). *Geology of the early Late Cretaceous Moreno Hill Formation, Zuni Basin, New Mexico* [Doctoral dissertation, Stellenbosch University].

Elder, W. P., & Kirkland, J. I. (1993). Cretaceous paleogeography of the Colorado Plateau and adjacent areas. Aspects of Mesozoic geology and paleontology of the Colorado Plateau. *Bulletin of the Northern Arizona Museum, 59*, 129-151.

Hoffman, G. K. (1994). Coal Geology of the Lower Moreno Hill Formation, Salt Lake Field, West Central New Mexico. In R. M. Chamberlin, B. S. Kue, S. M. Cather, J. M. Barker, & W. C. McIntosh (Eds.). *New Mexico Geological Society Guidebook, 45th Field Conference, Mogollon Slope, West Central New Mexico and East-Central Arizona* (pp. 283-290).

Huber, B. T., MacLeod, K. G., Watkins, D. K., & Coffin, M. F. (2018). The rise and fall of the Cretaceous Hot Greenhouse climate. *Global and Planetary Change, 167*, 1-23.

Miall, A. D. (2016). Facies analysis. In A. D. Miall (Ed.), *Stratigraphy: A modern synthesis* (pp. 77-159). Springer Cham.

Miall, A. D., & Catuneanu, O. (2019). Chapter 9: The Western Interior Basin. In A. D. Miall (Ed.), *The sedimentary basins of the United States and Canada*, 2nd ed (pp. 401-443). Elsevier.

Molenaar, C. M. (1983). Major depositional cycles and regional correlations of Upper Cretaceous Rocks, Southern Colorado Plateau and adjacent areas. In Reynolds MV, Dolly ED, editors. *Mesozoic Paleogeography of the West-Central United States: Rocky Mountain Paleogeography Symposium 2* (pp. 201-224). Society for Sedimentary Geology, The Rocky Mountain Section.

Molenaar, C. M., Cobban, W. A., Merewether, E. A., Pillmore, C. L., Wolfe, D. G., & Holbrook, J. M. (2002). Regional stratigraphic cross sections of Cretaceous Rocks from East-Central Arizona to the Oklahoma Panhandle. *US Geological Survey Miscellaneous Field Studies Map* MF-2382.

McLellan, M., Haschke, L., Robinson, L., Carter, M. D., & Medlin, A. (1983). Middle Turonian and younger Cretaceous rocks, northern Salt Lake coal field, Cibola and Catron Counties, New Mexico. In S. C. Hook (Ed.), *Contributions to Mid-Cretaceous Paleontology and Stratigraphy of New Mexico, part II* (pp. 41-47). New Mexico Bureau of Mines and Mineral Resources.

Nesbitt, S. J., Denton, R. K., Loewen, M. A., Brusatte, S. L., Smith, N. D., Turner, A. H., Kirkland, J. I., McDonald, A. T., & Wolfe, D. G. (2019). A mid-Cretaceous tyrannosauroid and the origin of North American end-Cretaceous dinosaur assemblages. *Nature Ecology & Evolution, 3*(6), 892-902.

Pecha, M. E., Gehrels, G. E., Karlstrom, K. E., Dickinson, W. R., Donahue, M. S., Gonzales, D. A., & Blum, M. D. (2018). Provenance of Cretaceous through Eocene strata of the Four Corners region: insights from detrital zircons in the San Juan Basin, New Mexico and Colorado. *Geosphere, 14*, 785-811.

Szwarc, T. S., Johnson, C. L., Stright, L. E., & McFarlane, C. M. (2015). Interactions between axial and transverse drainage systems in the Late Cretaceous Cordilleran foreland basin: Evidence from detrital zircons in the Straight Cliffs Formation, southern Utah, USA. *Bulletin of the Geological Society of America, 127*, 372-392.

Tabor, N. J., Myers, T. S., & Michel, L. A. (2017). Sedimentologist's guide for recognition, description, and classification of paleosols. In K. E. Zeigler & W. G. Parker (Eds.), *Terrestrial depositional systems, deciphering complexities through multiple stratigraphic methods* (pp. 165-208). Elsevier.

Poster Session 3 (Saturday, June 10, 2023)

BROKEN BONES AND BRUISED EGOS: TRAUMA AND INFECTION IN CERATOPSID DINOSAURS

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Paleopathologies are useful data for interpreting disease and behavior in extinct organisms. Isolated pathological specimens record discrete events in an individual's life, but pathologies common to many within a population may suggest habitual behaviors or diseases (Moodie, 1923; Peterson et al., 2013; Stilson et al., 2015; Wolff et al., 2009; Woodruff et al., 2022). Ceratopsian dinosaurs are frequently speculated to have used their cranial horns and bosses against conspecifics in agonistic interactions (Farke et al., 2009; Farlow & Dodson, 1976; Hatcher, 1907; Hieronymus et al., 2009). Studying their distributions and frequencies of pathology is one way to test this hypothesis. The crania of these animals frequently exhibit lesions, fracture calluses, extra fenestrae, and other pathologies suggesting traumatic injury or unusual ontogenetic change (Campbell et al., 2018; Farke et al., 2009; Tanke & Farke, 2006). The axial and appendicular skeletons receive less attention despite the abundance of bonebed material (but see Tanke & Rothschild, 2010).

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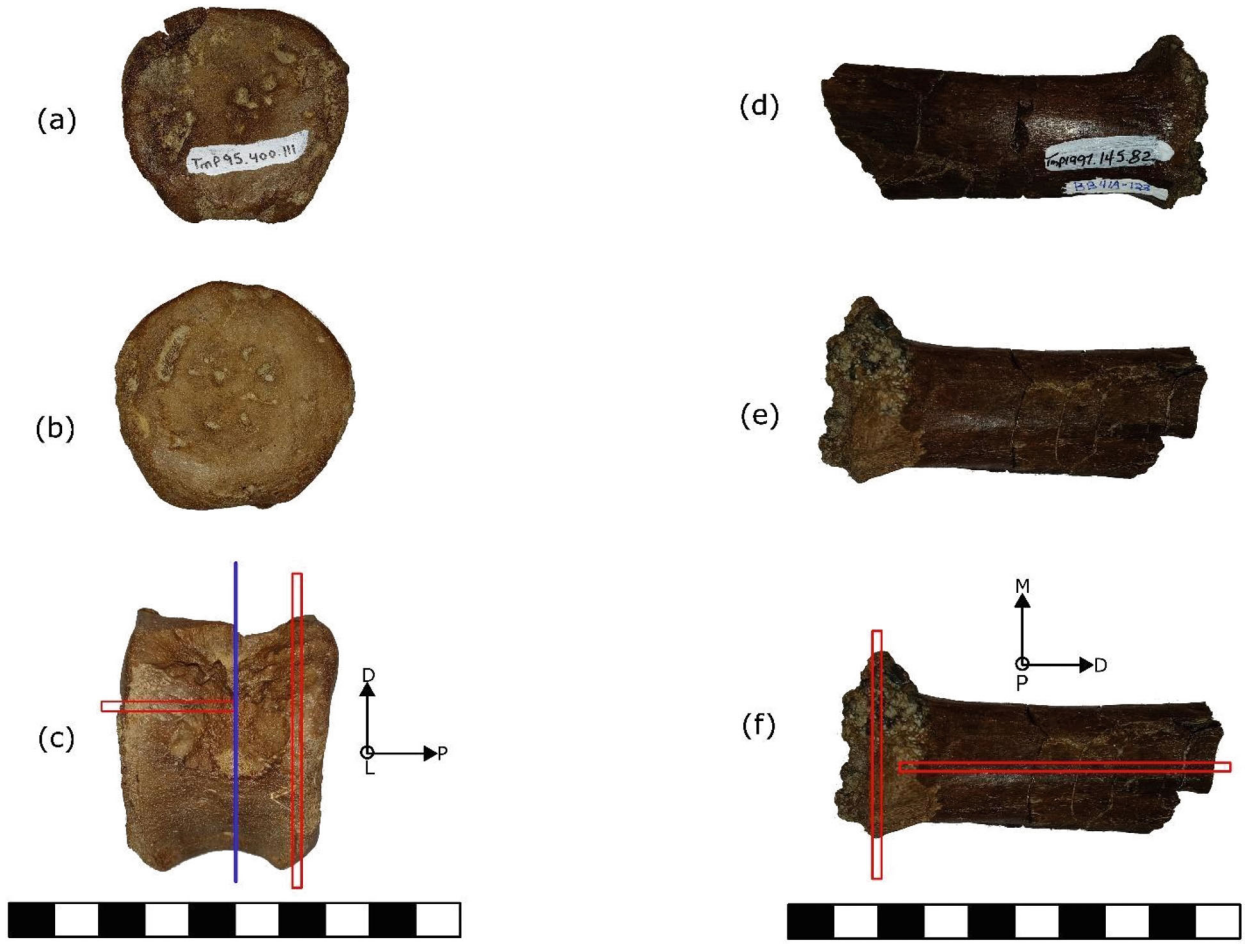


Figure 1. Selected pathological elements from monospecific ceratopsian bonebeds, with anatomical orientations graphed as vector coordinates. Anomalous pitting on vertebrae is common, such as this distal caudal vertebra from *Centrosaurus apertus* in anterior (a), posterior (b), and left lateral (c) view. Fractures are also common and subject to infection, such as this pseudarthrosis on a right anterior dorsal rib from *C. apertus* in anterior (d) and posterior (e-f) view. The red rectangles are the targets for histological sampling (not to scale); the blue line in (c) is the plane where the vertebra will be bifurcated to enable a coronal section. Abbreviations: D., dorsal; L., lateral; P., posterior; M., medial. Each scale bar is 10 cm.

Centrosaurus apertus and *Pachyrhinosaurus lakustai* have divergent headgear, with elongate nasal horns and inflated nasal bosses respectively, which may have been used differently in intraspecific interactions. This may be reflected in differing distributions and frequencies of postcranial pathology. Monodominant bonebeds in Alberta's Dinosaur Park, Horseshoe Canyon, and Wapiti Formations provide large sample sizes of both species throughout their ontogeny (Brown et al., 2020; Currie et al., 2008; Frederickson & Tumarkin-Deratzian, 2014; Langston, 1967; Sampson et al., 1997). Fracture calluses and lesions are most common on the thoracic ribs for both taxa, but they also occur on the dorsal vertebrae, pelvic girdle, and cervical vertebrae. Anomalous pitting is especially common on caudal vertebrae but may occur anywhere on the vertebral column. Forelimb and hindlimb pathologies commonly consist of infected metacarpals and metatarsals, but more proximal lesions and filigree textures are also known. A catalog of specimens from *Centrosaurus* and *Pachyrhinosaurus* bonebeds will allow testing of pathology occurrence versus phylogeny. Histological sectioning will also be used to study immune response and healing in these dinosaurs, using several specimens exhibiting common pathologies (Dyer et al., 2021; Padian & Lamm, 2013). Histology permits analysis of taphonomic alterations as well, such as authigenic mineral growth in healthy versus pathological bone (Chinsamy & Tumarkin-Deratzian, 2008; Dyer et al., 2021). Mass death assemblages provide "snapshots" of ceratopsid populations, giving unique opportunities to study the paleobiology of these iconic dinosaurs.

References

Brown, C., Holmes, R., & Currie, P. (2020). A subadult individual of *Styracosaurus albertensis* (Ornithischia: Ceratopsidae) with comments on ontogeny and intraspecific

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

variation in *Styracosaurus* and *Centrosaurus*. *Vertebrate Anatomy Morphology Palaeontology*, 8, 67-95. https://doi.org/10.18435/vamp29361.

Campbell, J. A., Ryan, M. J., Schröder-Adams, C. J., Evans, D. C., & Holmes, R. B. (2018). New insights into Chasmosaurine (Dinosauria: Ceratopsidae) skulls from the Upper Cretaceous (Campanian) of Alberta, and an update on the distribution of accessory frill fenestrae in Chasmosaurinae. *PeerJ, 6*, e5194. https://doi.org/10.7717/peerj.5194.

Chinsamy, A., & Tumarkin-Deratzian, A. (2009). Pathologic bone tissues in at vulture and a nonavian dinosaur: Implications for interpreting endosteal bone and radial fibrolamellar bone in fossil dinosaurs. *The Anatomical Record, 292*(9), 1478-1484. https://doi.org/10.1002/ar.20991.

Currie, P. J., Langston W., & Tanke, D. H. (2008). *A new horned dinosaur from an Upper Cretaceous bone bed in Alberta*. Canadian Science Publishing. https://doi.org/10.1139/9780660198194.

Dyer, A. D., LeBlanc, A. R. H., Doschak, M. R., & Currie, P. J. (2021). Taking a crack at the dome: Histopathology of a pachycephalosaurid (Dinosauria: Ornithischia) frontoparietal dome. *Biosis: Biological Systems, 2*(2), 248-270. https://doi.org/10.37819/biosis.002.02.0101.

Farke, A. A., Wolff, E. D. S., & Tanke, D. H. (2009). Evidence of combat in *Triceratops*. *PLoS ONE, 4*(1), e4252. https://doi.org/10.1371/journal.pone.0004252.

Farlow, J. O., & Dodson, P. (1975). The behavioral significance of frill and horn morphology in ceratopsian dinosaurs. *Evolution, 29*(2), 353-361.

Frederickson, J. A, & Tumarkin-Deratzian, A. R. (2014). Craniofacial ontogeny in *Centrosaurus apertus*. *PeerJ, 2*, e252.

Hatcher, J. B. (1907). *The Ceratopsia*, by John B. Hatcher, based on preliminary studies by Othniel C. Marsh, ed. and completed by Richard S. Lull. United States Geological Survey. Monographs; v. 49. Government Printing Office.

Hieronymus, T. L., Witmer, L. M., Tanke, D. H., & Currie, P. J. (2009). The facial integument of centrosaurine ceratopsids: Morphological and histological correlates of novel skin structures. *The Anatomical Record, 292*(9), 1370-1396. https://doi.org/10.1002/ar.20985.

Langston Jr., W. (1967). The thick-headed ceratopsian dinosaur *Pachyrhinosaurus* (Reptilia: Ornithischia), from the Edmonton Formation near Drumheller, Canada. *Canadian Journal of Earth Sciences, 4*(1), 171-186. https://doi.org/10.1139/e67-008.

Moodie, R. L. (1923). *Paleopathology; An introduction to the study of ancient evidences of disease*. University of Illinois Press.

Padian, K., & Lamm, E.-T. (2013). *Bone histology of fossil tetrapods: Advancing methods, analysis, and interpretation* (1st ed.). University of California Press.

Peterson, J. E., Dischler, C., & Longrich, N. R. (2013). Distributions of cranial pathologies provide evidence for head-butting in dome-headed dinosaurs (Pachycephalosauridae). *PLoS ONE*, 8(7), e68620. https://doi.org/10.1371/journal.pone.0068620.

Sampson, S. D., Ryan, M. J., & Tanke, D. H. (1997). Craniofacial ontogeny in centrosaurine dinosaurs (Ornithischia: Ceratopsidae): Taxonomic and behavioral implications. *Zoological Journal of the Linnean Society, 121*(3), 293-337. https://doi.org/10.1111/j.1096-3642.1997.tb00340.x.

Stilson, K. T., Hopkins S. S. B., & Davis, E. B. (2016). Osteopathology in Rhinocerotidae from 50 million years to the present. *PLoS ONE, 11*(2), e0146221. https://doi.org/10.1371/journal.pone.0146221.

Tanke, D. H., & Rothschild, B. M. (2010). Paleopathologies in Albertan ceratopsids and their behavioral significance. In M. J. Ryan, B. J. Chinnery-Allgeier, & D. A. Eberth (Eds.), *New perspectives on horned dinosaurs* (pp. 355-384). Indiana University Press.

Tanke, D. H., & Farke, A. A. (2006). Bone resorption, bone lesions and extra cranial fenestrae in ceratopsid dinosaurs: A preliminary assessment. In K. Carpenter (Ed.), *Horns and beaks: Ceratopsian and ornithopod dinosaurs* (pp. 319-347). Indiana University Press.

Wolff, E. D. S., Salisbury, S. W., Horner, J. R., & Varricchio, D. J. (2009). Common avian infection plagued the tyrant dinosaurs. *PLoS ONE, 4*(9), e7288. https://doi.org/10.1371/journal.pone.0007288.

Woodruff, D. C., Wolff, E. D. S., Wedel, M. J., Dennison, S., & Witmer, L. M. (2022). The first occurrence of an avian-style respiratory infection in a non-avian dinosaur. *Scientific Reports, 12*(1), 1954. https://doi.org/10.1038/s41598-022-05761-3.

Technical Session 3: Terrestrial Ecosystems – Late Jurassic (Friday, June 9, 2023, 2:00 PM)

NEW MATERIAL OF *HAPLOCANTHOSAURUS* (HATCHER 1903) FROM THE DRY MESA DINOSAUR QUARRY AND A COMMENT ON SAUROPOD DIVERSITY

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Haplocanthosaurus priscus (Hatcher, 1903), "simple-spined lizard," was named from partial skeletons collected from the Marsh-Felch Quarry near Cañon City, Colorado. Another species, *H. delfsi*, was named from a partial skeleton collected from the Cleveland Delfs Quarry, also in Colorado (McIntosh and Williams, 1988). To these specimens, fragmentary remains from several other localities have been assigned to the genus (Foster, 2020), and a nearly complete skeleton that may represent a new species awaits publication (Bilbey et al., 2000).

Brigham Young University Museum of Paleontology houses five *Haplocanthosaurus* dorsal vertebrae (BYU 9194, 11506, 17530 (Figure 1), 17531, 17689) and a tibia (BYU 12865, Figure 1) from the Late Jurassic Dry Mesa Dinosaur Quarry (DMDQ). The dorsal vertebrae possess diagnostic *Haplocanthosaurus* characters, including tall neural arch peduncles, dorsally-angled transverse processes, and parapophyses placed well below the diapophyses even on posterior dorsal vertebrae (Figure 1). The right tibia is identified as *Haplocanthosaurus* based on the robust nature of the element and the general morphology of a greatly expanded distal end and small cnemial crest. The least breadth\length (LB\L) measurement of 0.21 is greater than any other known sauropod taxa from DMDQ and compares well with USNM 4275, which includes a left tibia assigned to *H. priscus* (LB\L 0.23). While the left tibia of USNM 4275 has an articulated astragalus on its distal end, the morphology matches well with BYU 12865.

The primary importance of the new specimens is stratigraphic rather than morphological. *Haplocanthosaurus* is not abundant at any locality in the Morrison Formation, and the Marsh-Felch Quarry in Colorado is the only quarry to definitively produce more than one individual of *Haplocanthosaurus* (CM 572, CM 879, and USNM 4275). Despite its numerical scarcity, *Haplocanthosaurus* persisted through much of the deposition of the Morrison Fm. Dorsal vertebrae referrable to *Haplocanthosaurus* are present low in the Salt Wash Member of the Morrison Fm. in central Utah (MJW pers. obs., Figure 1), and other *Haplocanthosaurus* localities are in the upper Salt Wash, lower Brushy Basin, and upper Brushy Basin members of the Morrison Fm. (Turner & Peterson, 1999). The DMDQ *Haplocanthosaurus* material confirms the presence of this long-lived genus in the upper Brushy Basin (Britt, 1991). The *Haplocanthosaurus* elements reported herein from DMDQ do not help resolve the phylogenetic position of this enigmatic genus.

Hatcher (1903) considered *Haplocanthosaurus* to be "... the most generalized member of the Sauropoda yet discovered in America", with the species name *priscus* meaning "first." Historically the phylogenetic relationships of *Haplocanthosaurus* have been uncertain. Various analyses have found it to be a derived eusauropod just outside of Neosauropoda, a basal macronarian alongside *Camarasaurus* and *Brachiosaurus*, or the most basal diplodocoid, with more recent analyses tending to support the diplodocoid hypothesis (see Foster & Wedel, 2014 for a brief review; Foster, 2020).

The Dry Mesa Dinosaur Quarry has produced the most diverse assemblage of sauropod dinosaurs in any one locality in the world. The quarry, opened in 1972, was excavated for the better part of two decades and, at over 120m long, it is one of the larger Morrison Formation localities. Unfortunately, the majority of the nearly 5,000 elements prepared are disarticulated.

Six sauropod genera from four families are positively identified based on remains found at the quarry. The diplodocids are represented by at least three species. Most of the *Diplodocus* remains from the quarry belong to adults, as defined by complete neurocentral fusion. However, they are smaller than all other adult *Diplodocus*. Characters in the DMDQ *Diplodocus* and *Brachiosaurus* vertebrae suggest they may be new species.

DMDQ sauropods with representative diagnostic specimen numbers:

Apatosaurus sp. - putative caudal #1 (BYU 5065), rt. fibula (BYU 11420)

Brachiosaurus sp. - rt. scapulocoracoid (BYU 9462), sacral complex with three articulated caudal vertebrae (BYU 11434)

Camarasaurus sp. - caudal vertebrae (BYU 12852, 12853, 13286), rt. tibia (BYU 17352)

Diplodocus sp. - articulated skeleton from presacral 3 to caudal 15+ (BYU 12155), rt. tibia (BYU 12604)

Haplocanthosaurus sp. - dorsal vertebrae (BYU 9194, 11506, 17530, 17531, 17689, 17530), rt. tibia (BYU 12865)

Supersaurus - caudal vertebra (BYU 9044), holotype scapulocoracoid (BYU 12962)

Additionally, a cervical vertebra (BYU 11617) may belong to *Barosaurus*. If so, this would make a seventh sauropod genus present.

With the recognition that the specimens described herein are referable to *Haplocanthosaurus*, DMDQ is the first – and so far only – known quarry in the world with at least six distinct, valid genera of sauropods present. The quarry is hypothesized to represent a faunal assemblage that was first concentrated and then killed by a severe drought (Richmond and Morris, 1998), so the six sauropod genera might have originally been segregated among different nearby habitats during favorable, non-drought conditions. Still, the presence of at least six sauropod genera within the area that could be concentrated

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Figure 1. *Haplocanthosaurus* tibiae and dorsal vertebrae

during a severe drought emphasizes the high site-level diversity of Morrison sauropods.

Is DMDQ unique in the Morrison in supporting so many dinosaur taxa? At least nineteen dinosaur genera (six sauropods, eight theropods, and five ornithischians) are currently recognized. Is it a "disaster quarry," the bone salad resulting from a massive drought drawing all of the surrounding taxa into close quarters? Was it a crossroads site, occupying a migration path, or situated on the boundary between two ecosystems? Evidence from Whitlock et al. indicates this quarry was part of the western region of the Morrison Formation, and DMDQ's sauropod assemblage provides further evidence for the high diversity across the Western and Eastern regions of the Morrison (Whitlock et al., 2018).

References

Bilbey S. A., Hall, J. E., & Hall D. A. (2000). Preliminary results on a new haplocanthosaurid
sauropod dinosaur from the lower Morrison Formation of northeastern Utah. *Journal of Vertebrate Paleontology*, *20*(S3), 30A.

Britt, B. B. (1991). Theropods of Dry Mesa Quarry (Morrison Formation, late Jurassic), Colorado, with emphasis on the osteology of *Torvosaurus tanneri*. *Brigham Young University Geology Studies*, *37*, 1-72.

Foster, J. (2020). *Jurassic West: The dinosaurs of the Morrison Formation and their world* (2nd ed.). Indiana University Press.

Foster, J. R., Wedel, M. J. (2014). *Haplocanthosaurus* (Saurischia: Sauropoda) from the lower Morrison Formation (Upper Jurassic) near Snowmass, Colorado. *Volumina Jurassica*, *12*(2), 197-210.

Hatcher, J. B. (1903). *Osteology of Haplocanthosaurus, with description of a new species and remarks on the probable habits of the Sauropoda and the age and origin of the Atlantosaurus beds: Additional remarks on Diplodocus*. Vol. 2(1). Carnegie Museum.

McIntosh, J. S., & Williams, M. E. (1988). A new species of sauropod dinosaur, *Haplocanthosaurus delfsi* sp. nov., from the Upper Jurassic Morrison Fm. of Colorado. *Kirtlandia*, *43*, 3-26.

Richmond, D.R., & Morris, T. H. (1998). Stratigraphy and cataclysmic deposition of the Dry Mesa Dinosaur Quarry, Mesa County, Colorado. *Modern Geology*, *22*, 121-143.

Turner, C. E., & Peterson, F. (1999). Biostratigraphy of dinosaurs in the Upper Jurassic Morrison
Formation of the Western Interior, USA. *Utah Geological Survey Miscellaneous Publication, 99*, 77-114.

Whitlock, J. A., Trujillo, K. C., & Hanik, G. M. (2018). Assemblage-level structure in MorrisonFormation dinosaurs, Western Interior, USA. *Geology of the Intermountain West, 5*, 9–22.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 9:45 AM)

GEOLOGY AND PALEONTOLOGY OF THE UPPER TRIASSIC CHINLE FORMATION IN THE NORTHERN PARADOX BASIN OF SOUTHEASTERN UTAH: COMPARING SURVEYS FROM CANYONLANDS NATIONAL PARK AND INDIAN CREEK IN BEARS EARS NATIONAL MONUMENT

DeBlieux, Donald D.[1], Milner, Andrew R.C.[2], Irmis, Randall B.[3], Kirkland, James I.[1]

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The Utah Geological Survey recently partnered with the National Park Service to inventory fossil resources in the Upper Triassic Chinle Formation in the Island in the Sky District of Canyonlands National Park (CANY). Over the past decade, collaborative teams from the Natural History Museum of Utah and the St. George Dinosaur Discovery Site have been conducting paleontological investigations of the Chinle Formation to the south of CANY in the Indian Creek (IC) region of Bears Ears National Monument. Both IC and CANY had received little attention prior to these studies. CANY and IC lie in the Paradox Basin and Chinle deposition in the region was influenced by salt tectonism. Consequently, Chinle strata in the region are difficult to correlate with similar age strata elsewhere in southeastern Utah. The discovery of taxonomically identifiable fossils provides useful biostratigraphic data for comparing CANY, IC, and other regions of Utah and the Colorado Plateau.

Stewart and others (1972) identified five members of the Chinle Formation in the CANY region. From oldest to youngest, these are the mottled siltstone unit (sometimes called the Temple Mountain Member or mottled strata) followed by the Moss Back, Petrified Forest, Owl Rock, and Church Rock Members. The top of the formation is overlain by the Wingate Sandstone. They also recognized the Black Ledge beds at the base of the Church Rock Member and the Hite bed at the top of the Church Rock Member. Blakey and Gubitosa (1983, 1984) investigated the stratigraphy and depositional systems of the Chinle Formation in southeastern Utah, including detailed study of the Salt Anticline region around Moab that includes CANY and IC. They identified just two members in this region. These authors combined the lower sandstone unit, the slope-forming unit above it, and the upper sandstone unit into the "Kane Springs strata," which make up the lower half of the Chinle Formation. They suggested that these strata are lateral equivalents to parts of the Moss Back, Petrified Forest, and Owl Rock Members found to the southwest. Above the Kane Springs strata, they recognized the Black Ledge beds and the Church Rock Member. In a follow-up to this work, Hazel (1994) studied the facies architecture of the sandstone bodies and how they are related to intrabasinal salt tectonism. He named three informal sandstone units for the basal sandstone unit, the overlying slope-forming unit, and the cliff-forming unit above that underlies the Black Ledge beds, calling them the Kane Springs 1, 2, and 3 sand bodies (Figure 1). During our work in CANY we found this system to be useful because it provides a convenient way to note which stratigraphic unit the fossils were found in without making assumptions about how these units might be related to those found in other regions.

We observed clear lithostratigraphic correlations between CANY and IC, supporting the correlations of Martz and others (2014). Like CANY, IC Chinle lies unconformably on top of the Moenkopi Formation. The basal unit of the Chinle in IC is sandstone and conglomerate of the Kane Springs beds overlain by the fossil-rich Owl Rock and Church Rock Members. There are, however, some significant differences in the stratigraphy of CANY and IC. The Black Ledge beds at the base of the Church Rock Member are not present in IC. The Red Ledge beds first identified in nearby Lisbon Valley (LV) and correlated to IC (Martz and others, 2014) constitute a thick, cliff-forming unit mostly composed of sandstones and conglomerates, and they are situated within the upper one-third of the Church Rock Member. In IC, the Red Ledge beds thin toward the north, especially in the Lockhart Basin area, and they are not present in CANY. The Lockhart Basin area in the northern part of IC is stratigraphically similar to CANY and less fossiliferous than southern IC.

The Chinle Formation in CANY is less fossiliferous than in other areas to the southeast, such as in LV and IC. Despite this, we recorded over 70 new localities that contain vertebrate and invertebrate body fossils, petrified wood, and invertebrate trace fossils. Vertebrate fossils include the remains of actinopterygian and chondrichthyan fishes, metoposaurid amphibians, and reptiles (phytosaurs and aetosaurs). These were found primarily in sandstone and conglomerate of the Kane Springs strata and the Church Rock Member. Some notable observations in the Chinle Formation include: (1) the basal sandstone unit (KS 1 sand body) commonly contains fossil logs, but vertebrate fossils are rare; (2) petrified wood of conifers and tree ferns are common in the basal strata of the slope-forming KS 2 sand body; (3) crayfish burrows are common in the paleosols of the KS 2 sand body found below the upper sandstone unit (KS 3 sand body); (4) petrified logs of a type of tree fern are common in the fine-grained laminated sandstones of the Black Ledge; and (5) vertebrate fossils in the Church Rock Member are restricted to gravelly carbonate conglomerates. In CANY, most vertebrate fossils were found as fragmentary bones and teeth in the sandstones and conglomerates of the Kane Springs strata.

The Chinle Formation in IC and LV are very fossiliferous, with hundreds of localities recorded since 2004 for LV and since 2013 for IC. Most vertebrate sites preserve isolated elements. However, skulls and articulated/

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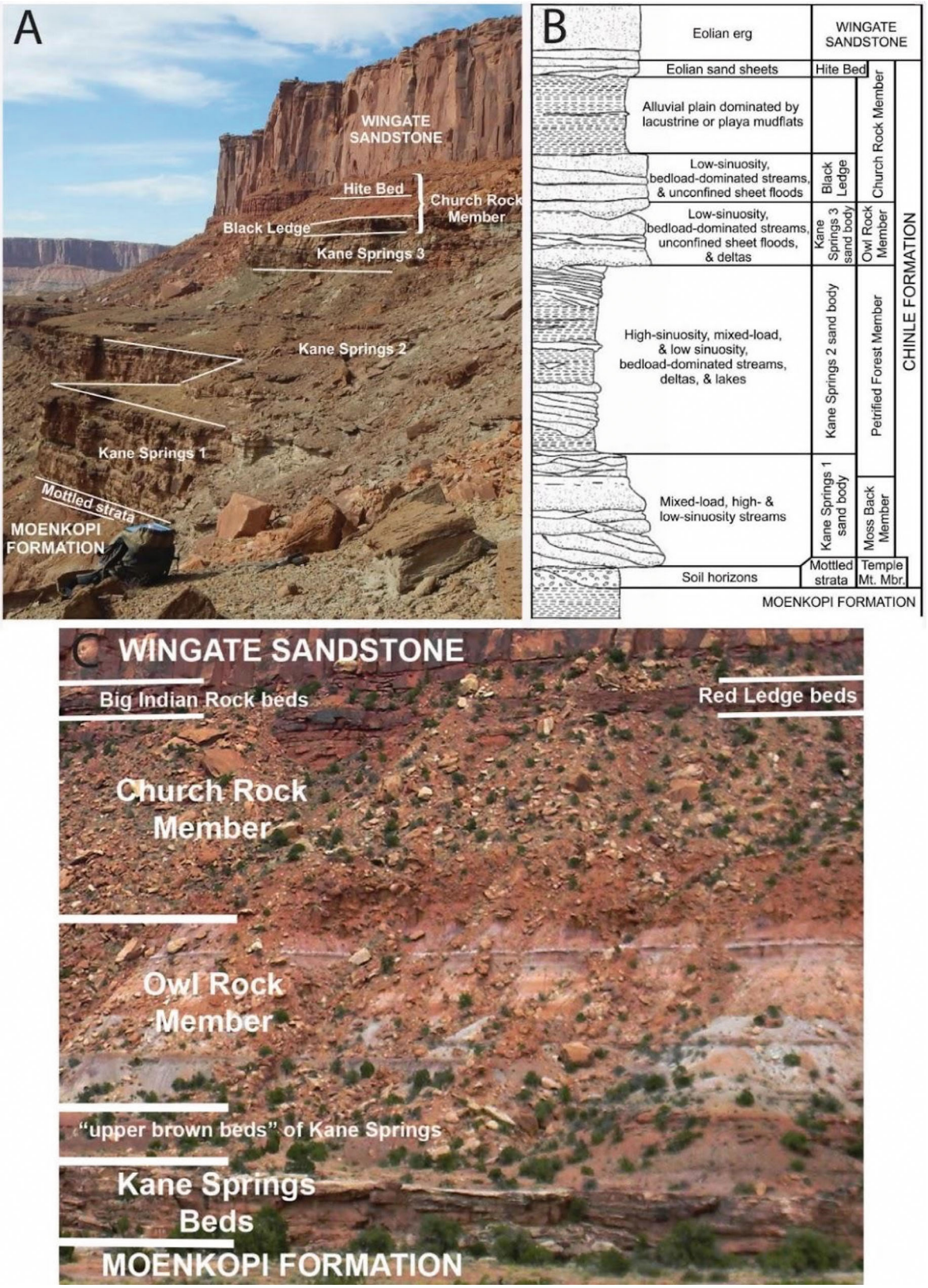


Figure 1. Chinle Formation stratigraphy in the Island in the Sky District of Canyonlands National Park (CANY) and Indian Creek (IC) in Bears Ears National Monument, Utah. A) Rocks in Upheaval Canyon of CANY. B) Lithofacies, depositional systems, and stratigraphic terminology for the Chinle Formation in the northern Paradox Basin (after Hazel, 1994). C) Chinle Formation rocks on the north side of Bridger Jack Mesa in IC.

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associated skeletons have been found, and horizons with articulated fish are locally abundant. Fossils in IC and LV include a diverse and abundant assemblage of chondrichthyans (hybodont sharks), actinopterygian fish (semionotids and redfieldiids), coelacanths, metoposaurid amphibians, and a diverse assemblage of archosauromoprh reptiles (tanystropheids, phytosaurs, aetosaurs, rauisuchids, and crocodylomorphs). Particularly notable is the presence of the aetosaurs *Typothorax coccinarum* and *Rioarribasuchus* and phytosaur "*Redondasaurus*," which have been used elsewhere in the Late Triassic of the southwestern U.S. for vertebrate biostratigraphic correlation (Martz et al., 2014; Martz & Parker, 2017).

These investigations add to the knowledge of the geology and paleontology of the Chinle Formation in the Salt Anticline region of the northern Paradox Basin and facilitate correlation of strata with other parts of the Colorado Plateau. Our work also provides valuable information about the paleontological resources of these areas that can aid public land management agencies to better oversee these important natural resources.

References

Blakey, R. C., & Gubitosa, R. (1983). Late Triassic paleogeography and depositional history of the Chinle Formation, southern Utah and northern Arizona. In M. Reynolds & E. D. Dolly (Eds.), *Mesozoic paleogeography of west-central United States* (pp. 57-76). Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section.

Blakey, R. C., & Gubitosa, R. (1984). Controls of sandstone body geometry and architecture in the Chinle Formation (Upper Triassic), Colorado Plateau. *Sedimentary Geology, 38*, 51-86.

Hazel, J. E. (1994). Sedimentary response to intrabasinal salt tectonism in the Upper Triassic Chinle Formation, Paradox basin, Utah. *U.S. Geological Survey Bulletin, 2000-F*, 1-34.

Martz, J. W., Irmis, R. B., & Milner, A. R. C. (2014). Lithostratigraphy and biostratigraphy of the Chinle Formation (Upper Triassic) in southern Lisbon Valley, southeastern Utah. In J. S. MacLean, R. F. Biek, & J. E. Huntoon (Eds.), *Geology of Utah's far South* (pp. 396-448). Utah Geological Association 43.

Martz, J. W., & Parker, W. G. (2017). Revised formulation of the Late Triassic land vertebrate "faunachrons" of western North America: recommendations for codifying nascent systems of vertebrate biochronology. In K. E. Zeigler & W. G. Parker (Eds.), *Terrestrial depositional systems: Deciphering complexities through multiple stratigraphic methods* (pp. 39-124). Elsevier.

Stewart, J. H., Poole, F. G., & Wilson, R. F. (1972). Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region. *U.S. Geological Survey Professional Paper, 690*, 1-342.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 1:30 PM)

THE FERRIS FORMATION: AN OVERLOOKED YET DIVERSE END-CRETACEOUS FORMATION IN WYOMING

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The Ferris Formation is an end-Cretaceous- early Paleocene terrestrial formation that outcrops solely within the Hanna Basin in south-eastern Wyoming. The Cretaceous portions of the formation are stratigraphically equivalent to the upper portions of the Lance and Hell Creek Formations (Wroblewski et al., 2022). The majority of paleontological research based in the formation has focused on the Paleocene mammal record, however a series of expeditions from the University of Wyoming in the 1990s collected a notable amount of dinosaur fossils from the formation, with a particular focus on collecting microsites. This is the only focused collecting effort from the formation, and a 1997 Master's Thesis by UW student Anton Wrobelewski is the only analysis of this material to date. Reanalysis of this material finds the formation to have a robust dinosaur fauna, with roughly 14 separate genera present, based on both tooth and body material. More unusual than the number of genera present from a formation with so little study, is the makeup of the ecosystem when compared to contemporary formations thought to share a similar environment. Unlike the Lance and Hell Creek Formations, hadrosaurs and ceratopsians make up only a little over a quarter of preserved material, combined. Other notable features of the material include specimens referred to both *Struthiomimus* and *Ornithomimus* and an unusually high number of localities containing ankylosaur body material- more than contain body fossils of either hadrosaurs or ceratopsians. This contradicts notions put forward in earlier analyses of this material, which equated the general diversity of the material to the Lance and Hell Creek. The Ferris Formation is severely understudied, and both continued reanalysis of old material as well as new finds could provide important information on the paleoecology of end-Cretaceous western North America.

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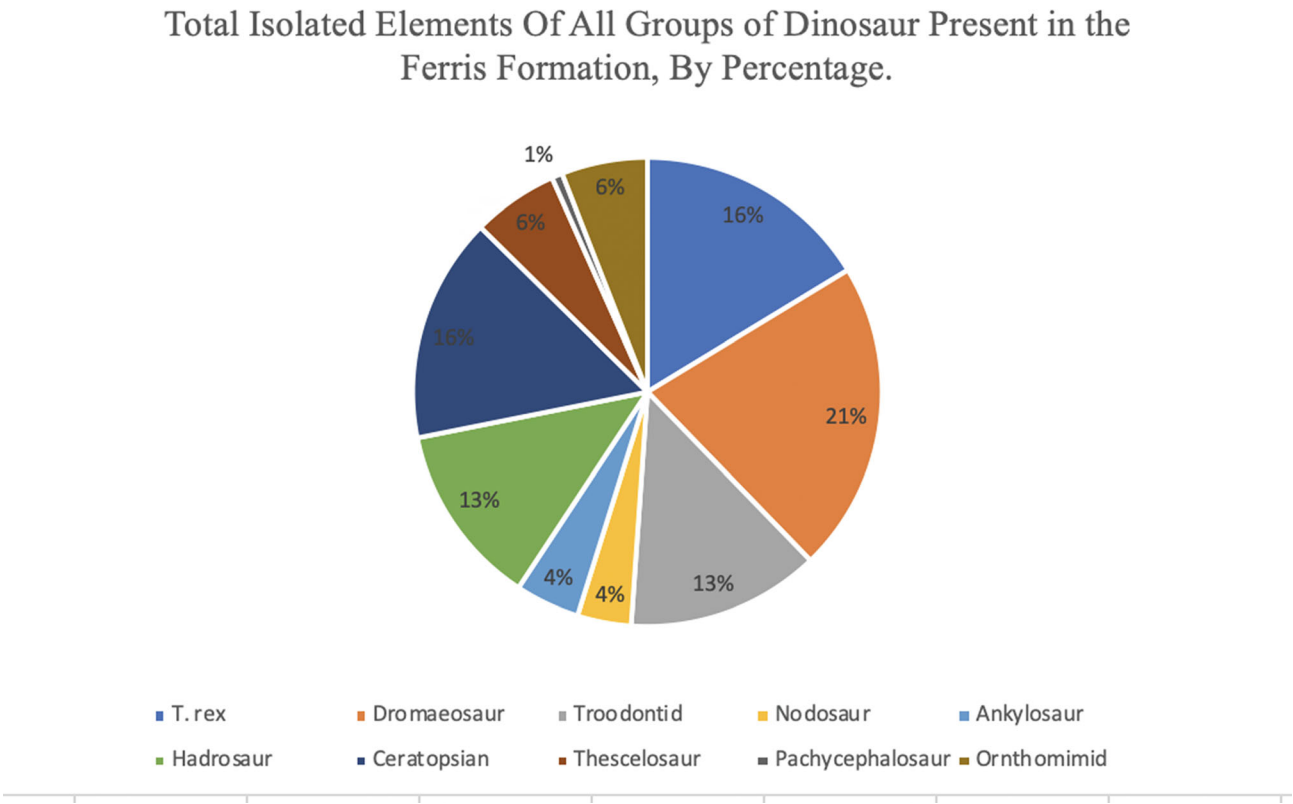


Figure 1. Diversity pie chart of the dinosaur groups represented by both isolated bones and teeth in the Ferris Formation. The percentage of preserved fossils that represent ankylosaurs, nodosaurs and ornithomimids is noticeably higher than in other nearby end-Cretaceous formations. The abundance of ceratopsian and hadrosaur fossils is notably lower.

References

Wroblewski, A. F.-J., & Steel, R. J. (2022). Paleocene (65–63 and 58.5 ma) marine flooding and 62–60 ma sediment bypass in southern Wyoming, USA: Implications for Laramide sediment flux to the Gulf of Mexico. *Journal of Sedimentary Research, 92*(10), 859-894. doi: https://doi.org/10.2110/jsr.2021.111

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 1:00 PM)

MAGNIFICENT MOLLUSCS – THE FIRST REGIONAL PALAEOBIOGEOGRAPHICAL RECONSTRUCTION OF THE MID-CRETACEOUS GRIMAN CREEK FORMATION, LIGHTNING RIDGE, EASTERN AUSTRALIA USING FRESHWATER MOLLUSCS

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The Griman Creek Formation (GCF) in eastern Australia, is a key mid-Cretaceous (Cenomanian/100.2–96.6 Mya) deposit (Bell et al. 2019) that preserves evidence for the final retreat of the intercontinental Eromanga Sea and subsequent development of fluvial floodplains. Vertebrate fossils are well known from the GCF at Lightning Ridge, in NSW, largely due to their preservation as opal pseudomorphs (Bell et al., 2019; Smith, 2010), however, invertebrate and plant fossils (also opalised) from the GCF have remained understudied. The opalised invertebrate fossils frequently retain original features that reveal their functional morphology and ecology, making them an excellent proxy for palaeoecological reconstructions (Stanley, 1970).

Bivalve molluscs comprise the vast majority of biomass recovered from the GCF, with tens of thousands of specimens held in public collections. This study leverages these vast collections and employs GIS technology to map occurrence data of over 21,100 individual mollusc specimens across the Lightning Ridge region, revealing the range of ecological niches that extended outwards from the main palaeo-river channels. Distribution of diverse mollusc taxa were mapped in this study; species from three families of gastropods (aquatic Thiaridae and Viviparidae, and terrestrial Succineidae), and bivalve

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species from the family Unionidae (Hocknull, 2000; Thompson & Stilwell, 2010).

Unionid bivalves are the most ubiquitous fossils in Lightning Ridge. They are considered ecosystem engineers and keystone taxa in modern food webs, living infaunally in flowing channels and permanent water bodies (Vaughn & Hoellein, 2018). Their fossils often retain evidence of desiccation, transportation, and compression that can reveal important aspects of pre-burial palaeoenvironmental conditions and post-burial diagenetic pathways (Fürsich & Pan, 2016). Aquatic thiarid gastropods are known for rapidly colonising organic-rich, muddy flood plains and drying billabongs, whilst viviparids tend to live amongst submerged aquatic vegetation in quiet pools and creeks. All Lightning Ridge gastropods were motile, epifaunal detritus feeders (Glaubrecht et al., 2009) or filter feeders (Jakubik, 2012). Even the very rare occurrence of terrestrial succineid gastropods (which today live only on moist, vegetated banks alongside permanent water) (Hamilton-Bruce & Kear, 2010) contributes to the region's palaeoecological diversity. These ecological niches in combination with the record of trophic interactions with other invertebrate and vertebrate taxa (predation evidence including bite marks, coprolites, gastric pellets), illustrate a diverse, freshwater ecosystem at 60° south during the mid-Cretaceous.

References

Bell, P., Fanti, F., Hart, L., Milan, L., Craven, S., Brougham, T., & Smith, E. (2019). Revised geology, age, and vertebrate diversity of the dinosaur-bearing Griman Creek Formation (Cenomanian), Lightning Ridge, New South Wales, Australia. *Palaeogeography, Palaeoclimatology, Palaeoecology, 514*, 655-671

Fürsich, F., & Pan, Y. (2016). Diagenesis of bivalves from Jurassic and Lower Cretaceous lacustrine deposits of northeastern China. *Geological Magazine, 153*(1), 17-37

Glaubrecht, M., Brinkmann, N., & Pöppe, J. (2009). Diversity and disparity 'down under': Systematics, biogeography and reproductive modes of the 'marsupial' freshwater Thiaridae (Caenogastropoda, Cerithioidea) in Australia *Zoosystematics and Evolution, 85*(2), 199-275

Hamilton-Bruce, R., & Kear, B. (2010). A possible succineid land snail from the Lower Cretaceous non-marine deposits of the Griman Creek Formation at Lightning Ridge, New South Wales. *Alcheringa, 34*(3), 325-331

Hocknull, S. (2000). Mesozoic freshwater and estuarine bivalves from Australia. *Memoirs of the Queensland Museum, 45*(2), 405-426

Jakubik, B. (2012). Life strategies of Viviparidae (Gastropoda: Caenogastropoda: Architaenioglossa) in various aquatic habitats: *Viviparus viviparus* (Linnaeus, 1758) and *V. contectus* (Millet, 1813*). Folia Malacalogica, 20*(3), 145-179

Smith, E. (2010). Early Cretaceous chelids from Lightning Ridge, New South Wales. *Alcheringa, 34*, 375-384

Stanley, S. (1970). *Relation of shell form to life habits of the Bivalvia (Mollusca)*. Geological Society of America Inc. Memoir 125.

Thompson, D., & Stillwell, J. (2010). Early Aptian (Early Cretaceous) freshwater bivalves from the Australian–Antarctic rift, southeast Victoria. *Alcheringa, 34*(3), 345-357

Vaughn, C., & Hoellein, T. (2018). Bivalve impacts in freshwater and marine ecosystems. *Annual Review of Ecology, Evolution, and Systematics, 49*(1), 183-208.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 11:00 AM)

CARBONATE MOUNDS IN THE TRIASSIC-JURASSIC NUGGET SANDSTONE NEAR DINOSAUR NATIONAL MONUMENT, NORTHEASTERN UTAH, OASES IN THE ERG

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The Nugget Sandstone in northeastern Utah spans the Triassic-Jurassic boundary. In the vicinity of Dinosaur National Monument (DNM), with the exception of a lower interval of mixed mudstone and sandstone facies that is transitional from the underlying Chinle Fm., the hundreds of meters of the Nugget section is dominated by eolian sands deposited as dunes in a great sand sea that covered a large part of what is now southwestern North America. The dunes are preserved as sandstones with high-angled cross-beds up to 7 meters thick. In most cases, one set of cross-bedded dune sands succeeds another, but occasionally, an interval of the horizontally-bedded sands of an interdunal facies up to 2 meters thick is preserved.

These interdunal facies are of interest because they represent recurring presence of environments more favorable to life than those of the dunes that created the bulk of the record. They are easily recognized, even at a distance in outcrop, by the horizontal laminae and a higher degree of reddish staining than is typical of the dunes. This is probably the result of weathering of iron-bearing minerals present in the interdunal sands from early diagenesis near the time of deposition. The interdunal facies include a greater fraction of relatively

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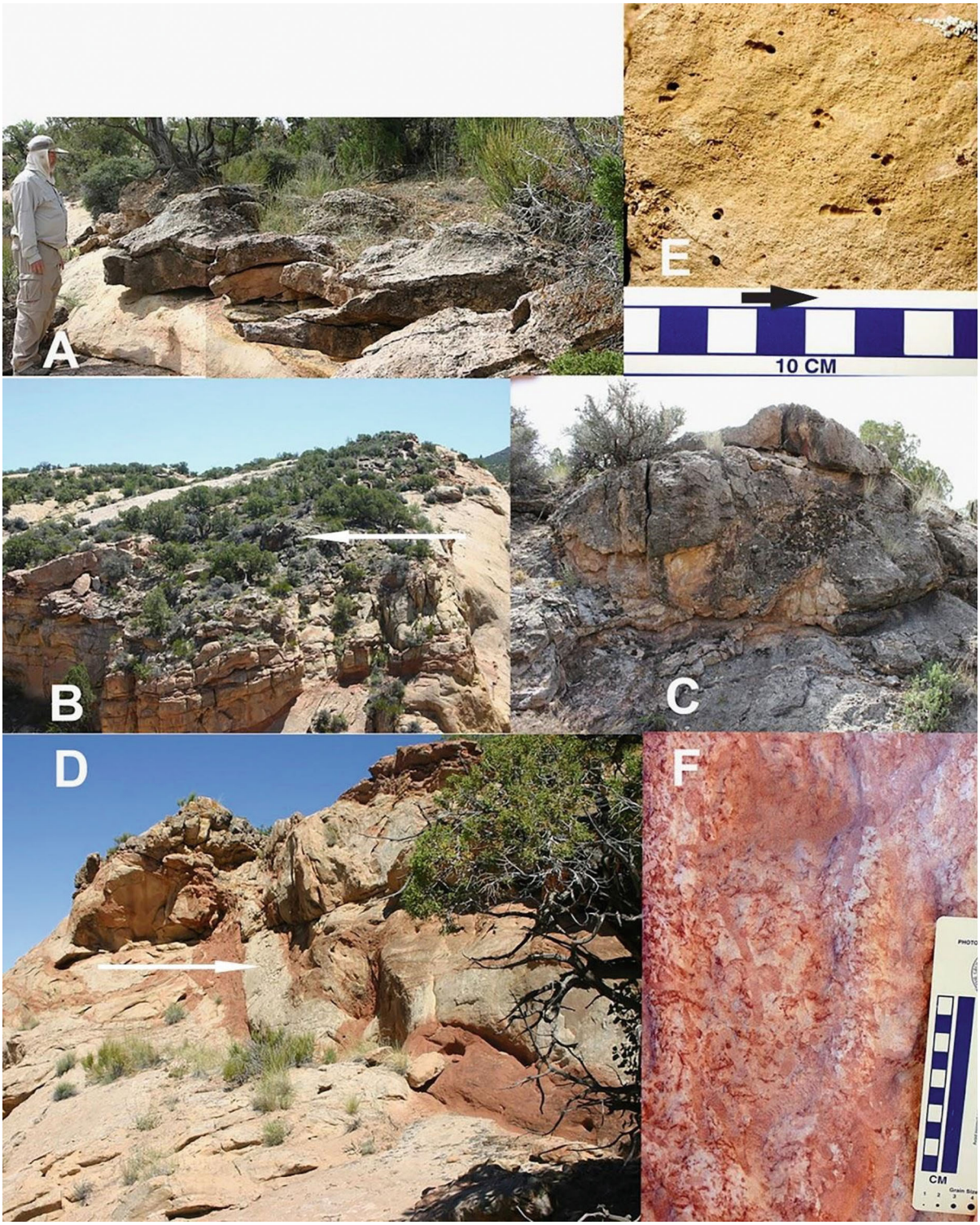


Figure 1. BYU Locality 2902. Carbonate mounds and fossils, Nugget Sandstone, NE Utah. A. Multiple, closely spaced carbonate mounds, GFE for scale. B. Multiple, closely-spaced large carbonate mounds, the one in center of photo (arrow), also figured in C. C. Closer image of central mound seen in B. D. Cross section through large carbonate mound showing sandstone pipe (arrow) cutting vertically through mound. E. Casts of high spired gastropods in sandstone immediately below the carbonate layer. F. Abundant burrows, including *Taenidium*, in sandstone immediately below the carbonate layer. B, C, D, F on north rim of canyon. A, E on south rim of canyon.

fine grains than the dune facies, although still dominantly fine sand. This may have been an important factor in retention of water available for early diagenesis.

Although very scarce in the dunes of the Nugget, fossils are more common in interdunal facies. Trace fossils are the most common and most widely distributed, both

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geographically and stratigraphically, within the formation. Vertebrate and invertebrate tracks, trails and burrows occur within interdunal facies and closely associated distal foreset beds. Body fossils are extremely rare in the formation, but one locality, the Saints & Sinners Quarry, is a lagerstatte that has produced plant impressions and abundant vertebrate skeletal remains that reveal a surprisingly diverse fauna. Sedimentologic and taphonomic evidence indicates that it accumulated in the margin of a shallow, interdunal lake. The relatively small size of some of the faunal elements suggests that they represent a resident population and that the lake persisted long enough for such populations to develop.

At three locations in the vicinity of DNM, exposures of interdunal facies within the Nugget contain carbonate beds: (1) along the margins of a flat topped hill northwest of Vernal and west of Steinaker Reservoir, (2) along a ridge on both sides of Cocklebur Draw, and (3) [BYU Locality 2902] along the rims of small canyons that drain to the west into the Green River near where it emerges from Split Mountain Gorge. The carbonates vary somewhat from place to place, from well bedded layers, as for much of the exposures west of Steinaker Reservoir, to irregular and discontinuous beds, as are typical of exposures at Cocklebur Draw. In all occurrences, the carbonates formed within originally quartz sand sediments enclosing and replacing quartz grains. The carbonates are dolomitic with some microscopic dolomite rhombs. Carbonate mounds are present at all three locations. They are low, conical structures that range from <1 m to several meters in diameter. The carbonate mounds are best preserved and most informatively exposed at BYU Locality 2902.

There, unlike the other carbonate exposures, several closely associated carbonate mounds are exposed on the canyon rims. On the south rim of the main canyon is a group of 5 mounds, each 1-2 meters in diameter, in a linear alignment oriented approximately NW-SE. Horizontally laminated carbonates extend away from these mounds along the outcrop and in one area contain many variously oriented external molds of small, high-spired gastropods similar to fossils in the laminated carbonates exposed west of Steinaker Reservoir. Along the north rim of the canyon, several large, carbonate mounds are aligned approximately NW-SE. They range in size from a few to several meters in diameter. One well-preserved mound about 7 meters across is nearly bisected by erosion of the canyon rim, revealing the mound core.

The structure of the large carbonate mound is similar to the other mounds. The form is the result of laminae inclined away from a central high point to lead distally to horizontal laminae that may continue to the next mound. Peripheral to this mound, sandstone immediately beneath the carbonate layer is heavily bioturbated and riddled with numerous, tubular, meniscate backfilled burrows (*Taenidium* sp.). Within the mound, the core carbonates are brecciated and carbonate fragments surrounded by sandstone that is continuous with the underlying sandstone. In some mounds, fractures are filled by sparry calcite. Sandstone below the mound is weakly bedded and contrasting red and white sandstone suggests deformation with prominent vertical orientation (Figure1D). Still lower within the large scale cross beds exposed in the canyon walls, contorted beds indicate large areas of soft sediment deformation. Dorney et al. (2017) have described similar carbonate deposits in the Navajo Sandstone in southeastern Utah, although these differ in detail, especially in the greater amount of identifiable organic remains than observed so far in the deposits described here.

The carbonate mounds appear to be the result of localized rising groundwater, possibly initiated by fluidized flow in water-saturated unconsolidated eolian sands triggered by seismic events. They formed at times when the water table was high enough to sustain shallow lakes and wetlands in interdunal environments. It is likely that this is the result of relatively wet climatic episodes that punctuated a prevailing arid climate. It may be that it is such wet episodes that are responsible for the preservation of interdunal facies throughout the Nugget by creating interdunal environments ranging from shallow lakes to simply enhanced soil moisture. Loope and Rowe (2003) envision such a scenario for the partially equivalent Navajo Sandstone farther south.

References

Dorney, L. J., Parrish, L. T., Chan M. A., & Hasiotis, S. T. (2017). Petrography and environmental interpretation of tufa mounds and carbonate beds in the Jurassic Navajo Sandstone of southeastern Utah, USA. *Journal of Sedimentology Research, 87*, 967-985.

Loope, D. B., & Rowe, C. M. (2003). Long-lived pluvial episodes during deposition of the Navajo Sandstone. *Journal of Geology, 111*, 223-232.

Theme Session: Laramidia to Asia: Biota and Biogeography of Interconnected Iconic Late Cretaceous Ecosystems (Saturday, June 10, 2023, 3:55 PM)

VERTEBRATE PALEONTOLOGY AND BIOSTRATIGRAPHY OF THE MESAVERDE FORMATION (MIDDLE CAMPANIAN) IN THE BIGHORN BASIN OF WYOMING, USA

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Vertebrate assemblages are increasingly well known from Campanian-aged deposits in the Western Interior Basin along the eastern half of Laramidia, particularly from Alberta, Saskatchewan, and Montana to the north, and Utah, New Mexico, Texas, and Coahuila to the south. The zone between northern and southern assemblages is relatively undersampled, hampering hypothesis testing of latitudinal trends as well as a comprehensive characterization of Laramidian Campanian ecosystem evolution.

The Mesaverde Formation of Wyoming (or "Mesaverde" Formation, recognizing the fact that it is not truly continuous [or age equivalent] with the type section in Colorado; Lillegraven and McKenna, 1986) presents an important geographically intermediate data point. Exposed along the margins of the Wind River and Bighorn basins, this unit preserves a variety of marine, marginal marine, and terrestrial deposits. Previous fieldwork primarily targeted microvertebrate fossils from three areas in the southern Wind River Basin and southwestern and southeastern Bighorn Basin. Published results feature mammals (Clemens & Lillegraven, 1986; Lillegraven & McKenna, 1986), chondrichthyans (Case, 1987), dinosaurs (Yun & Funston, 2021), and general faunal overviews (DeMar & Breithaupt, 2006, 2008). This work has assigned a "Judithian" North American Land Mammal Age to the assemblages, of middle and late Campanian ages (Clemens & Lillegraven, 1986; DeMar & Breithaupt, 2006, 2008).

Due to a lack of direct radiometric dates, the ages of key localities in the Mesaverde Formation cannot yet be constrained precisely, hampering comparisons with other regions. Furthermore, many outcrops in the Mesaverde Formation remain paleontologically unknown (especially in the western Bighorn Basin), which has prevented a deeper analysis of paleoenvironmental variation across depositional settings. Finally, recent advances in systematics and taxonomy of key groups such as chondrichthyans necessitates a reevaluation of previously published specimens.

In light of these research gaps, the Raymond M. Alf Museum of Paleontology at The Webb Schools (RAM) initiated fieldwork in the Mesaverde Formation in 2019. The initial focus was on outcrops in the western part of the Bighorn Basin in and around Oregon Basin, later expanding to the southeastern part of the Basin in the classic "Case localities" originally collected by other institutions during the 1970s and 1980s. Following three field seasons, numerous vertebrate localities—primarily microvertebrate accumulations with disarticulated and isolated elements but also some rare associated

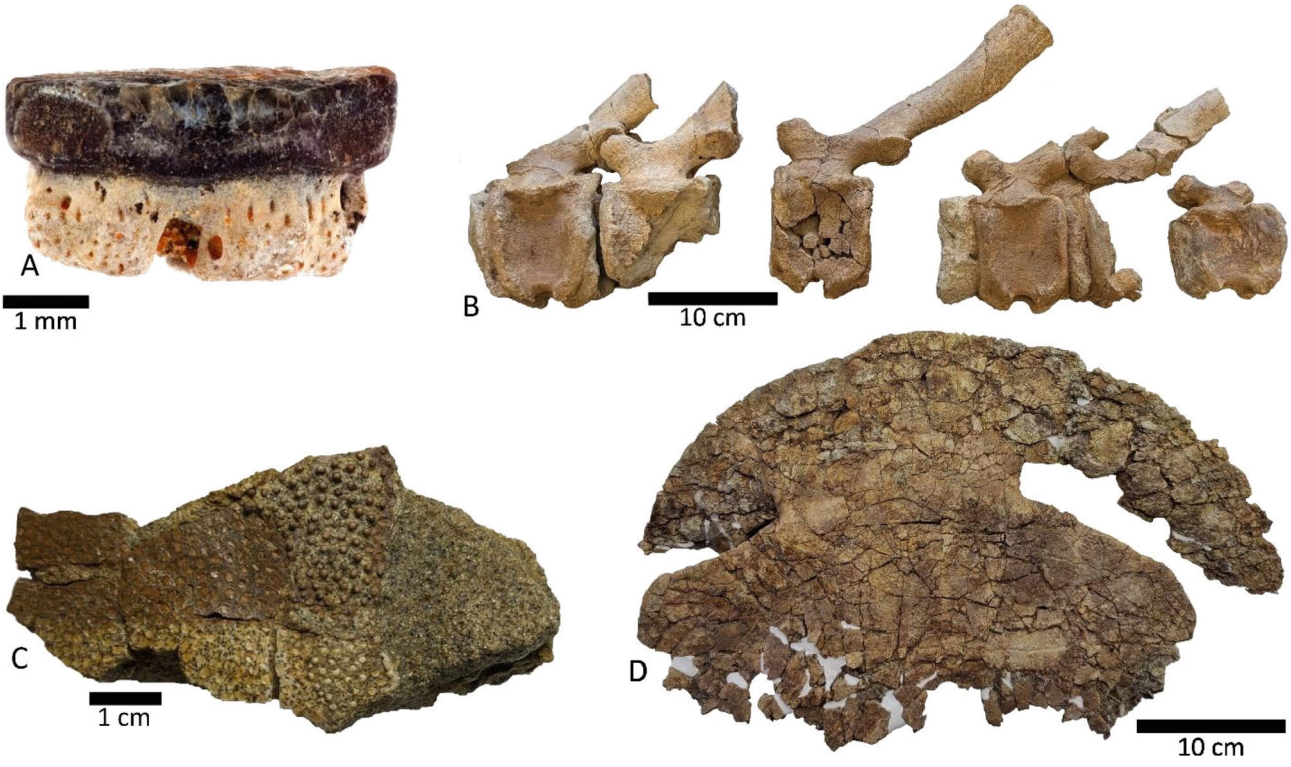


Figure 1. Representative fossils from the Mesaverde Formation of Wyoming, USA. A) Rhinobatiformes tooth, RAM 28443; B) Hadrosauridae, partially articulated series of caudal vertebrae, RAM unnumbered, lateral view; C) Solemydidae carapace fragment, RAM 27015. D) *Neurankylus* sp. carapace and plastron, ventral view, RAM 28750.

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specimens—are now identified throughout the middle and upper portions of the Mesaverde Formation.

The "Case Sites" of Washakie County have existing published microvertebrate samples collected in the 1970s and 1980s (DeMar & Breithaupt, 2006, 2008; Lillegraven & McKenna, 1986). New fieldwork, as well as reevaluation of earlier collections, has offered considerable additional data. Although previously unreported, both lissamphibian (*Opisthotriton* sp. and *Scapherpeton* sp.) and non-mosasaurian squamate fossils are now known, adding to the terrestrial assemblage from these marine-dominated sites. New turtle material is comparable to *Lophochelys*, and abundant hesperornithiform bird material is also previously unreported from the Bighorn Basin. Rhinobatoid teeth lack enamel ornamentation, unlike the condition in *Myledaphus bipartitus*, and are generally more similar to *Cristomylus* or *Pseudomyledaphus*. Importantly, a new locality was identified in the middle unit of the Mesaverde Formation, stratigraphically below the "Case Sites" in Washakie County. Marine influence is indicated by abundant chondrichthyan teeth and oysters, alongside relatively common hadrosaurid teeth.

Assemblages in the western Bighorn Basin from the Oregon Basin area of Park County were unknown previously and are much more terrestrial in character versus those in the eastern basin, as expected given distance from the Western Interior Seaway. A partial baenid turtle shell is referable to *Neurankylus* sp. (Figure 1D), and additional turtle material is referable to Solemydidae (Figure 1C), Trionychidae, and others. Associated and partially articulated hadrosaur specimens cannot be identified in depth (Figure 1B), but illustrate potential for future diagnostic material.

Biostratigraphic evidence points towards a minimum of a middle Campanian age for the Mesaverde Formation across the Bighorn Basin. Fragments of solemydid turtle carapace are distinctive and relatively common throughout the formation. Elsewhere in Laramidia, this clade does not persist past the middle Campanian, and in Alberta persists only to the very lower part of the early middle Campanian-aged Foremost Formation (e.g., Brinkman, 2003; Joyce et al., 2011). Similarly, rhinobatoid teeth in the current sample do not represent *Myledaphus bipartitus*. Unlike the condition in *M. bipartitus*, the rhinobatoid teeth in the Mesaverde Formation sample from all stratigraphic levels are generally smooth-crowned (Figure 1A), most similar to teeth of *Pseudomyledphus* and *Cristomylus*, which strongly suggests an age of middle Campanian or older (Kirkland et al., 2013).

A middle Campanian age hypothesis for the Mesaverde Formation in the Bighorn Basin of Wyoming highlights the importance of this unit for filling a knowledge gap in faunal evolution of Laramidia. To the north, the Mesaverde Formation is most likely correlative with the Foremost Formation, and lower parts of the Two Medicine and Judith River formations. To the south, the Mesaverde Formation is most likely correlative with the Wahweap, lower part of the Aguja, and upper part of the Menefee formations. Considerable work remains to revise, identify, and interpret microvertebrate assemblages in the Mesaverde Formation, in addition to collection of associated dinosaur material.

Acknowledgments

All fieldwork was completed under permit from the US Bureau of Land Management-Wyoming (permits PA19-WY-276, PA21-WY-288, PA21-WY-289); B. Breithaupt, G. Hurley, and B. Wade assisted with permitting and field logistics. Funding was provided by the David B. Jones Foundation and the Augustyn Family Research Fund. I am grateful to student collaborators from The Webb Schools who have undertaken much of the basic specimen identification, particularly L. Causley, E. Chai, C. Deng, A. Fu, D. Hu, T. Hu, V. Gonzalez, O. Ochuru, M. Raphael, K. Sirimontaporn, M. Stallings, P. Sun, Z. Wang, K. Wu, S. Zeiden, and J. Zeng, as well as volunteers, faculty and staff from Webb and the Alf Museum, for fieldwork assistance. J. Heuck and B. Jorgensen have been invaluable in fossil preparation and curation. Discussions and/or ongoing collaborations with A. Bell, D. DeMar, T. Harper, J. Kirkland, T. Tobin, L. Weaver, and H. Wooley have been helpful in identifying many specimens and clarifying stratigraphy.

References

Brinkman, D. B. (2003). A review of nonmarine turtles from the Late Cretaceous of Alberta. *Canadian Journal of Earth Sciences, 40*, 557-71.

Case, G. R. (1987). A new selachian fauna from the Late Campanian of Wyoming (Teapot Sandstone Member, Mesaverde Formation, Big Horn Basin). *Palaeontographica, A Paläozoologie, Stratigraphie, 197*, 1-37.

Clemens, W. A., & Lillegraven, J. A. (1986). New Late Cretaceous, North American advanced therian mammals that fit neither the marsupial nor eutherian molds. *Contributions to Geology University of Wyoming Special Papers, 3*, 55-85.

DeMar Jr, D. G., & Breithaupt, B. H. (2006). The non-mammalian vertebrate microfossil assemblages of the Mesaverde Formation (Upper Cretaceous, Campanian) of the Wind River and Bighorn basins, Wyoming. *Bulletin of the New Mexico Museum of Natural History and Science, 35*, 33-53.

DeMar Jr, D. G., & Breithaupt, B. H. (2008). Terrestrial and aquatic vertebrate paleocommunities of the

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Mesaverde Formation (Upper Cretaceous, Campanian) of the Wind River and Bighorn Basins, Wyoming, USA. In J. T. Sankey, & S. Baszio (Eds.), *Vertebrate microfossil assemblages: Their role in paleoecology and paleobiogeography* (pp. 78-103). Indiana University Press.

Joyce, W. G., Chapman, S. D., Moody, R. T., & Walker, C. A. (2011). The skull of the solemydid turtle *Helochelydra nopcsai* from the Early Cretaceous of the Isle of Wight (UK) and a review of Solemydidae. *Special Papers in Palaeontology, 86*, 75-97.

Kirkland, J. I., Eaton, J. G., & Brinkman, D. B. (2013). Elasmobranchs from upper Cretaceous freshwater facies in southern Utah. In A. L. Titus, & M. A. Loewen (Eds.), *At the top of the Grand Staircase: The Late Cretaceous of southern Utah* (pp. 153-194). Indiana University Press.

Lillegraven, J. A., & McKenna, M. C. (1986). Fossil mammals from the "Mesaverde" Formation (Late Cretaceous, Judithian) of the Bighorn and Wind River basins, Wyoming: with definitions of Late Cretaceous North American land-mammal "ages". *American Museum Novitates, 2840*, 1-68.

Yun, C., & Funston, G. G. (2021). A caenagnathid oviraptorosaur metatarsal from the Mesaverde Formation (Campanian), Wyoming. *Vertebrate Anatomy Morphology Palaeontology, 9*, 105-115.

Poster Session 1 (Thursday, June 8, 2023)

MONGOLIA TO THE WEST COAST OF CALIFORNIA: A POSSIBLE SAUROLOPHINE LARAMIDIA CONNECTION

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Species of *Saurolophus* are from the early Maastrichtian, Late Cretaceous with *Saurolophus osborni* (Brown, 1912), from the Horseshoe Canyon Formation, Alberta Canada and *Saurolophus angustirostris* (Rozhdestvensky, 1952), Nemegt Formation, Mongolia. The Fresno material is from the Late Maastrictatian, Marca Member, Moreno Formation, Rosario Group. late Maastrichtian, Late Cretaceous, *Augustynolophus morrisi* (Prieto-Marquez, et al., 2014). The most distinct feature of *Saurolophus* is a long thin crest. *Saurlophus osborni* has a shorter, taller adult skull than *S. angustirostris*, which has a longer, thinner adult skull. Because these two species are similar, there had to have been a connection from Mongolia to northern North America (Laramidia). This land-bridge allowed other dinosaurs to interact during the Cretaceous; ankylosaurs, theropods, hadrosaurs but oddly, not sauropods.

The vast majority of dinosaurs found in California are from marine sediments. Southern California (e.g., San Diego) has a hadrosaur femur, a partial hadrosaur vertebra, and the ankylosaur *Aletopelta coombsi* (Ford & Kirkland, 2001). Considering plate tectonics, everything west of the San Andreas fault was further south than is generally thought (Ford et al., 1998; Lund & Bottier, 1992; Lund et al., 1991). The San Diego area during the Campanian, Late Cretaceous was down by the southern edge of the current position of Mexico (therefore, this material is actually Mexican, not California). This also makes the Baja California Late Cretaceous dinosaurs the furthest south North American (Laramidia) dinosaur fauna.

Further north in the mid-section of California, Fresno County has produced hadrosaur specimens ("*Saurolophus"*) material from the marine Moreno Formation, Late Maastrichtian, Late Cretaceous. Since this area is on the east side of the San Andreas Fault, the material is in the general area where it was during the Late Cretaceous, making them true California (Laramidia)/west coast dinosaurs.

Chester Stock (1939, 1941, 1948) reported on two 'duckbill' dinosaurs from the Panoche-Tumey Hills area, the western part of Fresno County, California. A third specimen was discovered by Bennison and is at the University of California Museum of Paleontology at Berkeley (Hesse & Welles, 1936; Morris, 1973).

The California Institute of Technology collected the hadrosaurs, and the Los Angeles County Museum of Natural History acquired them (LACM [CIT] 2852, LACM [CIT] 2760) (Morris, 1973). The LACM [CIT] 2852 skull is incomplete, missing the most distinctive feature, the nasal crest. The two specimens are from different localities, LACM 2852 is an adult from LACM Locality CIT 357, and LACM 2760 is a juvenile from LACM locality CIT 336.

The LACM material has been studied and described by several authors and has been referred to hadrosauridae (Hesse & Welles, 1936), hadrosaurian (Stock, 1939, 1941), cf. *Saurolophus* sp (Morris, 1973), *Saurolophus* (Ford, 1999), hadrosaurinae gen. sp indet (Bell & Evans, 2010), *Saurolophus morrisi* (Prieto-Marquez & Wagner, 2013), and *Augustynolophus morrisi* (Prieto-Marquez et al., 2014). Even though LACM 2852 and 2760 were found in different localities, they are generally believed to belong to the same genus. However, LACM 2852 is an adult, and LACM 2760 is a juvenile and could very well belong to a different genus or possibly be a lambeosaurian?. It is beyond the scope of this research to redescribe this material, only compare the material to the Mongolian and Alberta, Canada *Saurolophus* material and infer possible paleogeographic distribution of *Saurolophus* saurolophine hadrosaurs.

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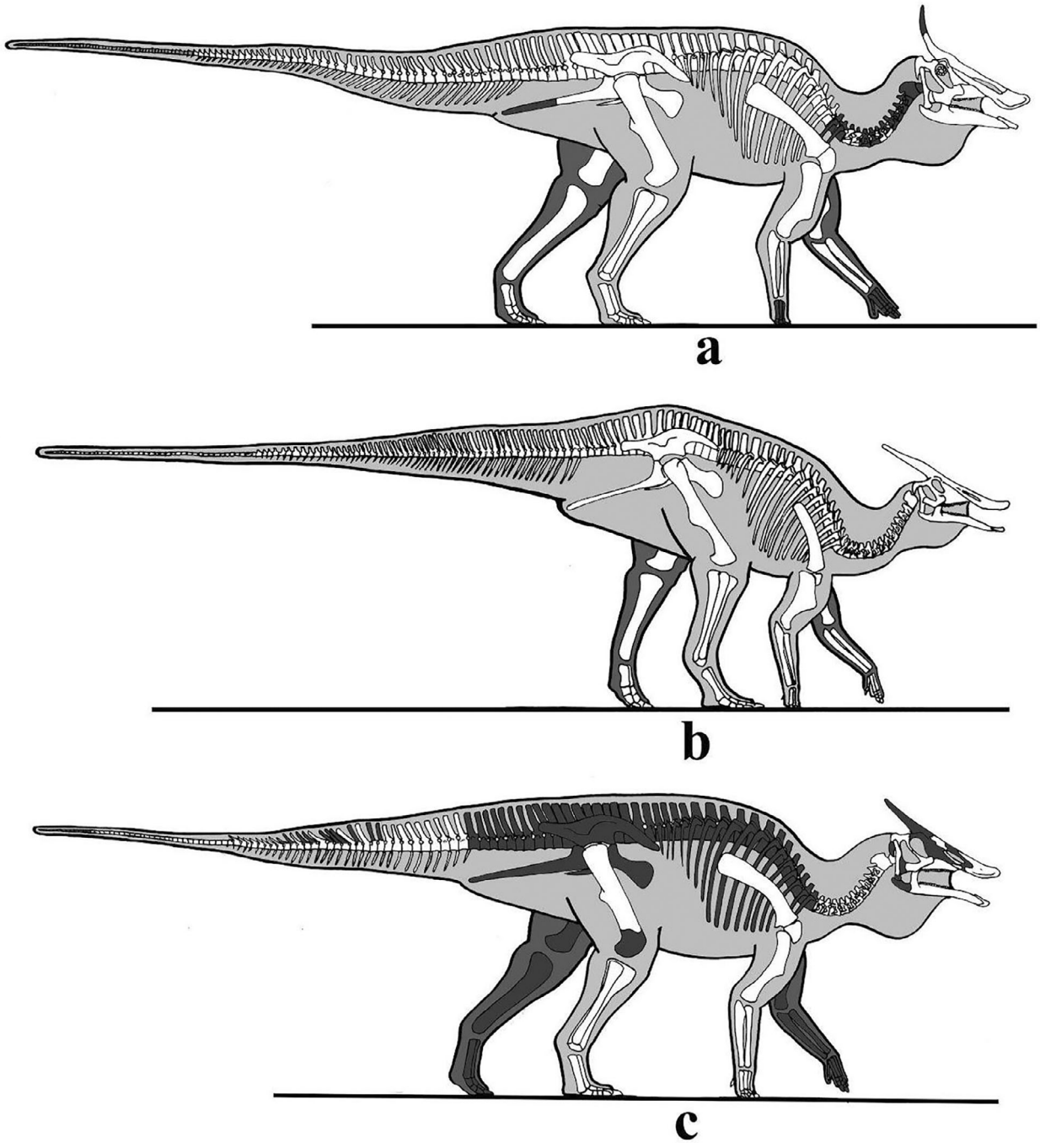


Figure 1. Skeletons of saurolophines, dark gray is missing elements. (a) *Saurolophus osborni*, composite with holotype and referred tail (in light gray), (b) *Saurlophus angustirostris* and (c) *Augustynolophus morrisi*.

Augustynolophus LACM 2852 individual skull elements are laterally compressed, and not well preserved, and the predentary is flipped vertically so that the ventral side is lateral. This may be due to preparation rather than preservation, and the dentary may have been longer and is missing a portion. Unfortunately, the crest is missing though some of the skull and dentary are known and show more similarities to *S. angustirostris* than *S. osborni*. The jugal in *Augustynolophus* has a straighter lower edge, similar to some specimens of *S. angustirostris*, while *S. osborni* has a more indented lower edge. The quadrate in *Augustynolophus* is thin, more similar to *S. angustirostris* than *S. osborni*. The postorbital in *Augustynolophus* lacks the Y-shape seen in *S. angustirostris* and *S. osborni*. The dentary of *Augustynolophus* is long and thin, more similar to that of *S. angustirostris* than to *S. osborni*, which is shorter in comparison.

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The tail in *S. angustirostris* is extremely long; where the neural spines and chevrons end, the caudal centra continues, and the tip of the tail is 'whip-like'. This is similar to that found in *Augustynolophus*, however, in *S. osborni* it is unknown if the caudal centra were similar because the mounted holotype skeleton at the American Museum of Natural History ends where the neural spine and chevron ends, however, the caudal centrum does not end in a point, and it is possible that it also had a 'whip-like tail' based on a referred specimen (AMNH 5271) which lacks a skull does indicate it also had a long 'whip-like' tail (Bell, 2012). This is not distinct for *Saurolophus*; a long 'whip-like' tail is also found in an *Edmontosaurus* (*Anatosaurus*) specimen (pers observation) and a juvenile *Brachycephalosaurus* specimen at Malta, Montana (pers. observation) (Ford, 2008).

Saurolophus osborni type skull (AMNH 5220) orbital area has a large orbital ridge (ridge over the orbit). *Edmontosaurus regailis* (CMN 2288, CNHM P15003) has a more extensive orbital ridge (Ford, 2008), while *Saurolophus angustirostris* has a much shallower orbital ridge. It is unknown what kind of orbital ridge *Augustynolophus* had or how large its nasal crest was. The nasal crest in *S. osborni* is broken off and could have been much larger, possibly as long as some adult *Saurolophus angustirostris* specimens.

It is here theorized that *Saurolophus* crossed from Mongolia, through northern Russia, across the Bering Strait into North America (e.g., Laramidia). Several dinosaur families have been found in Asia and North America from middle to late Cretaceous: ankylosaurids, theropods, and ornithopods. Saurolophine *Saurlophus angustirostris* (early Maastrichtian) predecessor made this trek from Mongolia, across the bearing strait and continued along the west coast of North America (Laramidia) and down to the mid-section of California during the late Maastrichtian to where *Augustynolophus* was discovered. *Saurolophus osborni* has far more differences with *Augustynolophus* than *S. angustirostris* therefore *Augustynolophus* did not have an Albertian connection. The question is could other dinosaurs from Mongolia have followed *Saurolophus* to the West Coast of California? Only more research can answer this.

References

Bell, P. R. (2012). Standardized terminology and potential taxonomic utility for hadrosaurid skin impressions: a case study for *Saurolophus* from Canada and Mongolia. *PLoS One, 7*, e31295.

Bell. P. R., & Evans, D. C. (2010). Revision of the status of *Saurolophus* (Hadrosauridae) from California, USA. *Canadian Journal of Earth Sciences, 47*, 1417-1426.

Brown, B. (1912). A crested dinosaur from the Edmonton Cretaceous. *Bulletin of the American Museum of Natural History, 31*, 131-136.

Ford, T. L. (1999). A review of the Hadrosaurs from California. In R. D. McCord, & D. Boaz (Eds.), *Southwest Paleontological Symposium-Proceedings 1999. Mesa Southwest Museum Bulletin, 6*, 59-60.

Ford, T. L. (2008). How to draw dinosaurs: Hadrosaurs revisited. *Prehistoric Times, 85*, 18-19.

Ford, T. L., & Kirkland, J. I. (2001). Carlsbad ankylosaur (Ornithischia, Ankylosauria): an ankylosaurid and not a nodosaurid. In E. Carpenter (Ed.), *The armored dinosaurs* (pp. 239-260). Indiana University Press.

Ford, T. L., Kirkland, J. I., & Elder, W. P. (1998). The surfing nodosaur or riding up the Pacific Plate. In D. L. Wolberg, K. Gittis, S. Miller, L. Carey, & R. Raynor (Eds.), *The Dinofest Symposium* (pp. 16-17). The Academy of Natural Sciences Philadelphia.

Hesse, C. J., & Welles, S. P. (1936). The first record of a dinosaur from the West Coast. *Science, 84*, 157-158.

Lund, S. P., & Bottjer, D. J. (1992). Paleomagnetic evidence for microplate tectonic development of southern and Baja California. In J. B. Dauphin, & B. R. Simoneit (Eds.), *The Gulf and peninsular province of the Californias. American Association of Petroleum Geologists Memoir, 47*, 231-248.

Lund. S. P., Bottjer, D. J., Whiddne, K. J., Powers, J. E., & Steele, M. C. (1991). Paleomagnetic evidence for Paleogene Terrance displacements and accretion in southern California. In P. L. Abbot, & J. A. May (Eds.), *Eocene geologic history of San Diego Region. Pacific Section. Society of Economic Paleontology and Mineralogy, 68*, 99-106.

Morris, W. J. (1973). A review of Pacific Coast hadrosaurs. *Journal of Paleontology, 47*(3), 551-561.

Prieto-Marquez, A., & Wagner, J. R. (2013). A new species of saurolophine hadrosaurid dinosaur from the Late Cretaceous of the Pacific coast of North America. *Acta Palaeontologica Polonica, 58*(2), 255-268.

Prieto-Marquez, A., Wagner, J. R., Bell, P. R., & Chiappe, L. M. (2015). The late-surviving 'duck-billed' dinosaur *Augustynolophus* from the Upper Maastrichtian of western North America and crest evolution in saurolophini. *Geological Magazine, 152*(2), 225-241.

Rozhdestvensky, A. K. (1952). A new representative of duck-billed dinosaurs from the Upper Cretaceous deposits of Mongolia. *Doklandy Akadamie Nauk SSSR, 86* (2), 405-408.

Stock, C. (1939). Occurrence of Cretaceous reptiles in the Moreno Shales of the Southern Coast Ranges, California. *Proceedings of the National Academy of Sciences, 25*, 617-620.

Stock, C. (1941). Duckbill dinosaur from the Upper Cretaceous of the San Joaquin Valley. *Bulletin of the Geological Society of America, 52*, 1956.

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Stock, C. (1948). Occurrence of dinosaurs in the Upper Cretaceous of California. *Yearbook of the American Philosophical Society, 147*, 133.

Poster Session 1 (Thursday, June 8, 2023)

PRELIMINARY WATER OXYGEN ISOTOPIC LANDSCAPE OF THE EARLY CRETACEOUS IMPLIES PRONOUNCED LATITUDINALLY INDUCED RAINOUT EFFECT

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Oxygen isotopes are heavily influenced by the water cycle and as such vary strongly with elevation, latitude, proximity to the ocean (which has a very distinct isotopic signature), and vital effects in organisms (the effects of metabolism and diet of organisms). The hydrologic cycle and the oxygen isotopic distribution of North America during the Cretaceous were heavily influenced by a pronounced latitudinal effect as a result of increased latent heat transport to the poles via an intensified hydrologic cycle. Analyses of oxygen isotopic composition of pedogenic siderite and carbonate nodules as well as phosphate in turtle bones have shown a significant rainout effect was present in North America during the late Early Cretaceous (Aptian to Cenomanian) (Suarez et al., 2021 and references therein).

A simple plot of paleolatitude and oxygen isotopic composition of precipitation and/or groundwater shows negative correlation, implying northern latitudes have increasingly more negative O-isotope values; however, this may hide other processes that a 2D representation would better represent. A method to provide a secondary check on the aforementioned negative correlation for the Cretaceous is by analyzing the spatial pattern with geostatistics, specifically kriging. Kriging and geostatistics are subset of statistics applied to spatial phenomena where you are predicting or 'modeling' the values in between sampled or known values from specific locations. These statistics rely on the concept of spatial autocorrelation.

Spatial autocorrelation is the concept that the value of points that are closer to each other will be more similar than points further away. For this project, a preliminary terrestrial isotopic landscape or 'isoscape' of North America will be generated using kriging on interpreted water oxygen isotopic values as they should exhibit spatial autocorrelation. This will produce predicted oxygen isotopic values of water for places where there are no sampled points either due to no water values being present or simply being inaccessible for collection (Bowen, 2010). Using Empirical Bayesian Kriging through ArcGIS Pro software, the Cretaceous of North America appears to have a distribution that corroborates the previous finding of a pronounced latitudinal effect (Suarez et al., 2021). Empirical Bayesian Kriging through ArcGIS Pro was chosen because of its strengths in analyzing smaller datasets (<100 points).

The distribution of oxygen isotopic values within various water samples collected in modern-day Mexico was also analyzed as Mexico provides an excellent modern-day representation of Laramidia during the Early Cretaceous (Reynaga et al., 2021). There are many similarities between the two, for example both have or had the Pacific Ocean on the western side of the continent and a relatively shallow seaway or ocean on the eastern side. In the Cretaceous, Laramidia (western present day United States) was bordered by the Western Interior Seaway on the east. The Western Interior Seaway was present in the mid-continent covering what is now the central U.S.

While the Cretaceous data from North America produced a pronounced latitudinal effect, the data from modern-day Mexico exhibits a strong correlation with orographic effects showing the majority of the lightest values plotting within the Sierra Madre Occidental and Sierra Madre Oriental mountain ranges as well as in the Trans-Mexican Volcanic Belt. The preliminary isoscapes are shown in Figure 1A and Figure 1B. The differences between the two may highlight an effect of time averaging as the Cretaceous samples span ~25 Ma from oldest to youngest analyzed (majority of the data from Suarez et al., 2021). A latitudinal effect may have been the dominant effect due to its constant presence unlike orographic effects which may not have had a lasting effect that could be documented at a high enough temporal/spatial resolution and may explain the difference is oxygen isotopic values between modern Mexico and Cretaceous of North America. To potentially elucidate finer scale processes, additional sample collection and cataloging are currently being undertaken. In future iterations of this isoscape, higher resolution analysis of both the temporal and spatial realms can be created with the addition of more sampled locations and dates and could provide a glimpse into the finer scale processes of the oxygen isotope spatial distribution in Cretaceous North America.

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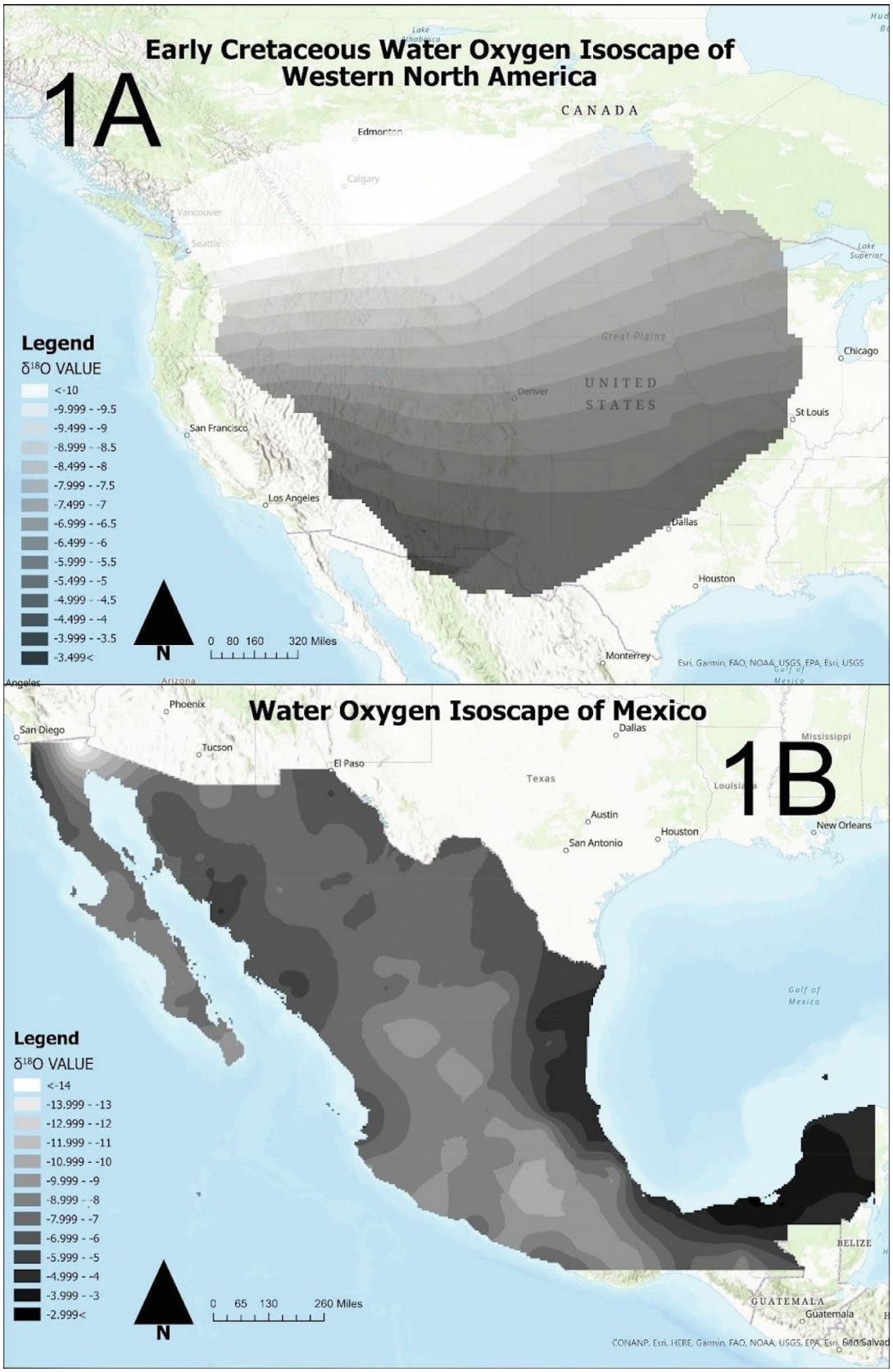


Figure 1. (A) A preliminary version of the Early Cretaceous water oxygen isoscape with distinct bands that are nearly parallel with paleolatitudes of the Early Cretaceous. Lighter colors are more negative oxygen isotope values and darker colors are heavier oxygen isotope values. (B) A water oxygen isoscape of present-day Mexico. Lighter colors are more negative oxygen isotope values and darker colors are heavier oxygen isotope values.

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References

Bowen, G. J. (2010). Isoscapes: Spatial pattern in isotopic biogeochemistry. *Annual Review of Earth and Planetary Sciences, 38*, 161-187.

Reynaga, D. K. M., Millaire, J.-F., Balderas, X. C., Berrelleza, J. A. R., Luján, L. L., & Longstaffe, F. J. (2021). Building Mexican isoscapes: Oxygen and hydrogen isotope data of meteoric water sampled across Mexico. *Data in Brief, 36*, 107084.

Suarez, C. A., Frucci, M. N., Tompkins, T. B., & Suarez, M. B. (2021). Quantification of a North American greenhouse hydrological cycle: using oxygen isotopic composition of phosphate from Early Cretaceous (Aptian–Albian) turtles. *Geological Society of London Special Publications, 507*, 335-345.

Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 3:15 PM)

PRELIMINARY OBSERVATIONS ON THE JURASSIC SALAD BAR, A NEW GINKGOPHYTE-DOMINATED FLORA FROM THE UPPER JURASSIC MORRISON FORMATION IN SOUTHEASTERN UTAH, USA

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1 INTRODUCTION

The Upper Jurassic Morrison Formation in western North America contains many plant localities of silicified wood and fragmentary leaves, but diverse floras with identifiable and abundant taxa in leaf mats are comparatively rare. Here we report on a new ginkgophyte-dominated flora from the middle Brushy Basin Member of Utah with diverse species in leaf mats.

The new fossil plant assemblage, called the Jurassic Salad Bar (Kirkland et al., 2022), was discovered in 2016 and contains an abundant and species-rich flora consisting of ferns, a horsetail, a seed fern, four types of ginkgophytes, a cycadophyte, and up to six different types of conifers. The fossil plant collection occupies more than 450 catalog numbers in the collections of the Utah Field House of Natural History State Park Museum (FHPR), although the total number of plant remains gathered so far probably exceeds 1000. In addition, the site preserves conchostracans, crayfish, insects such as a nepomorph (Lara et al., 2020), caddisflies, and a beetle, as well as fish and amphibians (Foster et al., 2022).

Abbreviations: FHPR, Utah Field House of Natural History State Park Museum, Vernal, Utah, USA

2 GEOLOGIC SETTING

The Jurassic Salad Bar site, hereafter JSB, consists of a 30-cm layer of soft, finely-laminated light gray (2.5Y 7/1) shale with the fossil plant material. The best preserved material occurs in leaf mats in a 5–10 cm thick central zone, which can also contain abundant, thin gypsum layering above and below the leaf mats, along with fine-grained sulfur. The site probably represents a freshwater pond or small lake deposit. Above and below the plant layer are several meters of gray, smectitic mudstone. The fossiliferous deposit occurs approximately in the middle of the approximately 80 m-thick section of the Brushy Basin Member in southeastern Utah (Kirkland et al., 2020).

3 PALEOFLORA

The JSB flora (Figure 1) contains a single, narrow shoot of *Equisetum* (Figure 1a). Ferns appear to be represented by several types, but only *Coniopteris* spp. (Figure 1b, d) and *Sphenopteris* (Figure 1c) have been identified so far. There is rare, scrappy material of a seed fern. Among the ginkgophytes, *Czekanowskia turneri* (Figure 1g) is common and occurs as leaf bundles with scales near their base. *Ginkgoites cascadensis* (Figure 1f) represents the first occurrence of this species in the southern part of the Morrison Formation, located well south of the *G. ginkgoites* type area at Belt, Montana. *Sphenobaiera* and *Eretmophyllum*-like leaves (Figure 1e) represent the first occurrences of these taxa in the Morrison Formation. A single specimen of *Nilssonia* sp. (Figure 1h) represents the only confirmed cycadophyte at the locality so far. Two types of conifers are particularly abundant: a highly branched form of *Brachyphyllum* and a second, new type of twig with distinctive, spade-shaped leaves that split upon disintegration into narrow, longitudinally aligned segments (Figure 1i). Additionally, up to four more types of conifers may be represented in the flora in low numbers.

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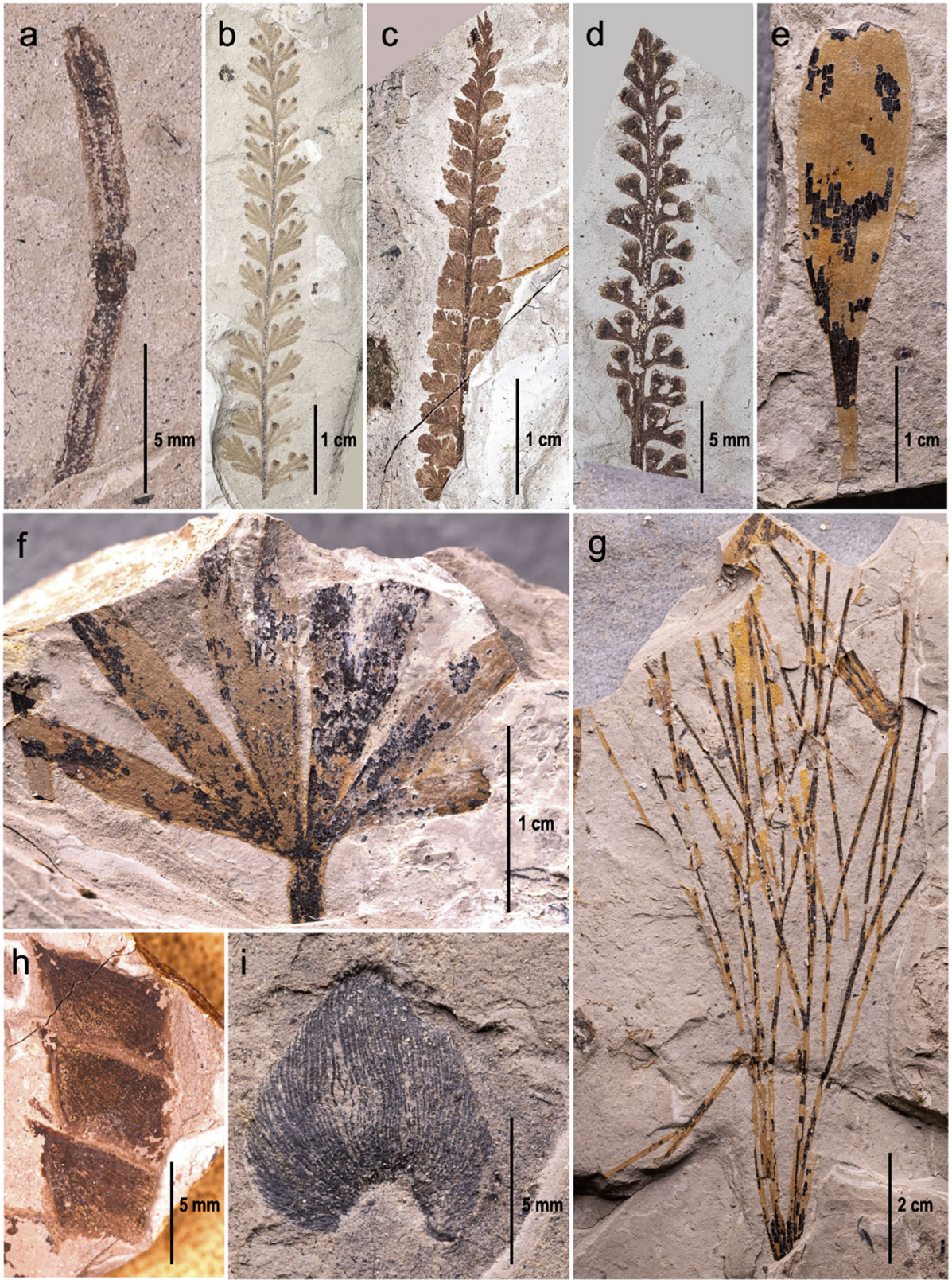


Figure 1. Selected representatives of the Jurassic Salad Bar flora from the Upper Jurassic Morrison Formation of southeastern Utah. **a)** *Equisetum* sp., shoot, FHPR 18293. **b)** *Coniopteris* sp., fertile pinna, FHPR 10529. **c)** *Sphenopteris* sp., sterile pinna, FHPR 15839. **d)** *Coniopteris* sp., fertile pinna of different form from b)., FHPR 10875. **e)** *Eretmophyllum*-like ginkgophyte, leaf, FHPR 16560. **f)** *Ginkgoites cascadensis*, leaf, FHPR 16525. **g)** *Czekanowskia turneri*, leaf bundle, FHPR 10522. **h)** *Nilssonia* sp., three pinnae of a frond, FHPR 10765. **i)** Undetermined conifer, leaf, FHPR 10060.

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4 DISCUSSION

Interestingly, most elements of the JSB flora are shared at the genus or even species level with the higher latitude sites in the Morrison Formation at Belt in Montana, USA, or in the coeval Kootenai Formation in British Columbia and Alberta, Canada. *Equisetum*, *Coniopteris*, *Ginkgoites cascadensis*, and *Nilssonia* are found in Montana, while *Equisetum*, *Coniopteris*, *Sphenopteris*, *Ginkgoites*, *Czekanowskia*, and *Nilssonia* also occur in the Kootenai Formation. It is also noteworthy that fossil evidence of the Araucariaceae, a conifer family that is so common elsewhere in Morrison Formation of Utah and Wyoming in regard to cones and leaves (Gee & Tidwell, 2010; Gee et al., 2014), and wood (Gee, unpub. work on fossil araucariaceous wood in Wyoming, 2020; Gee et al., 2019, 2022; Sprinkel et al., 2019;) have not yet been confirmed.

A ginkgophyte-dominated flora growing around a freshwater pond or small lake likely reflects the recognition of a new plant community in the Upper Jurassic Morrison Formation. While the pollen and spore flora from this site is quite different from the JSB compression flora, it is because the palynoflora reflects the regional flora (Hotton & Baghai-Riding, this volume), whereas the taxonomic composition of the compression flora from the same site represents the local flora growing in the vicinity of the depositional site, likely on the shores of a pond or small lake. The JSB flora, in its abundance and biodiversity of ginkgophytes, differs from other plant communities described from the Morrison Formation, such as the tall-tree, *Araucaria*-dominated forest along the shores of a meandering river in northcentral Wyoming (Gee, unpub. work; Gee & Tidwell, 2010), the tall-tree araucariaceous forest on a low-energy floodplain environment in northeastern Utah (Gee et al., 2019; Sprinkel et al., 2019), and the fern-dominated wetland in southcentral Colorado (Temple Canyon; Gorman et al., 2008).

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References

Foster, J. R., Hunt, A. P., & Kirkland, J. I. (2022). Significance of a small regurgitalite containing lissamphibian bones, from the Morrison Formation (Upper Jurassic), within a diverse plant locality deposit in southeastern Utah, USA. *Palaios*, *37*, 433-442.

Gee, C. T. (2020). The conifer forests of the "Jurassic Park" in western North America, Section 6.5. In C. T. Gee (Ed.), Unit 6, Postcards from the Mesozoic: Forest landscapes with giant flowering trees, enigmatic seed ferns, and other naked-seed plants. In E. Martinetto, E. Tschopp, & R. A. Gastaldo (Eds.), *Nature through time: Virtual field trips through the nature of the past* (pp. 165-169). Springer Nature Switzerland AG.

Gee, C. T., Dayvault, R. D., Stockey, R. A, & Tidwell, W. D. (2014). Greater paleobiodiversity in conifer seed cones in the Upper Jurassic Morrison Formation of Utah, USA. *Palaeobiodiversity and Palaeoenvironments*, *94*, 363-365.

Gee, C. T., Sprinkel, D. A., Bennis, M. B., & Gray, D. E. (2019). Silicified logs of *Agathoxylon hoodii* (Tidwell et Medlyn) comb. nov. from Rainbow Draw, near Dinosaur National Monument, Uintah County, Utah, USA, and their implications for araucariaceous conifer forests in the Upper Jurassic Morrison Formation. *Geology of the Intermountain West*, *6*, 77-92.

Gee, C. T., Xie, A., & Zajonz, J. (2022). Multitrophic plant–insect–fungal interactions across 150 million years: A giant *Agathoxylon* tree, ancient wood-boring beetles and fungi from the Morrison Formation of NE Utah, and the brood of an extant orchard mason bee. *Review of Palaeobotany and Palynology*, *300*, 104627.

Gorman, M. A., II, Miller, I. M., Pardo, J. D., & Small, B. J. (2008). Plants, fish, turtles, and insects from the Morrison Formation: A Late Jurassic ecosystem near Cañon City, Colorado. *Geological Society of America, Field Guide, 10*, 295-310.

Hotton, C. L., & Riding-Baghai, N. L. (This volume). Contrast between the palynoflora and megaflora in the Jurassic Salad Bar Site, Utah, USA: Implications for the regional flora. *The Anatomical Record*.

Kirkland, J. I., DeBlieux, D. D., Hunt-Foster, R. K., Foster, J. R., Trujillo, K. C., & Finzel, E. (2020). The Morrison Formation and its bounding strata on the western side of the Blanding Basin, San Juan County, Utah. *Geology of the Intermountain West*, *7*, 137-195. doi: 10.31711/giw.v7.pp137-195.

Kirkland, J. I., Foster, J. R., DeBlieux, D. D., & Hunt-Foster, R. K. (2022). New discoveries of Morrison Formation plant fossils expand our knowledge of Jurassic ecosystems. *Utah Geological Survey: Survey Notes*, *54*(2), 6-7. https://ugspub.nr.utah.gov/publications/survey_notes/snt54-2.pdf

Lara, M. B., Foster, J. R., Kirkland, J. I., & Howells, T. F. (2020). First fossil true water bugs (Heteroptera, Nepomorpha) from Upper Jurassic strata of North America

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(Morrison Formation, southeastern Utah). *Historical Biology*, *33*, 1996-2004.
Sprinkel, D. A., Bennis, M. B., Gray, D. E., & Gee, C. T. (2019). Stratigraphic setting of Morrison Formation (Upper Jurassic) permineralized wood sites near Dinosaur National Monument, Uintah County, Utah. *Geology of the Intermountain West*, *6*, 61-76, A1-A5.

Poster Session 2 associated with the Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023)

FIRST REPORT ON THE TURTLE ISLAND FLORA, A NEW UPPER JURASSIC PLANT ASSEMBLAGE FROM THE MORRISON FORMATION OF NORTHEASTERN UTAH, USA

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1 INTRODUCTION

We introduce a new fern-dominated flora from the Upper Jurassic Morrison Formation in northeastern Utah, USA. The fossil flora originates from an "island" or peninsula of land in a reservoir north of the city of Vernal that is emergent during low-water levels and which produced vertebrate material including a piece of turtle shell, hence the assemblage's name of "Turtle Island flora." The fossil flora consists of coalified compressions, mostly leaves, some with cuticle. The fossiliferous deposit itself was first discovered in the late 1980s when plant material identified as gymnosperms was collected on several visits from 1988–1991 by Alden Hamblin, Sue Ann Bilbey, Sid Ash, Fred Ziegler, Fred Peterson, and Christine Turner (Utah Field House records, accession 2022.26). Re-collecting at the site in the past three years has yielded at least nine species, including a horsetail, ferns, a cycadophyte, ginkgophytes, and conifers.

The Morrison Formation is a terrestrial-freshwater deposit of mudstone, sandstone, and minor carbonates that is exposed in eight states of the Rocky Mountain region of the western USA. The formation is subdivided into several members on the Colorado Plateau, the most widespread of these being, in ascending order, the Tidwell, Salt Wash, and Brushy Basin members (Kirkland et al., 2020). The Morrison Formation is best known for its abundant and diverse dinosaur communities including sauropods, theropods, stegosaurs, and others (Foster, 2020).

Fossil plant localities have historically been less well known in the Morrison Formation, but this is likely due to a lack of concerted exploration for these sites as compared to efforts to collect dinosaurs (Gee et al., 2019). There are currently more than 150 known plant localities in the Morrison Formation (Foster, unpub. data), and these sites indicate a diversity of ferns, cycads, ginkgoes, and conifers (Ash & Tidwell, 1998; Gee, 2020). In addition, there is an abundance of cones (Gee & Tidwell, 2010; Gee et al., 2014), as well as silicified wood and fossil logs (see recent summary by Gee, this volume). These macrofossil leaf and wood localities are known from a range of stratigraphic levels and geographic regions of the formation, from the Tidwell and lower Salt Wash members to the upper Brushy Basin Member, and ranging geographically from New Mexico up to central Montana. Although plant localities are common, sites that preserve leaf mats with multiple specimens of several identifiable taxa are less abundant. In fact, there are currently seven main "large" (∼100+ specimen, multitaxic) leaf fossil sites in the Morrison Formation: Belt, Montana (22 species; actually several sites stretching between Belt and Geyser); Como Bluff East, Wyoming (8 species); Temple Canyon, Colorado (11 species); Mygatt-Moore Quarry, Colorado (15 species); Montezuma Creek, Utah (7 species); Jurassic Salad Bar (∼12 species; Foster et al., this volume); and the new site we report here, Turtle Island (9 species). Of these sites, only Belt, Mygatt-Moore, and Montezuma Creek had been reported by 1998; the other four have all been first published since 2005.

Abbreviations: FHPR, Utah Field House of Natural History State Park Museum, Vernal, Utah, USA

2 LOCALITY AND GEOLOGIC SETTING

The Turtle Island site was found in the late 1980s (FHPR accession files 2022.26) but was not worked seriously for plant material until recently. The site is located on the shores of the reservoir in Red Fleet State Park 24 km (15 miles) northeast of Vernal, Utah. Collecting is only possible when water levels in the reservoir are low, and the site is wholly under water when the reservoir is full.

Stratigraphically, the fossil flora occurs in the lower Brushy Basin Member, which comprises approximately the upper half of the Morrison Formation in this area. The lithology at the site varies from gray to green

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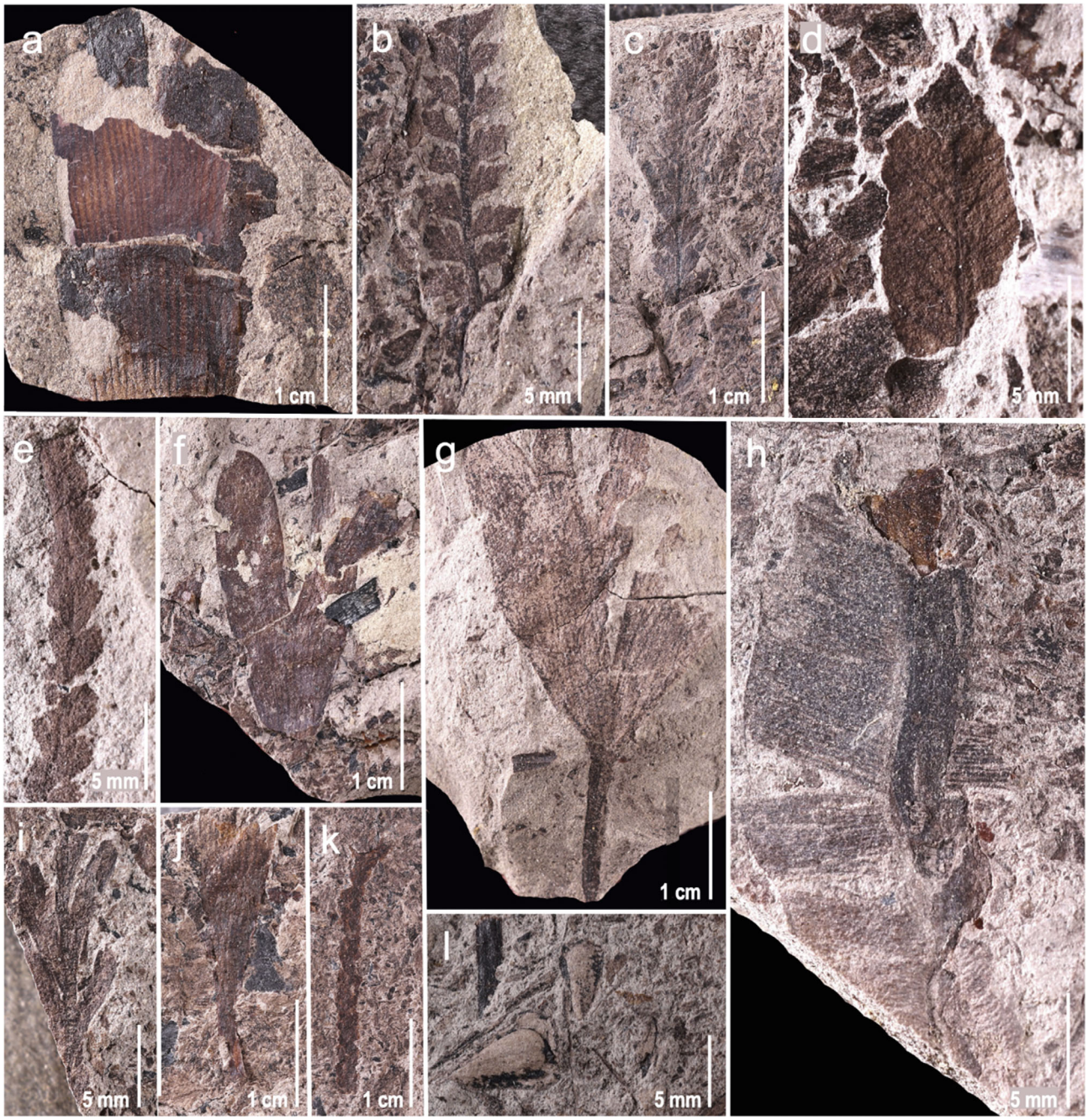


Figure 1. Selected representatives of the Turtle Island flora from the Upper Jurassic Morrison Formation of northeastern Utah. **a)** *Equisetum* sp., fragment of shoot, FHPR 18590. **b)** *Sphenopteris* sp., sterile pinna, FHPR 18541. **c)** *Sphenopteris* sp., sterile pinna, FHPR 18560. **d)** *Cladophlebis* sp., pinnule, FHPR 11264. **e)** Undetermined fern, sterile pinna, FHPR 11262. **f)** Undetermined ginkgophyte, leaf, FHPR 18575. **g)** Undetermined ginkgophyte, leaf, FHPR 18576. **h)** *Nilssonia* sp., partial leaf, FHPR 11265. **i)** Undetermined fern, fragmentary pinna, FHPR 18555. **j)** Undetermined ginkgophyte, partial leaf, FHPR 18563. **k)** Undetermined conifer, twig with leaves, FHPR 18583. **l)** *Araucaria* sp., seed cone scales, FHPR 18584.

mudstone through a mixed interval in the plant-producing zone of about 1 m of gray to dark gray mudstone and into an overlying gray to green mudstone. The section exposed on the peninsula (at low water) is approximately 15 m thick. The plant-producing 1-m-thick interval consists of gray to nearly black carbonaceous mudstone with abundant fragmentary wood and plant remains. Some of the wood is silicified, but most of the wood is carbonized within the mudstone. Identifiable plant remains occur in three ~10 cm layers within the 1 m section, which consist of gray (2.5Y 6/1, fresh) to white (weathered)

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mudstone, and the uppermost of these three layers contains the greatest abundance of intact leaf remains. The greatest abundance of carbonized wood occurs between the lower and middle of the three light-gray identifiable plant-producing layers.

Bones have been found at numerous levels within the Turtle Island outcrop, from a *Barosaurus* cervical at an unknown level and a *Camarasaurus* femur in the lower gray-green mudstone to a turtle shell fragment (*Glyptops*?) and a sauropod humerus in the upper gray-green mudstone. Interestingly, the 1 m-thick plant producing interval has produced numerous dinosaur bones as well. These bones are not well preserved but some are identifiable and they represent a rare occurrence of vertebrate bones in the same layers as fossil plants. Among these bones are limb elements of sauropods, a centrum of a theropod, and two femora of basal neornithischian or dryosaurid dinosaurs.

3 PALEOFLORA

The fossil flora at the site has so far yielded horsetails, abundant ferns, a cycad, ginkgophytes, and conifers (Figure 1). The fossil floral assemblage consists of approximately 117 cataloged specimens. Ferns are numerically dominant in the main layer of plant compressions, whereas carbonized wood dominates the rest of the plant-producing zone.

The paleoflora includes a relatively large piece of a shoot of *Equisetum* with cuticle (Figure 1a). Most common at the site are pinnae of *Sphenopteris* (Figure 1b, c), which are represented by numerous sterile pinnae that are generally similar to those in the Late Jurassic flora from Hope Bay, Antarctica (Gee, 1989). One small pinnule likely represents the fern *Cladophlebis* (Figure 1d). Several other unidentified fern morphotypes are also present (Figure 1e, i), represented by rare single specimens.

Ginkgophytes are represented by petiolate leaves with a deeply lobed lamina (Figure 1f, g, j). Cycadophytes are present in the Turtle Island flora as a single identifiable specimen of *Nilssonia* (Figure 1h). Finally, conifers occur as seed cone scales and detached seeds (Figure 1l) pertaining to *Araurcaria*, as well as slender twigs with short, curved leaves (Figure 1k). Also present are the abundant carbonized wood fragments above and below the leaf mat layer and rare silicified wood from the same interval.

ACKNOWLEDGEMENTS

Thanks to Zachary Nelson and the Bureau of Reclamation (permit #UC-PRPA-2019-001). We are especially grateful to the Utah Department of Natural Resources Division of State Parks for allowing us to conduct field work and to Park Managers Amanda White and Josh Hansen of Red Fleet State Park for logistical support.

References

Ash, S. R., & Tidwell, W. D. (1998). Plant megafossils from the Brushy Basin Member of the Morrison Formation near Montezuma Creek Trading Post, southeastern Utah. *Modern Geology*, *22*, 321-339.

Foster, J. R. (2020). *Jurassic West: The dinosaurs of the Morrison Formation and their world*. Indiana University Press.

Foster, J. R., Gee, C. T., Ash, S. R., & Kirkland, J. I. (This volume). Preliminary observations on the Jurassic Salad Bar, a new ginkgophyte-dominated flora from the Upper Jurassic Morrison Formation in southeastern Utah, USA. *The Anatomical Record*.

Gee, C. T. (1989). Revision of the Late Jurassic/Early Cretaceous flora from Hope Bay, Antarctica. *Palaeontographica B*, *213*, 149-214.

Gee, C. T. (2020). The conifer forests of the "Jurassic Park" in western North America. Section 6.5 in C. T. Gee (chapter editor and coordinator), Unit 6, Postcards from the Mesozoic: Forest landscapes with giant flowering trees, enigmatic seed ferns, and other naked-seed plants. In E. Martinetto, E. Tschopp, & R. A. Gastaldo (Eds.), *Nature through time: Virtual field trips through the nature of the past* (pp. 165-169). Springer Nature Switzerland AG.

Gee, C. T. (This volume). Paleobotany of the Upper Jurassic Morrison Formation: What's new and what's to come? *The Anatomical Record*.

Gee, C. T., Dayvault, R. D., Stockey, R. A., & Tidwell, W. D. (2014). Greater paleobiodiversity in conifer seed cones in the Upper Jurassic Morrison Formation of Utah, USA. *Palaeobiodiversity and Palaeoenvironments*, *94*, 363-365.

Gee, C. T., & Tidwell, W. D. (2010). A mosaic of characters in a new whole-plant *Araucaria*, *A. delevoryasii* Gee sp. nov., from the Late Jurassic Morrison Formation of Wyoming, USA. In C. T. Gee (Ed.) *Plants in Mesozoic time: Morphological innovations, phylogeny, ecosystems* (pp. 67-94). Indiana University Press.

Gee, C. T., Sprinkel, D. A., Bennis, M. B., & Gray, D. A. (2019). Silicified logs of *Agathoxylon hoodii* (Tidwell et Medlyn) comb. nov. from Rainbow Draw, near Vernal, Utah, and their implications for conifer forests in the Late Jurassic Morrison Formation. *Geology of the Intermountain West*, *6*, 77-92.

Kirkland, J. I., DeBlieux, D. D., Hunt-Foster, R. K., Foster, J. R., Trujillo, K. C., & Finzel, E. (2020). The Morrison Formation and its bounding strata on the western side of the Blanding Basin, San Juan County, Utah. *Geology of the Intermountain West*, *7*, 137-195.

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Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 9:00 AM)

A THERIZINOSAUR IN TROODONTID'S CLOTHING? REASSESSING THE TROODONTID *GEMINIRAPTOR SUAREZARUM* IN LIGHT OF NEW THERIZINOSAURIAN MATERIAL FROM THE LOWER CRETACEOUS YELLOW CAT MEMBER OF THE CEDAR MOUNTAIN FORMATION, UTAH, USA

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The Crystal Geyser Quarry (CGQ) is an extensive ∼1 m thick paucispecific bonebed from the Lower Cretaceous (Berriasian-Valenginian; Joeckel et al., 2020) lower Yellow Cat Member of the Cedar Mountain Formation. The CGQ preserves the disarticulated remains of the early-diverging therizinosaurian *Falcarius utahensis* and represents one of the largest maniraptoran bonebeds globally (Figure 1A-B; Kirkland et al., 2005; C. Suarez et al., 2007; M. Suarez et al., 2007; Zanno, 2010). A second bonebed ∼1 km northwest of CGQ, the Suarez Site (SS), represents a second paucispecfic assemblage containing hundreds of therizinosaurian remains, potentially representing a distinct taxon (Kirkland et al., 2016; Zanno et al., 2014). In 2010, an isolated partial maxilla collected from the SS was described and interpreted as a troodontid, *Geminiraptor suarezarum*, the only Early Cretaceous representative of the clade from North America (Figure 1C; Senter et al., 2010). The lack of comparative *F. utahensis* materials from the CGQ available at the time of description and its recovery from a monodominant therizinosaurian site complicated this interpretation. Several discoveries since the initial description of *Geminiraptor*, including troodontids (e.g., Lü et al., 2010; Pei et al., 2017; Tsuihiji et al., 2014), therizinosaurians (Pu et al., 2013), and a recently collected well-preserved *F. utahensis* maxilla from CGQ (Figure 1B), permit a reassessment of *Geminiraptor* in a broader phylogenetic scope.

Several characteristics used to diagnose *Geminiraptor* are present in the new *F. utahensis* maxilla and other therizinosaurians, as well as troodontids. *Geminiraptor* possesses an inflated, pneumatized anterior body of the maxilla, a feature also present in the therizinosaurians *F. utahensis* and *Erlikosaurus*, and the troodontid *Byronosaurus*. The maxillary fenestra is large and elliptical in *Geminiraptor* and many late-branching troodontids, whereas it is large, dorsoventrally taller, and rounded in *F. utahensis* and *Jianchangosaurus*, and greatly reduced in size in *Erlikosaurus*. Other reported diagnostic features of *Geminiraptor* are more widely prevalent in therizinosaurians and troodontids, including craniocaudally narrow promaxillary and interfenestral bars and small, square maxillary alveoli separated by bony septa. Crucially, CT scans of the *Geminiraptor* maxilla reveal previously unknown replacement teeth that possess relatively bulbous, lanceolate, labially convex crowns with minute denticles on both the anterior and posterior carinae. These features of the maxillary dentition are consistent with the primitive therizinosaurs *F. utahensis* (Zanno, 2010) and *Jianchangosaurus* (Pu et al., 2013), and differ from the maxillary dentition of troodontids. Accordingly, we hypothesize that *Geminiraptor*, as well as the remaining material from the SS, belong to a single therizinosaurian taxon.

Despite the geographic and stratigraphic proximity of CGQ and SS, as well as ontogenetic and individual variation within each bonebed, differences in craniodental features suggest the SS therizinosaurian material may be taxonomically distinct from *F. utahensis*. These include a rostrocaudally longer, dorsoventrally lower maxillary profile in lateral view, a dorsoventrally short and elliptical maxillary fenestra, presence of a pneumatic excavation along the rostrodorsal margin of the maxillary fenestra, relatively straight symphyseal aspect of the dentary, reduced recurvature of the dentary teeth, and marked ventral displacement of the medial mandibular condyle of the quadrate.

A principal component analysis using an expanded dataset (Powers et al., 2020) of log-transformed linear measurements recovers substantial overlap in morphospace among troodontids and early-branching therizinosaurians in agreement with morphological similarities (Figure 1E), potentially suggesting broadly similar feeding ecologies, sensory capabilities, or other paleobiological functions. If the proposed interpretation of *Geminiraptor* and the Suarez material as a distinct therizinosaurian holds true, this would add a third potential therizinosaurian taxon to the basal Cedar Mountain Formation (*F. utahensis* and *Martharaptor greenriverensis*) and restrict the definitive occurrences of large-bodied North American troodontids to the latest Cretaceous.

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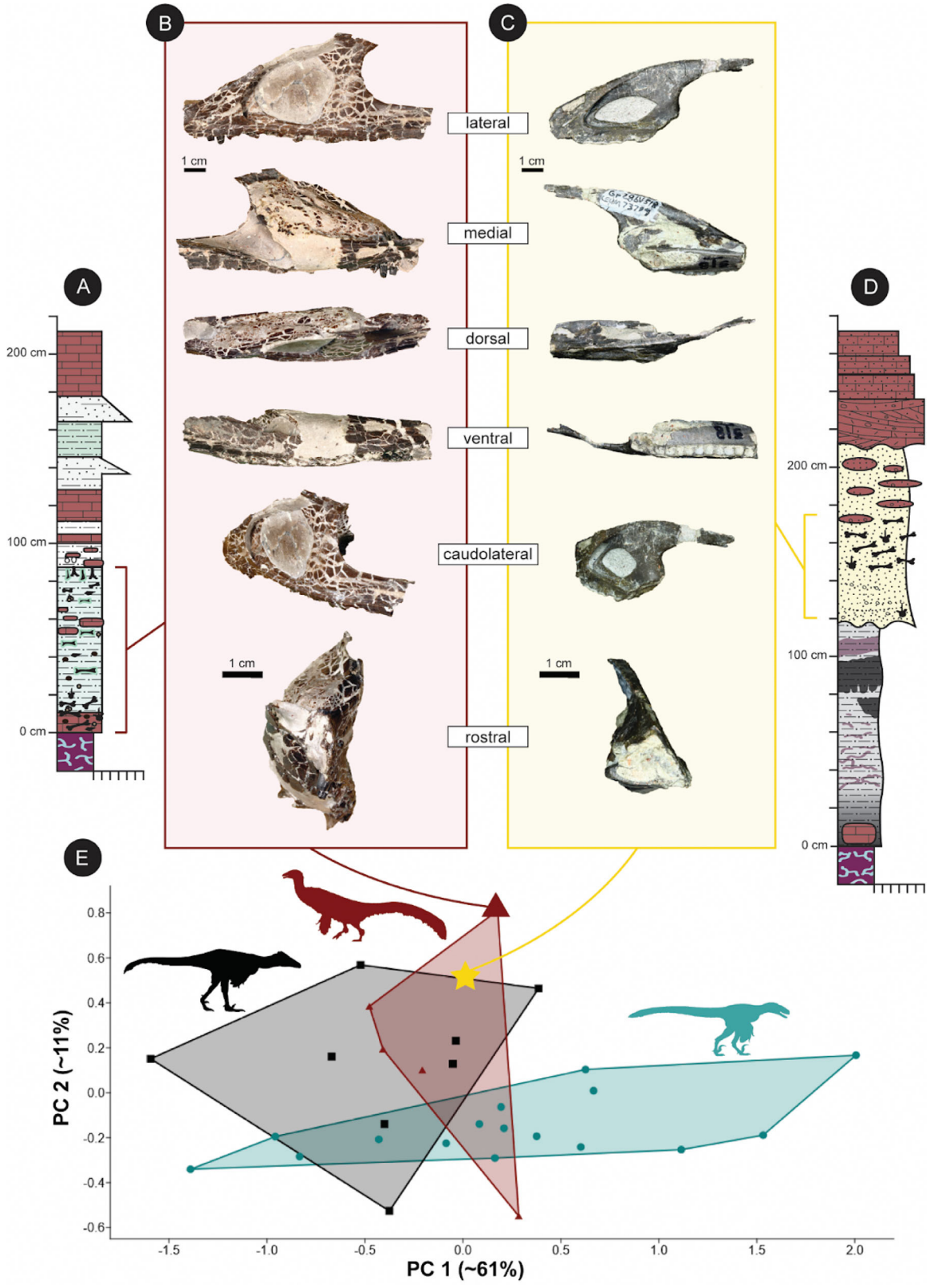


Figure 1. A) Generalized stratigraphic section through the Crystal Geyser Quarry, modified from Suarez et al., (2007a); brackets indicate bone-bearing units. B) Left maxilla of the *Falcarius utahensis*. C) Left maxilla of *Geminiraptor suarezarum*. D) Generalized stratigraphic section through the Suarez Site; brackets indicate bone-bearing units. E) Principal component analysis of different maniraptoran maxillae, including therizinosaurians (red triangles), troodontids (black squares), and dromaeosaurids (teal circles). Note *Falcarius utahensis* (large red triangle) and *Geminiraptor suarezarum* (gold star). Silhouettes modified from originals by: PaleoNeolithic (therizinosaurian), Jason Hogan (troodontid), Mette Aumala (dromaeosaurid).

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References

Joeckel, R. M., Ludvigson, G. A., Möller, A., Hotton, C. L., Suarez, M. B., Suarez,. C A., Sames, B., Kirkland, J. I., & Hendrix, B. (2020). Chronostratigraphy and terrestrial palaeoclimatology of Berriasian–Hauterivian strata of the Cedar Mountain Formation, Utah, USA. *Geological Society of London Special Publications, 498*, 75-100.

Kirkland, J. I., Zanno, L. E., Sampson, S. D., Clark, J. M., & DeBlieux, D. D. (2005). A primitive therizinosauroid dinosaur from the Early Cretaceous of Utah. *Nature, 435*, 84-87.

Kirkland, J., Suarez. M., Suarez, C., & Hunt-Foster, R. (2016). The Lower Cretaceous in East-Central Utah—The Cedar Mountain Formation and its bounding strata. *Geology of the Intermountain West, 3*, 101-228.

Lautenschlager, S., Witmer, L. M., Altangerel, P., Zanno, L. E., & Rayfield, E. J. (2014). Cranial anatomy of *Erlikosaurus andrewsi* (Dinosauria, Therizinosauria): new insights based on digital reconstruction. *Journal of Vertebrate Paleontology, 34*, 1263-1291.

Lü, J., Xu, L., Liu, Y., Zhang, X., Jia, S., & Ji, Q. (2010). A new troodontid theropod from the Late Cretaceous of central China, and the radiation of Asian troodontids. *Acta Palaeontologia Polonica, 55*, 381-388.

Pei, R., Norell, M. A., Barta, D. E., Bever, G. S., Pittman, M., & Xu, X. (2017). Osteology of a new late Cretaceous troodontid specimen from Ukhaa Tolgod, Ömnögovi Aimag, Mongolia. *American Museum Novitates, 3889*, 1-47.

Powers, M. J., Sullivan, C., & Currie, P. J. (2020). Re-examining ratio based premaxillary and maxillary characters in Eudromaeosauria (Dinosauria: Theropoda): Divergent trends in snout morphology between Asian and North American taxa. *Palaeogeography, Palaeoclimatology, Palaeoecology, 547*, 109704.

Pu, H., Kobayashi, Y., Lü, J., Xu, L., Wu, Y., Chang, H., Zhang, J., & Jia, S. (2013). An unusual basal therizinosaur dinosaur with an ornithischian dental arrangement from Northeastern China. *PloS One, 8*, e63423.

Suarez, C. A., Suarez, M. B., Terry Jr, D. O., & Grandstaff, D. E. (2007). Rare earth element geochemistry and taphonomy of the Early Cretaceous Crystal Geyser Dinosaur Quarry, east-central Utah. *Palaios, 22*, 500-512.

Suarez, M. B., Suarez, C. A., Kirkland, J. I., González, L. A., Grandstaff, D. E., & Terry Jr, D. O. (2007). Sedimentology, stratigraphy, and depositional environment of the Crystal Geyser Dinosaur Quarry, east-central Utah. *Palaios, 22*, 513-527.

Senter, P., Kirkland, J. I., Bird, J., & Bartlett, J. A. (2010). A new troodontid theropod dinosaur from the Lower Cretaceous of Utah. *PloS One, 5*, e14329.

Shen, C., Lue, J., Liu, S., Kundrat, M., Brusatte, S. L., & Gao, H. (2017). A new troodontid dinosaur from the Lower Cretaceous Yixian Formation of Liaoning Province, China. *Acta Geologica Sinica, 91*, 763-780.

Tsuihiji, T., Barsbold., R, Watabe, M., Tsogtbaatar, K., Chinzorig, T., Fujiyama, Y., & Suzuki, S. (2014). An exquisitely preserved troodontid theropod with new information on the palatal structure from the Upper Cretaceous of Mongolia. *Naturwissenschaften, 101*, 131-142.

Zanno, L. E. (2010). Osteology of *Falcarius utahensis* (Dinosauria: Theropoda): characterizing the anatomy of basal therizinosaurs. *Zoological Journal of the Linnaean Society, 158*, 196-230.

Zanno, L. E., Kirkland, J. I., & Herzog, L. L. (2014). Second therizinosaurian mass death locality in the Lower Cretaceous Cedar Mountain Formation yields a new taxon. *Journal of Vertebrate Paleontology, Program Abstracts 2014*, 260.

Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 3:00 PM)

PALEOBOTANY OF THE UPPER JURASSIC MORRISON FORMATION: WHAT'S NEW AND WHAT'S TO COME?

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1 A TIMELINE OF PALEOBOTANICAL STUDIES

Never before have so many paleobotanists worked concurrently on the Upper Jurassic Morrison Formation in western North America (Figure 1a). Although brief reports of putative fossil plants from this formation appeared at the turn of the last century (Knowlton, 1907, 1916; Ward, 1900), it is unclear if these paleobotanical remains truly originated from the Upper Jurassic Morrison Formation as defined today (cf. Foster, 2020). In any case, the first detailed taxonomic descriptions of fossil plants, *Cupressinoxylon* wood (Lutz, 1930) and freshwater calcareous charophytes from Wyoming (Peck 1937), appeared nearly a century ago. It was 20 years after that, starting in 1957, when a series of studies on Morrison plants arose (Figure 1a). Among these 10 studies, nearly all major types of plant fossils came under investigation: freshwater calcareous algae (Peck, 1957; Ross, 1960), silicified stems and wood (Arnold, 1962; Medlyn &

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Tidwell, 1975, 1979; Tidwell & Rushforth, 1970), reproductive structures (Bass, 1964; Chandler, 1966), and leaf compressions (Brown, 1972, 1975). The only major group absent was palynomorphs.

Following a curious near-decade-long hiatus in publications from 1980 to 1989, research on the Morrison flora suddenly blossomed in 1990. During the next 32 years, from 1990 to 2022, 26 taxonomic papers on fossil plants would appear. Much of the research momentum was created by W.D. "Don" Tidwell who turned out 14 papers altogether on wood and leaf compression floras from 1970 onwards. In the late 2000's, a new generation of paleobotanists burst on to the research scene. Not only do wood and leaves continue to be of importance, but gymnosperm reproductive structures and pollen floras have also advanced to become major targets of study.

2 WHAT'S NEW

Despite intense research in Morrison paleobotany in the past three decades, there has been no slowdown in the publication rate of taxonomic studies. In fact, nearly all papers appearing in the last nine years concentrate on discovering, excavating, identifying, describing, and naming new fossil plants. Thus, the goal of paleobotanical research in the Morrison Formation is still alpha taxonomy, because there is still so much to discover about Upper Jurassic plant life in western North America.

It goes without saying that the depth and breadth of the Upper Jurassic Morrison flora needs to be completely explored before the patterns in plant species diversity and biogeography can be interpreted and applied to paleoenvironmental or paleoclimatic questions. In other words, it may be still much too early to make general inferences on the Morrison environmental conditions or paleoclimate before a greater understanding of Morrison plant life has been achieved. For example, the Morrison Formation has been described as singularly lacking in fossil wood, which was attributed to a paucity of forest vegetation caused by aridity (e.g., Parrish et al., 2004). However, judging from the many taxonomic papers published on

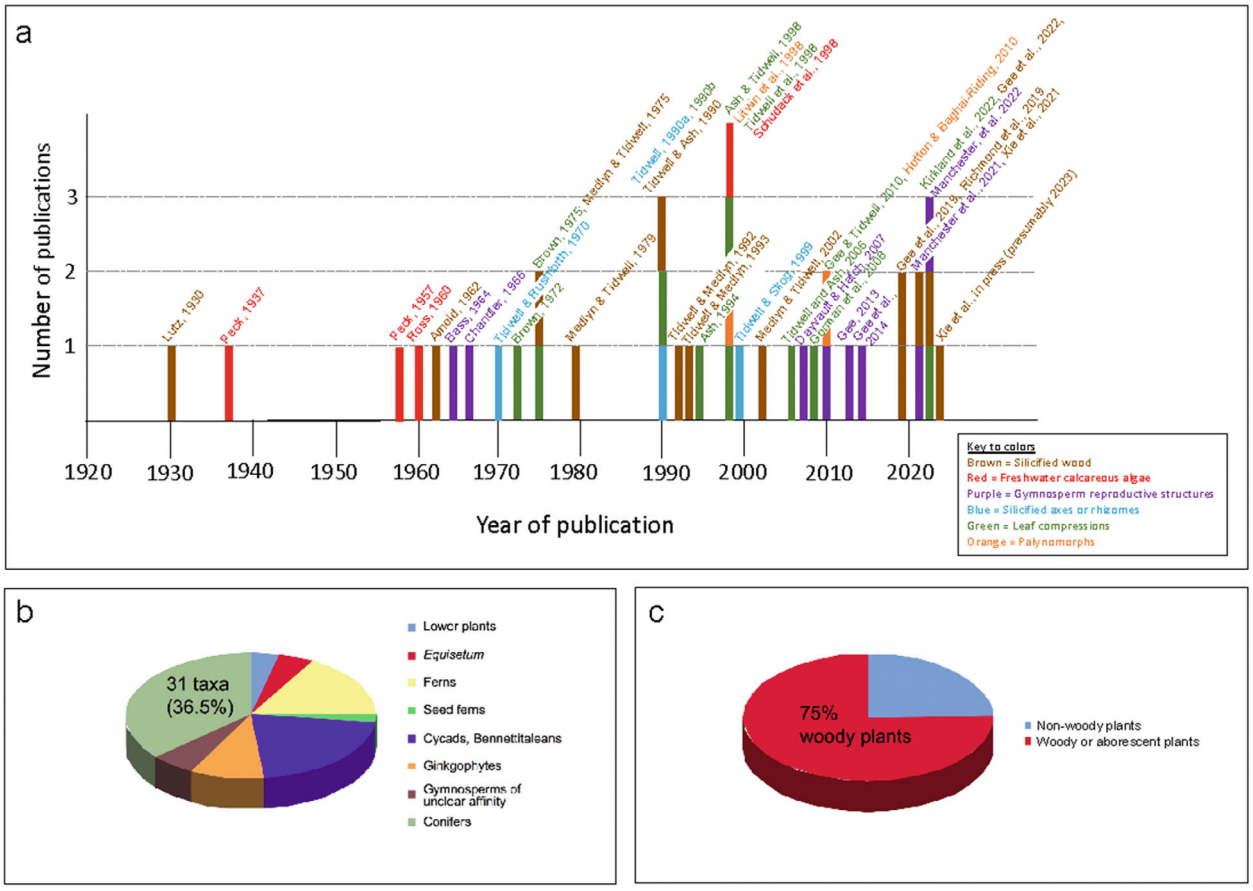


Figure 1 (a) Timeline of taxonomic publications on Upper Jurassic plants from the Morrison Formation, USA (the Kootenai Formation, Kootenay Group, and Canadian sites are excluded here). **(b)** Pie chart showing the relative taxonomic abundance of major plant groups in the Morrison Formation, based on data from Ash and Tidwell (1998). Here, conifers make up over one-third of the flora. Modified from Gee (2020). **(c)** Pie chart showing the relative abundance of non-woody (herbaceous) plants and woody or arborescent plants in the Morrison Formation, based on data from Ash and Tidwell (1998). Here, woody and arborescent plants comprise three-quarters of the flora. Modified from Gee (2020).

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silicified wood thus far—12 in all from 1930 to 2022, with several more to come (Hoff & Gee, this vol.; Philippe et al., this vol.; Richmond, this vol.; Xie et al., in revision)—the shortage may have been due not to the absence of ancient trees in the Upper Jurassic, but rather, to a lack of silicified wood well preserved enough to warrant scientific study and sufficient numbers of paleobotanists who understand the complexities of wood to study it.

There are several lines of solid evidence for widespread, tall-tree forests in the Morrison Formation (Gee, 2020). In 1998, Ash and Tidwell undertook a review of the plant species in the Morrison Formation. A subsequent quantitative analysis of their data shows that conifer taxa make up over one-third of the species diversity in the flora (Figure 1b), while woody and arborescent species comprise three-quarters of the biodiversity (Figure 1c); hence, the flora is clearly dominated by woody plants. Tangible fossil evidence of tall-tree, forest vegetation is documented by an assemblage of large-diameter logs in the Morrison Formation of northeastern Utah (Gee et al., 2019; Sprinkel et al., 2019). Another exceptionally large and complex tree trunk, newly discovered at a nearby site, reaches a remarkable 1.3 m in diameter, bears several massive branch scars, and divides at its top into three large upright trunks (Bennis et al., this vol.).

Giant logs also occur in the Morrison Formation in the Escalante Petrified Forest State Park of southern Utah (Gee et al., this vol.). Here, the largest trees top out at 160 to 170 cm in diameter. There are more than 100 fossil logs along the two major trails in the state park, documenting the heavily forested Jurassic landscape of what is today southern Utah. For the log assemblage in northeastern Utah, which was identified as an araucariaceous forest (Gee et al., 2019), new modeling based on living *Araucaria* trees shows that the original heights given for the log assemblage in northeastern Utah may have underestimated their heights by 2.5 times; new calculations based on height modeling of living trees of *Araucaria* spp. propose a height of 70 m for the tallest of the ancient trees (Xie et al., submitted).

3 WHAT'S TO COME

The Symposium on Mesozoic Terrestrial Ecosystems in Salt Lake City (MTE14) showcases current studies on Morrison paleobotany. Emerging data continues to show that the Morrison forests consisted of a mix of conifers and gymnosperms. New occurrences of wood are continually being described from Montana and Utah (Philippe et al., this vol.; Richmond, this vol; Richmond et al., 2019; Xie et al., 2019). In one species from Montana, it can be shown quantitatively from growth ring analysis that the trees were evergreen, not deciduous (Hoff and Gee, this vol.). The palynoflora also continues to reflect a species-diverse, fully vegetated landscape dominated by woody plants (Hotton & Baghai-Riding, 2010, this vol.).

Similarly, new leaf compression floras from eastern Utah are providing evidence for new plant communities in the Morrison Formation. For instance, the Jurassic Salad Bar and Turtle Island floras represent ginkgophyte-dominated woods with tree ferns and conifers (both reported by Foster et al., this vol.). Three-dimensional reproductive structures of the Gnetales document the first occurrences of these unusual gymnosperms (Manchester et al., 2020, 2021, this vol.) and complement the ongoing research on conifer seed cones (Gee, 2013; Gee et al., 2014). Correlating the regional palynological flora with local wood and leaf assemblages supports the interpretation of a mosaic of plant communities growing in the Morrison Formation (Hotton & Baghai-Riding, this vol.). Finally, we are beginning to gain some insight into Morrison trees and their ecological interactions with fungi and insects (Gee, this volume; Gee et al., 2022; Xie et al., submitted), as well as into dinosaur herbivory and coprolites (Howell et al., this vol.).

DEDICATION

This review is dedicated to Dr. William D. Tidwell (1932–2015), formerly Professor Emeritus at Brigham Young University in Provo, Utah, for his manifold contributions to the study of Mesozoic plants, especially to the Upper Jurassic paleobotany of the Morrison Formation.

REFERENCES

Arnold, C. A. (1962). A *Rhexoxylon*-like stem from the Morrison Formation of Utah. *American Journal of Botany*, *49*, 883-886.

Ash, S. R. (1994). First occurrence of *Czekanowskia* (Gymnospermae, Czekanowskiales) in the United States. *Review of Palaeobotany and Palynology*, *81*, 129-140.

Ash, S. R., & Tidwell, W. D. (1998). Plant megafossils from the Brushy Basin Member of the Morrison Formation near Montezuma Creek Trading Post, southeastern Utah. *Modern Geology*, *22*, 321-339.

Bass, C. (1964). Significant new fossil plant locality in Utah. *Contributions to Geology*, *University of Wyoming*, *3* (2), 94-95.

Bennis, M. B., Gee, C. T., Gray, D. E., & Love, R. (This volume). Recovery of an exceptional permineralized tree trunk from the Salt Wash Member of the Morrison Formation of NE Utah: The Manwell Log. *The Anatomical Record*.

Brown, J. T. (1972). *The Flora of the Morrison Formation (Upper Jurassic) of Central Montana* [Doctoral dissertation, University of Montana].

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Brown, J. T. (1975). Upper Jurassic and Lower Cretaceous ginkgophytes from Montana. *Journal of Paleontology*, *49*, 724-730.

Chandler, M. E. J. (1966). Fruiting organs from the Morrison Formation of Utah, USA. *Bulletin of the British Museum* (*Natural History*), *Geology*, *12*, 139-171.

Dayvault, R. D., & Hatch, H. S. (2007). Conifer cones from the Jurassic and Cretaceous rocks of eastern Utah. *Rocks & Minerals*, *82*, 382-397

Foster, J. (2020). *Jurassic West*. Indiana University Press.

Foster, J. R., Gee, C. T., Ash, S. R., & Kirkland, J. I. (This volume). Preliminary observations on the Jurassic Salad Bar, a new ginkgophyte-dominated flora from the Upper Jurassic Morrison Formation in southeastern Utah, USA. *The Anatomical Record*.

Foster, J. R., Gee, C. T., & Sroka, S. D. (This volume). First report on the Turtle Island flora, a new Upper Jurassic plant assemblage from the Morrison Formation of northeastern Utah, USA. *The Anatomical Record*.

Gee, C. T. (2013). Applying micro CT and 3D visualization to Jurassic silicified conifer seed cones: a virtual advantage over thin-sectioning. *Applications in Plant Sciences*, *1*, 1300039.

Gee, C. T. (2020). The conifer forests of the "Jurassic Park" in western North America, Section 6.5. In C. T. Gee (chapter editor and coordinator), Unit 6, Postcards from the Mesozoic: Forest landscapes with giant flowering trees, enigmatic seed ferns, and other naked-seed plants (pp. 165-169). In E. Martinetto, E. Tschanz, & R. A. Gastaldo (Eds.) *Nature through time: Virtual field trips through the nature of the past*. Springer Nature Switzerland AG.

Gee, C. T. (This volume). Elucidating the ecological interactions among trees, insects, fungi, and dinosaurs in the Upper Jurassic biota of the Morrison Formation. *The Anatomical Record*.

Gee C. T., Dayvault, R. D., Stockey, R. A., & Tidwell, W. D. (2014). Greater paleobiodiversity in conifer seed cones in the Upper Jurassic Morrison Formation of Utah, USA. *Palaeobiodiversity and Palaeoenvironments*, *94*, 363-365.

Gee, C. T., Sander, P. M., Hoff, F. V., Richmond, D. R., Xie, A., & Wang, Y. (This volume). First paleobotanical report on the Escalante Petrified Forest of the Upper Jurassic Morrison Formation in Utah, USA: Survey and data collection of trail logs, occurrence of giant trees, genesis of fossil deposit. *The Anatomical Record*.

Gee, C. T., Sprinkel, D. A., Bennis, M. B., & Gray, D. E. (2019). Silicified logs of *Agathoxylon hoodii* (Tidwell et Medlyn) comb. nov. from Rainbow Draw, near Dinosaur National Monument, Uintah County, Utah, USA, and their implications for araucariaceous conifer forests in the Upper Jurassic Morrison Formation. *Geology of the Intermountain West*, *6*, 77-92.

Gee, C. T., & Tidwell, W. D. (2010). A mosaic of characters in a new whole-plant *Araucaria*, *A. delevoryasii* Gee sp. nov., from the Late Jurassic Morrison Formation of Wyoming, USA (pp. 67-94). In C. T. Gee (Ed.), *Plants in Mesozoic time: Morphological innovations, phylogeny, ecosystems*. Indiana University Press.

Gee, C. T., Xie, A., & Zajonz, J. (2022). Multitrophic plant-insect-fungal interactions across 150 million years: A giant *Agathoxylon* tree, ancient wood-boring beetles and fungi from the Morrison Formation of NE Utah, and the brood of an extant orchard mason bee. *Review of Palaeobotany and Palynology*, *300*, 104627.

Gorman, M. A. II, Miller, I. M., Pardo, J. D., & Small, B. J. (2008). Plants, fish, turtle, and insects from the Morrison Formation: A Late Jurassic ecosystem near Canon City, Colorado. *Geological Society of America*, *Field Guide, 10*, 295-310.

Hoff, F. V., & Gee, C. T. (This volume). Deciduous or evergreen? A case study on a new species of Upper Jurassic wood from the Morrison Formation of Montana, USA. *The Anatomical Record*.

Hotton, C. L., & Baghai-Riding, N. L. (2010). Palynological evidence for conifer dominance within a heterogeneous landscape in the Late Jurassic Morrison Formation, USA (pp. 67-94). In C. T. Gee (Ed.), *Plants in Mesozoic time: Morphological innovations, phylogeny, ecosystems*. Indiana University Press.

Hotton, C. L., & Baghai-Riding, N. L. (This volume). Contrast between the palynoflora and megaflora in the Jurassic Salad Bar Site, Utah, USA: Implications for the regional flora. *The Anatomical Record*.

Howell, M. M., Gee, C. T., & Südekum, K.-H. (This volume). Preliminary observations on experimentally produced plant-based coprolites as a basis to understanding dinosaur herbivory. *The Anatomical Record*.

Kirkland, J. I., Foster, J. R., DeBlieux, D. D., & Hunt-Foster, R. K. (2022). New discoveries of Morrison Formation plant fossils expand our knowledge of Jurassic ecosystems. *Utah Geological Survey: Survey Notes*, *54(2)*, 6-7.

Knowlton, F. H. (1907). Description of a collection of Kootanie plants from the Great Falls Coal Field of Montana. *Smithsonian Miscellaneous Collections*, *50*, 105-127.

Knowlton, F. H. (1916). Note on a recent discovery of fossil plants in the Morrison Formation. *Journal of Washington Academy of Sciences*, *6*, 180-181.

Litwin, R. J., Turner, C. E., & Peterson, F. (1998). Palynological evidence on the age of the Morrison Formation, Western Interior U.S. *Modern Geology*, *22*, 297-319.

Lutz, H. J. (1930). A new species of *Cupressinoxylon* (Goeppert) Gothan from the Jurassic of South Dakota. *Botanical Gazette*, *90*, 92-107.

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Manchester, S. R., Zhang, X., Hotton, C. L., Wing, S., & Crane, P. R. (2021). Distinctive quadrangular seedbearing structures of gnetalean affinity from the Late Jurassic Morrison Formation of Utah, USA. *Journal of Systematic Palaeontology*, *19*, 743-760.

Manchester, S. R., Zhang, X., Hotton, C. L., Wing, S., & Crane, P. R. (2022). Two-seeded cones of probable gnetalean affinity from the Morrison Formation (Late Jurassic) of Utah and Colorado, USA. *Acta Palaeobotanica*, *62*, 77-92.

Manchester, S. R., Gee, C. T., & Crane, P. R. (This volume). Newly recognized gymnosperm diversity in the Upper Jurassic Brushy Basin Member of the Morrison Formation based on 3-dimensionally preserved reproductive structures from the Henry Mountains of Utah, USA. *The Anatomical Record*.

Medlyn, D. A., & Tidwell, W. D. (1975). Conifer wood from the Upper Jurassic of Utah, Part I—*Xenoxylon morrisonense* sp. nov. *American Journal of Botany*, *62*, 303-309.

Medlyn, D. A., & Tidwell, W. D. (1979). A review of the genus *Protopiceoxylon* with emphasis on North American species. *Canadian Journal of Botany*, *57*, 1451-1463.

Medlyn, D. A., & Tidwell, W. D. (2002). *Mesembrioxylon obscurum*, a new combination for *Araucarioxylon*? *obscurum*, from the Upper Jurassic Morrison Formation. *Western North American Naturalist*, *62*, 210-217.

Peck, R. E. (1937). Morrison Charophyta from Wyoming. *Journal of Paleontology*, *11*, 83-90.

Peck, R. E. (1957). North American Mesozoic charophytes. *U.S. Geological Survey Professional Paper*, *294-A*, 1-44.

Parrish, J. T., Peterson, F., & Turner, C. E. (2004). Jurassic "savannah"—plant taphonomy and climate of the Morrison Formation (Jurassic, Western USA) and its equivalents in Canada. *Sedimentary Geology*, *167*, 137-162.

Philippe, M., Richmond, D. R., Lupia, R., & McLeomore, D. (This volume). Reappraisal of *Xenoxylon morrisonense* leads to recognition of a new fossil wood genus. *The Anatomical Record*.

Richmond, D. R. (This volume). A strange wood in a strange land: The paleoecology of the fossil wood *Xenoxylon* in the Late Jurassic of North America. *The Anatomical Record*.

Richmond, D., Lupia, R., Philippe, M., & Klimek, J. (2019). First occurrence of the boreal fossil wood *Xenoxylon meisteri* from the Jurassic of North America: Morrison Formation of central Montana, USA. *Review of Palaeobotany and Palynology*, *267*, 39-53.

Ross, C. A. (1960). Population study of charophyte species, Morrison Formation, Colorado. *Journal of Paleontology*, *34*, 717-726.

Schudack, M. E., Turner, C. E., & Peterson, F. (1998). Biostratigraphy, paleoecology, and biogeography of charophytes and ostracodes from the Upper Jurassic Morrison Formation, Western Interior, USA. *Modern Geology*, *22*, 379-414.

Sprinkel, D. A., Bennis, M. B., Gray, D. E., & Gee, C. T. (2019). Stratigraphic setting of Morrison Formation (Upper Jurassic) permineralized wood sites near Dinosaur National Monument, Uintah County, Utah. *Geology of the Intermountain West*, *6*, 61-76, A1-A5.

Tidwell, W. D. (1990a). A new osmundaceous species (*Osmundacaulis lemonii* n. sp.) from the Upper Jurassic Morrison Formation, Utah. *Hunteria*, *2*, 3-11.

Tidwell, W. D. (1990b). Preliminary report on the megafossil flora of the Upper Jurassic Morrison Formation. *Hunteria*, *2*, 1-11.

Tidwell, W. D., & Ash, S. R. (1990). On the Upper Jurassic stem *Hermanophyton* and its species from Colorado and Utah, USA. *Palaeontographica Abteilung B*, *218*, 77-92.

Tidwell, W. D., & Ash, S. R. (2006). Preliminary report on the Early Jurassic flora from the St. George Dinosaur Discovery Site, Utah. In J. D. Harris, S. G. Lucas, J. A. Spielmann, M. G. Lockley, A. R. C. Milner, & J. I. Kirkland (Eds.), *The Triassic-Jurassic Terrestrial Transition. New Mexico Museum of Natural History and Science Bulletin, 37*, 414-420.

Tidwell, W. D., Britt, B. B., & Ash, S. R. (1998). Preliminary flora analysis of the Mygatt-Moore Quarry in the Jurassic Morrison Formation, west-central Colorado. *Modern Geology*, *22*, 341-378.

Tidwell, W. D., Connely, M., & Britt, B. B. (2006). A flora from the base of the Upper Jurassic Morrison Formation near Como Bluff, Wyoming, USA. In J. R. Foster & S. G. Lucas (Eds.), *Paleontology and Geology of the Upper Jurassic Morrison Formation. New Mexico Museum of Natural History and Science, Bulletin*, *36*, 171-181.

Tidwell, W. D., & Medlyn, D. A. (1992). Short shoots from the Upper Jurassic Morrison Formation, Utah, Wyoming, and Colorado, USA. *Review of Palaeobotany and Palynology*, *71*, 219-238.

Tidwell, W. D., & Medlyn, D. A. (1993). Conifer wood from the Upper Jurassic of Utah, USA-Part II. *Araucarioxylon hoodii* sp. nov. *Palaeobotanist*, *42*, 70-77.

Tidwell, W. D., & Rushforth, S. R. (1970). *Osmundacaulis wadei*, a new osmundaceous species from the Morrison Formation (Jurassic) of Utah. *Bulletin of the Torrey Botanical Club*, *97*, 137-144.

Tidwell, W. D., & Skog, J. E. (1999). Two new species of *Solenostelopteris* from the Upper Jurassic Morrison Formation in Wyoming and Utah. *Review of Palaeobotany and Palynology*, *104*, 285-298.

Ward, L. F. (1900). Description of a new genus and twenty new species of fossil cycadean trunks of the

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Jurassic of Wyoming. *Proceedings of the Washington Academy of Sciences*, *1*, 253-300.

Xie, A., Gee, C. T., Bennis, M. B., Gray, D., & Sprinkel, D. A. (2021). A more southerly occurrence of *Xenoxylon* in North America: *X. utahense* Xie et Gee sp. nov. from the Upper Jurassic Morrison Formation in Utah, USA, and its paleobiogeographic and paleoclimatic significance. *Review of Palaeobotany and Palynology*, *291*, 104451.

Xie, A., Gee, C. T., & Griebeler, E. M. (Submitted). Modelling the height–diameter relationships in living trees to reconstruct ancient conifer height. I. *Araucaria* (Araucariaceae). Submitted to *Palaeontology*.

Xie, A., Tian, N., & Gee, C. T. (In revision). Ancient Basidiomycota in an extinct conifer-like tree, *Xenoxylon utahense*, and a brief survey of fungi in the Upper Jurassic Morrison Formation, USA. *Journal of Paleontology*, in revision.

Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 3:30 PM)

ELUCIDATING ECOLOGICAL INTERACTIONS BETWEEN TREES, INSECTS, FUNGI, AND DINOSAURS IN THE UPPER JURASSIC BIOTA OF THE MORRISON FORMATION

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Elucidating interactions between members of an ancient community is often quite tricky, because these interrelationships are commonly inferred using only trace fossils. However, with serenpiditous fossil discoveries, application of traditional and modern techniques, and comparison with living analogs, the relationships between organisms of the geological past can be unraveled. A block of silicified wood of *Agathoxylon hoodii* from the Upper Jurassic Morrison Formation in Rainbow Draw, Utah, has yielded remarkable evidence of ecological interactions between a tree, parasitic fungi, primary consumers, primary shelter users, and secondary shelter users (Gee et al., 2022). Within the framework of reconstructing ecological relationships in the Morrison Formation, the flow of energy in a dinosaur-dominated ecosystem is also outlined here in a hypothetic food chain.

1 ENERGY FLOW IN AN UPPER JURASSIC TERRESTRIAL ECOSYSTEM

It is well known that nearly all the energy of sunlight entering earth's atmosphere today is absorbed as heat. If the total input of solar radiation is set at a theoretical 100%, 99% of the energy goes into warming the earth, whereas only 1% is absorbed by the primary producers (green plants) for photosynthesis (e.g., Riisgård, 2017). Yet, despite this low percentage of solar radiation, plants can convert enough light energy into chemical energy to power all the ecosystems on earth. Between each trophic level, there is a 90% loss of energy; only 10% of the energy at one level flows up to the next level.

In Late Jurassic times in what is currently western North America, the sun presumably shone down on the biota of the Morrison Formation as brightly as it does today. If we assume that the partitioning of solar energy was similar in the Late Jurassic, 99% percent of the sunlight warmed

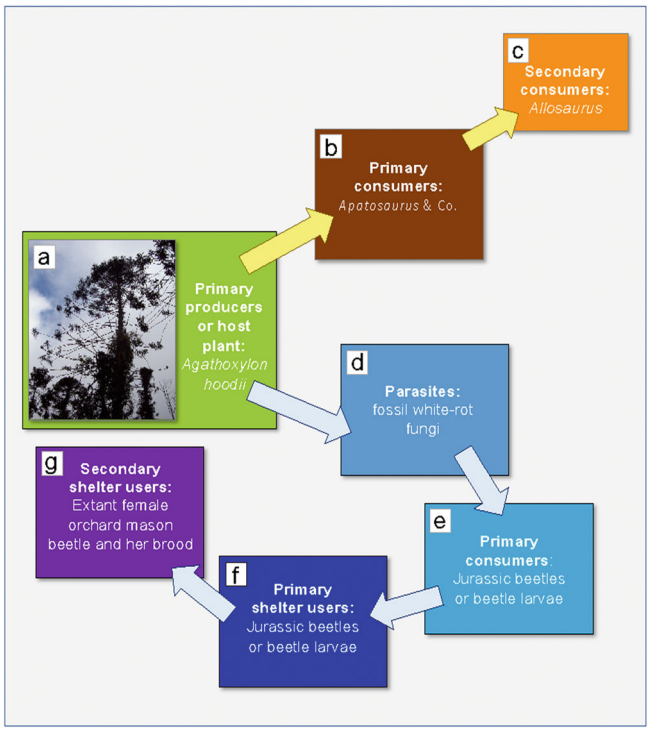


Figure 1. Ecological interactions in the Upper Jurassic Morrison Formation. **(a–c)** A hypothetical food chain (yellow arrows), starting with **(a)** the primary producers and continuing to the next trophic level with **(b)** the primary consumers of herbivorous dinosaurs, then to **(c)** the secondary consumers of carnivorous dinosaurs. **(a, d–g)** Ecological interactions evident in a block of silicified *Agathoxylon hoodii* wood (blue arrows), showing the links between **(a)** the host plant, **(d)** fossil parasitic white-rot fungi, **(e)** primary consumers of Jurassic beetles or beetle larvae, (f) primary shelter users of Jurassic beetles or beetle larvae, and **(g)** secondary shelter users of an extant female orchard mason bee and her brood. Photo in 1a: A living tree of *Araucaria bidwillii* in Northern Queensland, Australia, taken by the author.

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the earth, while 1% was captured by the chloroplasts in green plants. Through the process of photosynthesis, the light energy was converted by the Morrison plants into chemical energy, then used to form the organic matter of their bodies.

In northeastern Utah, the Upper Jurassic Morrison landscape was covered by large forest trees of *Agathoxylon hoodii*, similar to the living monkey-puzzle trees of *Araucaria* (Figure 1a), along with a few enigmatic conifers such as *Xenoxylon utahense* (Xie et al., 2021). *Araucaria*-like trees grew in a wide expanse across the central Morrison Formation, in northeastern Utah (Gee et al., 2019; Sprinkel et al., 2019) and at several different sites in southern Utah (Gee, unpubl. Data; Gee et al., 2014; Tidwell & Medlyn, 1993) as well as in northcentral Wyoming (Gee & Tidwell, 2010) and elsewhere in the Morrison Formation (Hotton & Baghai-Riding, 2010).

The foliage of the *Araucaria*-like trees and other plants was then eaten by the primary consumers of the Upper Jurassic ecosystem. In Morrison times, the primary consumers were mainly herbivorous dinosaurs, such as sauropods and ornithischians (Figure 1b). In the Morrison fauna in Utah, sauropods like *Apatosaurus*, *Barosaurus*, and *Camarasaurus* and ornithischians like *Stegosaurus* and *Camptosaurus* have been recovered from the bonebed at the Cleveland-Lloyd Dinosaur Quarry (Foster, 2020).

The primary consumers—the herbivorous dinosaurs—were then preyed upon by the secondary consumers constituting the next trophic level—the carnivorous theropods (Figure 1c). In Utah, there is an unusually high concentration of theropods at the Cleveland-Lloyd Dinosaur Quarry. Here, nearly 70% of all bones pertain to the theropod *Allosaurus fragilis*, although four other genera of carnivorous dinosaurs are also represented at the quarry (Foster, 2020).

2 ECOLOGICAL INTERACTIONS IN A GIANT UPPER JURASSIC CONIFER TREE

In the Upper Jurassic conifer forest of *Agathoxylon hoodii* in northeastern Utah, it is possible to go deeper into ecological interactions. Based on trace fossils discovered in the body fossil of one conifer tree, a complex chain of interrelationships between the primary producer, fungal parasites, primary consumers, primary shelter users, and secondary shelter users can be reconstructed (Gee et al., 2022).

The primary producer and host plant is a conifer tree of *Agathoxylon hoodii* with *Araucaria*-like wood (Figure 1a). Based on the preserved minimum diameter of 1.30 m of the fossil log found in Rainbow Draw in northeastern Utah, the Upper Jurassic tree can be reconstructed as 68 to 72 m tall and at least 100 years old (Gee et al., 2019; Xie et al., submitted). Multiple occurrences of stratigraphically equivalent pieces of fossil wood and logs at Rainbow Draw indicates that this area was covered by a tall-tree forest of *Agathoxylon hoodii* (Gee et al., 2019; Sprinkel et al., 2019). As one of the largest and oldest trees in the forest (Gee et al., 2019), it is no surprise that the individual fossil tree trunk under study became infected in part by white-rot fungi (Figure 1d).

Thin sections of the silicified wood of the tree trunk show that when the fungus tried to infect the wood, individual cells attempted to keep the pathogen out by actively reinforcing its cell wall with additional cell-wall material at the site of attempted penetration. As fungal destruction increased, the tree tried repelling the pathogen with the release of resin. At first, the resin was discharged between infected wood cells, appearing today as small angular particles. As the infection worsened, the resin became more copious and viscous in the void spaces between intact wood tissue. The reinforcement of wood cell walls and release of resin by the tree show that the tree was alive during the fungal infection and thus that the wood-damaging fungus was parasitic, not saprophytic. The differential decoloration of the cell walls suggests that the fungal infection was caused by white rot.

Fungal formation of void spaces in the tree trunk facilitated the boring of vertical galleries by a Jurassic insect. The galleries are large in diameter, ca. 1.3 cm across, and are positioned in the areas of the wood with the greatest structural damage. MicroCT shows that the insect galleries are straight and unbranched. The galleries were produced by primary consumers (Figure 1e), likely Jurassic wood-boring beetles. Among living insects, round-headed borers (family Cerambycidae) or flat-headed borers (family Buprestidae) bore large-diameter galleries to brood their larvae. The Jurassic beetle larvae would have been the primary shelter users in this ecological chain (Figure 1f).

MicroCT also revealed a remarkable repurposing of one Jurassic beetle gallery 150 million years later. In the longest-preserved gallery, two chambers of a linear nest of a modern orchard mason bee can be observed. Each chamber contains a cocoon with a nearly mature bee, with a pollen nest of presumably pollen and nectar to serve as provisions for the hatchlings. The bee larvae make up the secondary shelter users in this ecological chain of interactions (Figure 1g). The partition between the chambers is composed of the very fine to fine, well-

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sorted sand of the Morrison Formation in the surrounding area.

References

Foster, J. (2020). *Jurassic West*. Indiana University Press.

Gee, C. T., Dayvault, R. D., Stockey, R. A., & Tidwell, W. D. (2014). Greater paleobiodiversity in conifer seed cones in the Upper Jurassic Morrison Formation of Utah, USA. *Palaeobiodiversity and Palaeoenvironments*, *94*, 363-365.

Gee, C. T., Sprinkel, D. A., Bennis, M. B., & Gray, D. E. (2019). Silicified logs of *Agathoxylon hoodii* (Tidwell et Medlyn) comb. nov. from Rainbow Draw, near Dinosaur National Monument, Uintah County, Utah, USA, and their implications for araucariaceous conifer forests in the Upper Jurassic Morrison Formation. *Geology of the Intermountain West*, *6*, 77-92.

Gee, C. T., & Tidwell, W. D. (2010). A mosaic of characters in a new whole-plant *Araucaria*, *A. delevoryasii* Gee sp. nov., from the Late Jurassic Morrison Formation of Wyoming, USA (pp. 67-94). In C. T. Gee (Ed.), *Plants in Mesozoic time: Morphological innovations, phylogeny, ecosystems*. Indiana University Press.

Gee, C. T., Xie, A., & Zajonz, J. (2022). Multitrophic plant-insect-fungal interactions across 150 million years: A giant *Agathoxylon* tree, ancient wood-boring beetles and fungi from the Morrison Formation of NE Utah, and the brood of an extant orchard mason bee. *Review of Palaeobotany and Palynology*, *300*, 104627.

Hotton, C. L., & Baghai-Riding, N. L. (2010). Palynological evidence for conifer dominance within a heterogeneous landscape in the Late Jurassic Morrison Formation, USA (pp. 67-94). In C. T. Gee (Ed.), *Plants in Mesozoic time: Morphological innovations, phylogeny, ecosystems*. Indiana University Press.

Riisgård, H. U. (2017). *General Ecology: Outline of Contemporary Ecology for University Students*. Bookboon.com.

Sprinkel, D. A., Bennis, M. B., Gray, D. E., & Gee, C. T. (2019). Stratigraphic setting of Morrison Formation (Upper Jurassic) permineralized wood sites near Dinosaur National Monument, Uintah County, Utah. *Geology of the Intermountain West*, *6*, 61-76, A1-A5.

Tidwell, W. D., & Medlyn, D. A. (1993). Conifer wood from the Upper Jurassic of Utah, USA-Part II. *Araucarioxylon hoodii* sp. nov. *Palaeobotanist*, *42*, 70-77.

Xie, A., Gee, C. T., Bennis, M. B., Gray, D., & Sprinkel, D. A. (2021). A more southerly occurrence of *Xenoxylon* in North America: *X. utahense* Xie et Gee sp. nov. from the Upper Jurassic Morrison Formation in Utah, USA, and its paleobiogeographic and paleoclimatic significance. *Review of Palaeobotany and Palynology*, *291*, 104451.

Poster Session 2 associated with the Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023)

FIRST PALEOBOTANICAL REPORT ON THE ESCALANTE PETRIFIED FOREST OF THE UPPER JURASSIC MORRISON FORMATION IN UTAH, USA: SURVEY AND DATA COLLECTION OF TRAIL LOGS, OCCURRENCE OF GIANT TREES, GENESIS OF FOSSIL DEPOSIT

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The Escalante Petrified Forest (EPF) is a sizeable accumulation of giant fossil logs in the Brushy Basin Member of the Upper Jurassic Morrison Formation near Escalante in southcentral Utah, USA (Morgan et al., 2010). The 150-million-year-old logs are highly agatized and exhibit bright colors of reds, yellows, browns, violets, and blacks. While logs can be viewed in their original geological setting in the Escalante Petrified Forest State Park (Morgan et al., 2012), until now, basic paleobotanical work had yet to be conducted on this fossil occurrence. Here we present our preliminary results on mapping, measuring, cataloging, and describing the logs found along the trails in the state park. We also extrapolate the height of the trees based on measured maximum diameter data and put forth a hypothesis for the origin of the log deposit. Altogether, we counted more than 115 logs along the two main trails in the park: seven logs on the Petrified Forest Trail and at least 108 on the Trail of Sleeping Rainbows. Segments of logs from the same tree trunk were counted, mapped, measured, and cataloged as a single log with our EPF number. Many logs were broken up into several, often-displaced segments, which slowed the survey process and made for tedious work. Note that many log sections do occur not in situ and could not be assigned to a specific in-situ log. In addition, there are rare dinosaur

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Figure 1 Selected silicified logs from the Upper Jurassic Escalante Petrified Forest, Utah, all occurring on the Trail of Sleeping Rainbows. **(a)** A large, multicolored log, nicknamed by us as "Rainbow Giantess" measures 110 cm across in diameter. Note the horizontal orientation of the log on the substrate and its horizontally compressed state. The major subdivision on the scale is 10 cm. **(b)** Top view of EPF-023, dubbed "Hagrid," with a long diameter of 145 cm. Note the upright orientation of this fossil tree. This vast, transverse surface of the trunk appeared above the soil surface only after extensive excavation and cleaning, while the rest of the tree trunk remains deeply buried in the substrate. **(c)** Side view of EPF-030, with a long diameter of 170 cm. Coined "Goliath" for its enormous size, this fossil trunk stands upright and has the most massive diameter in the Escalante Petrified Forest. The top of the tree splits into a multi-stemmed tree of five large-diameter, upright branches, of which the largest branch measures nearly a half meter across (arrow). **(d)** Side view of EPF-037 ("Amazonia"), with a main-trunk diameter of 115 cm which splits into two massive, co-dominant upper trunks with vertical diameters of 73 (arrow) and 67 cm (arrowhead), respectively. **(e)** An example of a fossil log with a huge branch scar with a long diameter of 65 cm indicates the side branch's large size. **(f)** View of EPF-009, referred to by us as the "Log in the Wall," with diameters of 62 cm (horizontal) and 71 cm (vertical). This log is horizontally half-buried within a coarse sandstone with trough cross-bedding and covered by a poorly-sorted pebble conglomerate. The fossil log occupies a prominent position in the park, in a wall of sandstone high up in the stratigraphic section and is crowned by a small juniper tree. Brunton compass for scale. All photos: CTG.

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bones reported from the Brushy Basin Member of the park (Morgan, 2010).

The large diameter sizes of some of the fossil logs are noteworthy. Several logs measured about 1 m in diameter, such as a multicolored log inventoried as EPF-090 that we nicknamed "Rainbow Giantess" for its size, prominence, and isolated position on the Trail of Rainbows. This fossil log is oriented horizontally to the substrate, and although it has been compressed geologically, it measures 110 cm along its maximum diameter (Figure 1a). The horizontal diameter represents the tree's original diameter without compaction, because compaction from overburden does not increase the log diameter perpendicular to the direction of compaction (Rex & Chaloner, 1983). In general, tree trunks with large diameters are preserved in the upright position, and their girths are not affected by overburden compaction. Two examples include EPF-023, a log that we dubbed "Hagrid," which has a maximum diameter of 145 cm (Figure 1b), and another log, EPF-030 called "Goliath," which has a maximum diameter of 170 cm (Figure 1c). One exception to this generalization is one of the longest and widest tree trunks found at the start of the Petrified Forest Trail. The log EPF-003 is oriented horizontally to the substrate and is one of a set of three logs ("The Titans"). At this site, the parallel lengths of wood appear to represent four logs, but careful excavation will reveal that two of these lengths are the same log, EPF-003. EPF-003 ("Top Titan") measures 160 cm in diameter and is over 8 m in length. Thus, to date, EPF-003 (ø=160 cm) rivals EPF-030 (ø=170 cm) as one of the broadest tree trunks in the Escalante Petrified Forest.

Botanically, it is not length, but the measurement of maximum preserved diameter in fossil logs (e.g., Mosbrugger et al., 1994; Xie et al., submitted) that is important for the reconstruction of ancient tree heights. Based on recent height–diameter models for a tracheid-dominated tree such as *Araucaria* (Xie et al., submitted), for a generalized conifer (Xie & Gee, unpub. data), or a shorter, stouter tree such as *Agathis* (Xie & Gee, unpub. data), the tallest trees with a diameter of 170 cm would have attained a height of at least 82 m, 56 m, or 30 m, respectively. A tree with a height greater than 30 m is large, and one measuring 82 m is very large. Thus, given these values for the estimated minimum height of the tallest tree ("Goliath"), it is highly likely the Upper Jurassic Escalante forest represents a mature, tall-tree, old-growth forest of gymnosperms.

While the fossil wood and logs in the Escalante Petrified Forest are silicified, their internal anatomical structure is so poorly preserved that the taxonomic determination of individual trees is difficult. However, clues to the identity of the trees can be gleaned from the gross morphology of the tree trunks. In larger specimens, the upper portion of the tree divides into several massive multi-stemmed woody trunks (Figure 1c, d). In EPF-030 (Goliath), the top of the trunk is separated into five massive, co-dominant trunks, the largest of which measures 45 cm in diameter (Figure 1c, arrow). Even more impressive is the central trunk of EPF-037 (named "Amazonia"), which measures 115 cm in diameter, that divides into two massive, co-dominant upper trunks with vertical diameters of 73 and 67 cm, respectively (Figure 1d, arrow, arrowhead). In other cases, it can be observed that some tree trunks bore massive branches documented by huge branch scars (a maximum diameter of ca. 65 cm; Figure 1e). Based on their huge sizes, the fossil trees are gymnosperms with robust, woody trunks and branches similar to conifers or ginkgophytes. However, it is unclear if the Upper Jurassic Escalante forest consisted of a single taxon or several genera.

The fossil logs occur in the upper Brushy Basin Member in an up to 25-m-thick unit of coarse clastic sediments ranging from medium sand to pebble conglomerate. This unit was laid down in a braided fluvial system, which consists in places of two stacked channels, and the emplacement of the logs was attritional. There is a consistent pattern of logs found half-buried in coarse sandstone, then covered in a poorly-sorted conglomerate (Figure 1f), suggesting initial deposition in a river channel, followed by complete burial by a flood event of greater energy at a later time. The only exception thus far is the last log on the Petrified Forest Trail, EPF-007 that was emplaced in a bentonitic mudstone near a coarse-grained river channel, suggesting transport from a high-energy facies onto a paleosol in an overbank environment.

Acknowledgments

The authors sincerely thank former park manager Kendall Farnsworth and current park manager Chad Jones, as well as their friendly staff for access to the state park on multiple trips to the Escalante Petrified Forest since 2011. Financial support for fieldwork in Utah from Open Funding grant no. 193101 from the State Key Laboratory of Palaeobiology and Stratigraphy (Nanjing Institute of Geology and Palaeontology, CAS) State Grant to CTG is greatly appreciated. Financial support from the China Scholarship Council for the doctoral studies of AX (CSC no. 201804910527) is also gratefully acknowledged.

References

Morgan, S. K., Lindsay, B. W., & Williams, A. P. (2010). Geology of Escalante State Park, Utah. *The Geology of Utah Parks and Monuments*, *Utah Geological Association Publication*, *28*, 429-438.

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Morgan, S. K., Lindsay, B. W., & Hoffmann, A. P. (2012). Geologic trail guide for Escalante State Park, Utah. In P. B. Anderson & D. A. Sprinkel (Eds.), *Geological Road, Trail, and Lake Guides of Utah's Parks and Monuments. Utah Geological Association Publication*, *29* (3rd ed.) (pp. 1-8).

Mosbrugger, V., Gee, C. T., Belz, G., & Ashraf, A. R. (1994). Three-dimensional reconstruction of an in situ Miocene peat forest from the Lower Rhine Embayment, NW Germany—new methods in palaeovegetation analysis. *Palaegeography, Palaeoclimatology, Palaeoecology*, *110*, 295-317.

Rex, G. M., & Chaloner, W. G. (1983). The experimental formation of plant compression fossils. *Palaeontology*, *26*, 231-252.

Xie, A., Gee, C. T., & Griebeler, E. M. (Submitted). Modelling the height–diameter relationships in living trees to reconstruct ancient conifer height. I. *Araucaria* (Araucariaceae).

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 2:00 PM)

PALEOECOLOGY OF VERTEBRATE MICROFOSSIL ASSEMBLAGES FROM THE EASTERNMOST DINOSAUR PARK FORMATION (UPPER CAMPANIAN) SASKATCHEWAN, CANADA: RECONSTRUCTING DIVERSITY THROUGH TRANSGRESSIVE SEQUENCES

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The Campanian Dinosaur Park Formation (DPF) of Western Canada is co-equivalent to the upper Judith River Formation in Montana and is one of the most productive and well-studied dinosaur bearing units in the world. In Canada, the DPF outcrops spectacularly in Central Alberta, most famously in Dinosaur Provincial Park, a UNESCO World Heritage Site. Further east in the province of Saskatchewan the DPF is present, but outcrop is sparse, widely distributed, and often difficult to access. Notably the DPF in Saskatchewan represents the northeasternmost occurrence of the formation in North America and was far more proximal to the Western Interior Seaway (WIS) than deposits in Alberta. Therefore, these deposits hold considerable potential for addressing questions concerning large-scale spatial diversity patterns across northwestern North America.

Three localities with various stratigraphic representation within the DPF across southwestern Saskatchewan were sampled for microvertebrate fossils (when possible), ichnofossils, and palynoforms. This data was integrated with detailed facies analysis to reconstruct the paleoecology and paleoenvironment of the DPF through the various stratigraphic levels. The data indicate an increasing marginal marine influence, culminating in rapid transgression of the shoreline at the top of the formation. Paleocommunities responded to these changes with shifts in diversity and distribution. Freshwater taxa such as pelycopod gastropods, unionids, *Meristodonoides montanemsis*, a variety of teleosts, and turtles (Baenids, *Basilemys* sp.) dominate basal DPF deposits. Upsection increasingly marginal marine to marine taxa appear, culminating in a variety of sharks (*Eucrossorhinus microcuspidatus, Carcharias, steineri, Archaeolamna kopingensis, Squalicorax* sp.) and rare marine reptile remains at the formations transition with the overlying Bearpaw Formation. This ongoing research provides critical insight into large-scale diversity patterns and drivers that were occurring in the Late Campanian of North America.

Technical Session 3: Terrestrial Ecosystems – Late Cretaceous (Saturday, June 10, 2023, 1:15 PM)

UPPER CRETACEOUS CONTINENTAL DEPOSITS FROM THE BAURU GROUP, PARANÁ BASIN, SOUTHEASTERN BRASIL: STRATIGRAPHY, PALEOENVIRONMENTS, PALEOBIOTAS AND BIOSTRATIGRAPHIC ASSESSMENTS

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The Bauru Group (Paraná Basin, Southeastern Brazil) is one of the most important continental Cretaceous deposits in South America. There have been few efforts to date the geological units and stratigraphic levels of the Bauru Group. Attempts to develop a biostratigraphic framework for these deposits were based mainly on microfossils (e.g., ostracods, charophytes), although vertebrates have also been used (turtles, dinosaurs, mammals). We propose a biostratigraphic model for the different geological units of the Bauru Group, a sedimentary deposit above Paraná-Etendeka Traps (Serra Geral Formation).

The Caiuá Formation is situated below the basalts related to the Serra Geral Formation and are composed mainly

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of purple, medium- to coarse-grained, cross-stratified sandstones. We interpret the Caiuá Formation as eolian, deposited as a continuation of the Botucatú Formation. Based on the presence of diagnostic pterosaur remains (Tapejaridae), it seems clear the stratigraphic level of the lowest age of the Caiuá Formation could be Aptian to Albian. Following the deposition of the Caiuá Formation there is an erosive temporal hiatus.

It is possible that the Caiuá Formation may be correlative to part of the São Bento Group, situated stratigraphically below Bauru Group, where Botucatú and Serra Geral formations are positioned. It is justifiable, considering the similar paleoenvironment compared to the Botucatú Formation, and the presence of erosional surfaces above Caiuá Formation.

Not considering sub-surface geological units, for instance Pirapozinho and Birigui formations, the following sedimentation sequence begins with Santo Anastácio Formation; a fluvial, probably braided system, restricted to Western São Paulo State (Figure 1). These sediments, especially the medium purple sandstones, display some cross stratifications, and up to now have not yielded microfossils, but observations of the vertebrates (Testudines, Baurusuchidae) indicate Campanian age.

The overlying, Araçatuba and Adamantina formations, are laterally correlative in all or in part, and they partially overlap the Santo Anastácio Formation. There are macrofossils in common between Santo Anastácio and Adamantina formations, so it would be reasonable that both geological units are biochronologically correlative (Figure 1).

The Araçatuba Formation occurs in the Central-Western regions of São Paulo State, and are composed of red siltstones and mudstones, that are laminarly bedded, representing an environment of shallow lacustrine and deltaic deposits, related to deltas of the Adamantina fluvial system (Figure 1). The delicate ostracods found in Araçatuba Formation are ornate, consistent with lacustrine environment, and are identified as *Ilyocypris riograndensis*, *I. argentiniensis*, *Wolburgiopsis vicinalis*, and *W. neocretacea*, which appear to co-occur biostratigraphically. Among vertebrates, occurrences of Testudines and Crocodyliformes (Notosuchia) are recognized.

The Adamantina Formation consists mainly of red and cream, fine-grained sandstones and siltstones. There are some levels of conglomeratic sandstones, associated with bone beds. The paleoenvironment would be anastomosed and meandering fluvial system. The formation is the most geographically widespread of all units of the Bauru Group (Figure 1). It preserves a very well-known and rich paleobiota, invertebrates, such as ostracods, and vertebrates, including dinosaurs and mammal. The charophyte-ostracod association includes *Lychnothamnus barbosai*, *Feistiella* aff. *gildemeisteri forma minor* as charophytes, and *Ilyocypris riograndensis*, *I. wichmani*, *Stenocypris cylindrica* and *Vecticypris* aff. *punctata* as ostracods. This microfossil assemblage strongly suggests a Campanian / Maastrichtian age. Although it is assumed to be Campanian / Maastrichtian in age, the geological sequence represented by Santo Anastácio, Araçatuba and Adamantina Formations, exhibit clear paleoenvironmental lateral relationships in the field.

Among vertebrates, the Adamantina Formation shows the most abundant and diversified vertebrate assemblage of the Bauru Group. There are occurrences of fish (Dipnoiformes, Lepisosteidae, Characiformes and other groups); testudines (at least three different morphotypes); few Lacertiformes; diverse Crocodyliformes (around ten different species of Notosuchia, about five distinct remains associated to Baurusuchidae); Theropoda (especially Dromaeosauria, Abelisauridae, represented mostly by isolated teeth and some bone fragments); sauropods (around a dozen different morphotypes of Titanosauria); Mammalia (probably Metatheria and Eutheria). This assemblage, together with microfossils, suggests an upper Campanian / lower Maastrichtian interval to the Adamantina Formation deposits.

The Marília Formation is composed of white medium- to coarse-sandstones, with limestone layers, representing a fluvial, probably meandering river, floodplain paleoenvironment, with restricted lacustrine environments, under

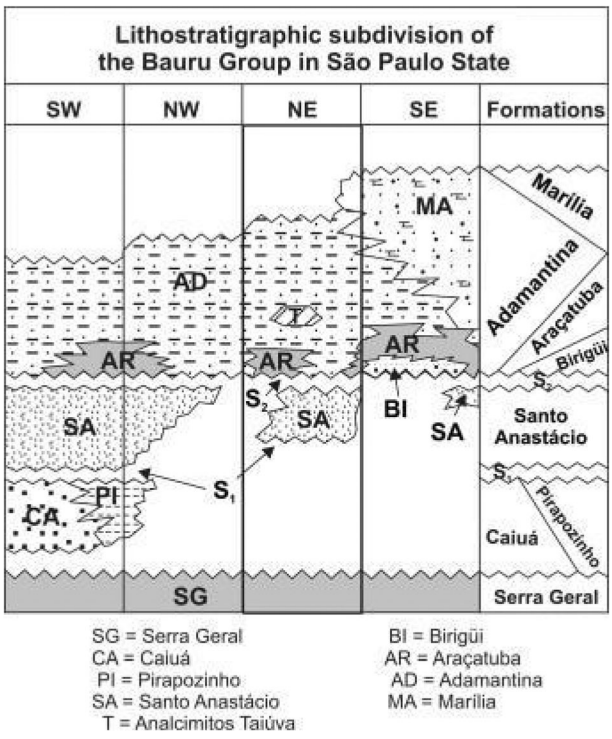


Figure 1. Lithostratigraphic subdivision of the Bauru Group in São Paulo State. From Paula and Silva *et al*. (2009).

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dry conditions (Figure 1). It is considered Maastrichtian in age, based on microfossils, like charophytes (*Feistiella* cf. *globose*, *F.* cf. *costata*, *Amblyochara* sp., cf. *Gobichara groeberi*), ostracods (*Ilyocypris argentiniensis*, *I. triebeli*, *I. wichmanni punctata*, *Wolburgiopsis neocretacea*) and macrofossils, including Testudines (around three different taxa), Crocodyliformes (about ten distinct species), Dromaeosauria (isolated teeth and some fragments of bones), Titanosauria (at least six different species).

These strong biostratigraphic correlations make it difficult to assume, and even to accept, a Cenomanian age for the Santo Anastácio Formation, a Turonian -Santonian age for the Adamantina and Araçatuba formations (Dias-Brito et al., 2001), and a Maastrichtian age for the Marilia Formation. The actual data based on fossils, and the absence of depositional hiatuses between these geological units, together with identified lateral correlations, without any kind of erosional surfaces, make it advisable to establish a Campanian / Maastrichtian age to the upper portion of the Bauru Group. In conclusion, there are no confirmed pre-Campanian age fossils in the Adamantina Formation.

Additionally, paleomagnetic data, and well-established microfossil correlations with Campanian / Maastrichtian Neuquen Basin strata, and the Deccan intertrappean beds of India, allows us to designate the Campanian as the oldest age for these deposits.

References

Dias-Brito, D., Musacchio, E. A, Castro, J. C., Maranhão, M. S. A. S., Suárez, J. M., & Rodrigues, R. (2001). Grupo Bauru: Uma unidade continental do Cretáceo no Brasil. Concepções baseadas em dados microplaeontológicos, isotópicos e estratigráficos. *Révue de Paléobiologie, 20*, 245-304.

Paula e Silva, F., Kiang, C. H., & Caetano-Chang, M. R. (2009). Sedimentation of the Cretaceous Bauru Group in São Paulo, Paraná Basin, Brazil. *Journal of South American Earth Sciences, 28*, 25-39.

Technical Session 3: Terrestrial Ecosystems – Late Jurassic (Friday, June 9, 2023, 11:45 AM)

THE ALBANERPETONTIDAE (LISSAMPHIBIA) FROM THE LOURINHÃ FORMATION (UPPER JURASSIC, PORTUGAL)

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The Albanerpetontidae are an extinct group of derived small ballistic-tongue-feeding amphibians. They ranged from the early Bathonian to the early Pleistocene and have been recovered from Europe, North America, Asia and North Africa (Carrano et al., 2022; Gardner & Böhme, 2008). Due to their small size, their fossil record is scarce and usually fragmentary, most generally recovered as isolated bones from vertebrate microfossil assemblages. The family currently comprises six genera: the type genus *Albanerpeton* (Early Cretaceous — Pleistocene of Central Asia, Europe and North America); *Anoualerpeton* (Bathonian — Berriasian of England and Morocco); *Shirerpeton* (Barremian of Japan); *Wesserpeton* (Barremian of England); *Yaksha* (Cenomanian of Myanmar); and *Celtedens* (Kimmeridgian — Albian of Europe), a genus previously reported from Portugal, among other European localities, which includes two valid species, *C. ibericus* (Barremian, Spain) and *C. megacephalus* (Albian, Italy).

Albanerpetontids were small animals, whose fossil record is fragmentary and scarce, most generally known only by isolated bones recovered by sieving. Therefore, albanerpetontid taxonomy is mostly based on few but highly diagnostic bones (Gardner, 2000), as the fused frontals, considered to be key to both identifying and diagnosing taxa at generic and specific level (Gardner, 2000; McGowan, 1998). However, recent works challenged such use, due to plasticity and intraspecific variation in the frontals and other bones (Guillaume et al., 2022; Sweetman & Gardner, 2013). In this work we present new material from the Lourinhã Formation (Kimmeridgian-Tithonian), which includes cranial and post-cranial elements, in order to better characterize the anatomy of the albanerpetontid from the Late Jurassic of Portugal (Figure 1).

Fused frontals exhibit bell-shaped outline, with a curved orbital margin and a broad, and blunt internasal process, diagnostic features for the genus *Celtedens*. However, they differ from *C. megacephalus* (Aptian-Albian, Italy) by having beveled ventrolateral crests, instead of V-shaped, and from *C. ibericus* by having more curved orbital margins. The paired premaxillae here described differ from those in *C. ibericus* (Barremian, Spain) by having a small, undivided suprapalatal pit facing laterolingually, instead of having it more medial and facing

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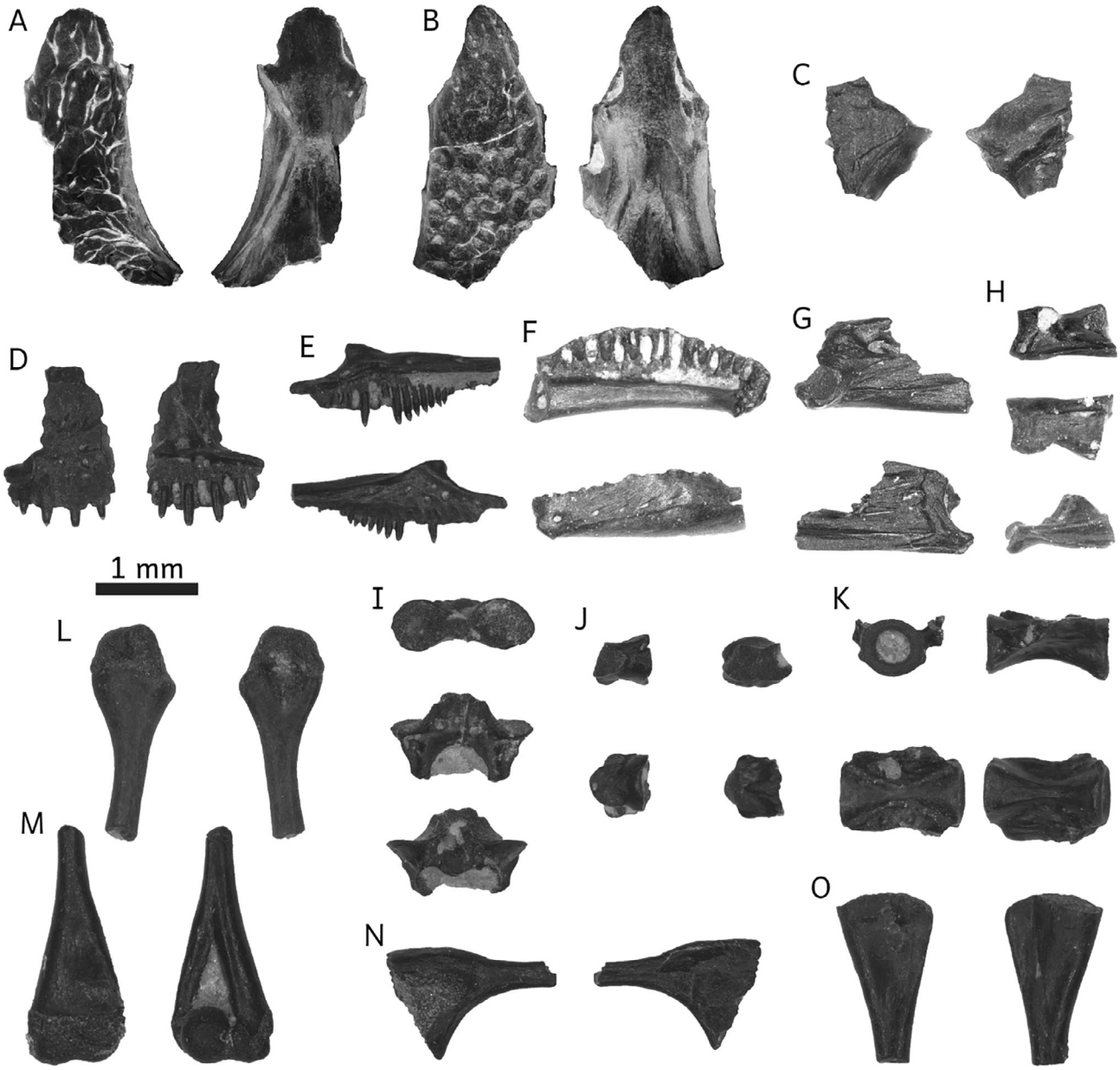


Figure 1. Albanerpetontidae indet. from the Lourinhã Formation (Upper Jurassic, Lusitanian Basin, Portugal). A, fused frontals from a juvenile individual; B, fused frontals from adult individual; C, right parietal with postorbital wing preserved; D, right premaxilla; E, right maxilla; F, left dentary; G, left articular; H, right quadrate; I, atlas; J, axis; K, dorsal vertebra; L, right proximal humerus; M, right distal humerus; N, left ilium; O, right proximal femur. Scale bar is 1mm.

lingually. However, this feature makes the Portuguese material similar to the premaxillae observed in the *Celtedens* sp. specimens of the Isle of Purbeck (Berriasian, England) and in both *Anoualerpeton priscum* (Bathonian, England) and *An. unicum* (Berriasian, Morocco). The triangular nasal process differs from the material of the Isle of Purbeck by having a round apex projecting slightly anteriorly instead of acute. The dentary exhibits a sinusoid convex dental parapet, a feature shared with *Anoualerpeton*, and the more derived *Shirerpeton* and *Albanerpeton nexuosum*; and a second canal, located dorsolabially of the closed Meckelian canal –a condition absent in the Isle of Purbeck specimens. The parietal differs from *C. megacephalus* by exhibiting a unique anteromedial-posterolateral transverse crest, separating the short ornamented postorbital wing from the rest of the bone. The articular differs from *C. megacephalus* and *Wesserpeton* in presenting a saddle-shaped cotylar facet less pronounced in the glenoid fossa, as observed in the material from Isle of Purbeck. Concerning the axial skeleton, the axis of the specimens from the Lourinhã Formation differs from that of the Isle of Purbeck taxon in

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having a dorsally hemmed anterior cotyle, instead of being smooth and more prominent. Finally, the ilium shares with *Wesserpeton* a dorsoventrally elongated acetabulum but differs from it and other ilia in presenting a strongly posteriorly-tilted long axis.

Our material supports the presence of a new species of Albanerpetontidae in the Upper Jurassic of Portugal, different from *Celtedens* as previously proposed (Wiechmann, 2000). Its affinities among the family remain to be determined, as the group requires a revision to tackle the recent conflicted hypotheses. Some affinities seem to be shared between our material and the one described from the Lower Cretaceous Isle of Purbeck from United Kingdom assigned to *Celtedens* sp. (McGowan & Ensom, 1997), such as the small suprapalatal pit facing laterolingually, the saddle-shaped cotylar facet in the glenoid fossa of the articular, the frontal bones with bell-shaped outline and a broad, and blunt internasal process. The material from the Lourinhã Formation shares strong affinities with the historic material from the Guimarota beds (Wiechmann, 2003): frontals outline and blunt internasal process; the presence of a lateral suprapalatal pit (which can be divided in Guimarota specimens), and the shape of the labial articular facet of the *pars dentalis* in the premaxilla; and the features in the dentaries, such as the sinusoid convex dental parapet, the labial ornamentation, and the second canal dorsolabially located of the Meckelian canal. However, some differences occur in the overlapping material: the axis possesses a prominent anterior cotyle, without hemmed ridges; the glenoid fossa of the articular exhibits a subvertical cotylar surface; and the presence of the dorsal edge facet of the *pars dentalis* in the premaxillae. However, due to the high number of specimens (over 300 from Lourinhã, several thousands from Guimarota) and their fragmentary nature, more work is still required to quantify and characterize the intraspecific variation and test to what degree these features are diagnostic of a separate species.

This material highlights the importance and the pressing need to describe more bones in Albanerpetontidae and include them in future works in order to solve the intricated relationships of this group.

References

Carrano, M. T., Oreska, M. P. J., Murch, A., Trujillo, K. C., & Chamberlain, K. R. (2022). Vertebrate paleontology of the Cloverly Formation (Lower Cretaceous), III: a new species of Albanerpeton, with biogeographic and paleoecological implications. *Journal of Vertebrate Paleontology, 41*, e2003372.

Gardner, J. D. (2000). Revised taxonomy of albanerpetontid amphibians. *Acta Palaeontologica Polonica*, *45*, 55-70.

Gardner, J. D., & Böhme, M. (2008). Review of the Albanerpetontidae (Lissamphibia), with comments on the paleoecological preferences of European Tertiary Albanerpetontids. In J. T. Sankey, & S. Bazio (Eds.), *Vertebrate microfossil assemblages: Their role in paleoecology and paleobiogeography* (pp. 178-218). Indiana University Press.

Guillaume, A. R., Natário, C., Mateus, O., & Moreno-Azanza, M. (2022). Plasticity in the morphology of the fused frontals of Albanerpetontidae (Lissamphibia; Allocaudata). *Historical Biology*, 1-18.

McGowan, G. J. (1998). Frontals as diagnostic indicators in fossil albanerpetontid amphibians. *Bulletin of the National Science Museum, Series C (Geology and Paleontology)*, *24*, 185-194.

McGowan, G. J., & Ensom, P. C. (1997). Albanerpetontid amphibians from the Lower Cretaceous of the Isle of Purbeck, Dorset. *Proceedings of the Dorset Natural History and Archaeological Society*, *118*, 113-117.

Sweetman, S. C., & Gardner, J. D. (2013). A new albanerpetontid amphibian from the Barremian (Early Cretaceous) Wessex Formation of the Isle of Wight, southern England. *Acta Palaeontologica Polonica*, *58*, 295-324.

Wiechmann, M. F. (2000). The albanerpetontids from the Guimarota mine. In T. Martin & B. Krebs (Eds.), *Guimarota: A Jurassic ecosystem* (pp. 51-54). Verlag Dr. Friedrich Pfeil.

Wiechmann, M. F. (2003). *Albanerpetontidae (Lissamphibia) aus dem Mesozoikum der Iberischen Halbinsel und dem Neogen von Süddeutschland* [Doctoral dissertation, Freie Universität Berlin].

Poster Session 1 (Thursday, June 8, 2023)

VERTEBRATE MICROFOSSIL ASSEMBLAGES FROM THE LOURINHÃ FORMATION: A SNEAK PEEK ON THE PALEOECOLOGY OF THE LATE JURASSIC IN PORTUGAL

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Vertebrates Microfossil Assemblages (VMAs) capture a time averaged, accurate record of their surrounding

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Table 1. Faunal composition of the three Vertebrates Microfossil Assemblages (VMA).

	Valmitão VMA	Zimbral VMA	Porto das Barcas VMA
Hybodontidae			x
Semionotidae	x	x	x
Pycnodontidae		x	
Caturidae	x	x	x
Albanerpetontidae	x	x	x
Anura indet.	x		
Caudata indet.	x		
Dryolestidae	x		
Multituberculata indet.	x		
Choristodera indet.	x	?	
Sauropterygia	x	x	
Plesiosaura indet.	x	x	
Sincomorpha	x	x	x
Atoposauridae	x	x	x
Bernissartiidae	x		
Goniopholidae	x	x	x
***Lusitanisuchus mitracostatus* (Seiffert, 1970)**	x		
Mesoeucrocodylia indet.	x		
Dromaeosauridae	x	x	
Megalosauridae	x	x	
Thyreophora indet.	x		
Neornitischia indet.	x	x	
***Phyllodon henkeli* Thulborn, 1973**	x		
Rhamphorhynchidae	x	x	

paleocommunities, share similar taphonomic history, and provide reliable signals for paleo-metacommunity analysis (Rogers et al., 2017). They provide a snapshot of the paleobiodiversity over the period of their formations and allow high-resolution information and, therefore, constitute a keystone for integrative paleoecological studies (Eberth et al., 2007; Gilbert et al., 2018). Despite their proven interests, the task of collecting microfossils is time consuming and in general produces relatively unimpressive fossils, which results in very few, well studied Mesozoic VMAs worldwide. Portugal represents one of the major data points for the Upper Jurassic, thanks to the Konzentrat-Lagerstätte of the Guimarota beds (Martin & Krebs, 2000). Nevertheless, despite other slightly younger VMAs that have been reported from the Alcobaça Formation (Malafaia et al., 2010) and the Lourinhã Formation (Guillaume, 2018), no extensive study has been carried out on them.

For this study, six samples of bulk rock have been collected in three different localities (Porto das Barcas, Zimbral, and Valmitão), representing a total sampling of over 150kg. From the 74kg of concentrates retrieved from screen-washing, over 17,000 fossil remains have been collected, among which 3328 vertebrates fossils could have been identified so far. This sample from three localities represent the first statistically significative approach to the microvertebrate diversity of the Lourinhã Formation and its paleoecology.

The Lourinhã Fm. is well known for its vertebrate fossils, mainly dinosaurs, including osteological, ichnological and oological remains of great importance (e.g., Antunes & Mateus, 2003; Fernandes et al., 2021; Mateus & Milàn, 2010). The Late Jurassic succession represents transitional to continental environments, (Hill, 1988) and was subdivided in five members: Praia de Amoreira Mbr., Porto Novo Mbr., Praia Azul Mbr., Assenta Mbr., and Santa Rita Mbr. (Hill, 1988). Traditionally, the formation has been characterized as fluvial and deltaic deposits with shallow marine intercalations, being the marine entrances more common in the Praia Azul Mb., in which three major transgressions have been recognized (e.g., Hill, 1988). The three localities described here are close to the Lourinhã village: Valmitão VMA is located in the upper part of the Porto Novo member while Zimbral VMA and Porto das Barcas VMA belong to the Praia Azul member.

In the Valmitão VMA (5 m-thick) is characterized by a multicolored succession of greyish and purplish silty marls, violet and orange mudstones, being common interbedded brownish sandstones. Strata are dm in thickness and show a tabular geometry. The fine-grained lithologies show massive texture and frequently carbonate nodules, while in the mudstones rhizoliths, rhizotubules and mottling are also very common. The fine to medium sandstones comprise massive or cross-laminated strata with some rounded extraclats (< 2 cm in diameter). Zimbral VMA (2.8 m-thick) involves greyish marls with occasional silty levels that comprise three massive tabular beds. The deposits coarsen upwards (m in thickness) and show coal or plants debris along the strata. Porto das Barcas VMA (3.75 m-thick) comprises massive tabular beds of dark marls with occasional silts and very coarse sandstones interbedded. They form five, dm in thickness, coarsening upwards sequences based on an increase in

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grain size, intraclasts and bioclasts occurrence. The bioturbation or nodulization are practically absent.

The three localities are dominated by fine-grained deposits but show clear differences in colors, terrigenous fraction and degree of pedogenesis. The variegated colors, lack of grading, coupled with more carbonate nodules and rhizocasts in the Valmitão locality suggest an environment with low sediment supply and long periods of subaerial exposure. The greyish sediments in Zimbral exhibit coal remains and poor development of nodules related to oscillations in the water availability, implying an area of alternating conditions between wet and dry periods. Finally, the very low degree of pedogenesis and the dark-colored materials of Porto das Barcas site indicate wetter conditions, probably associated with permanent sheet of water and anoxic environments.

All localities yielded a multi-individual, multi-taxic accumulation of fragmented and isolated bones (Table 1), in which teeth and fish scales are the most common vertebrate remains. Osteichthyes, Crocodylomorpha and Amphibia are the most represented clades, while Dinosauria and Crocodylomorpha are the most diverse (Figure 1A). Although obligate aquatic taxa remains are the most abundant in each VMA, these taxa represent the lower diversity (Figure 1B). Valmitão VMA is dominated by facultative and amphibious taxa, suggesting it was the most continental of the assemblages, sharing taphonomic similarities the Uña assemblage, from La Huérguina Fm (Buscalioni et al., 2008). Zimbral VMA faunal assemblage is close to the one observed in the Cloverly Fm, being rich in amphibious taxa (Oreska et al., 2013). This would suggest that Zimbral would have been a terrestrial ecosystem, more coastal than Valmitão, which was more upstream. In the contrary, Porto das Barcas VMA seems to have less continental influence compared to the two others VMAs, which is congruent with the presence of hybodontid

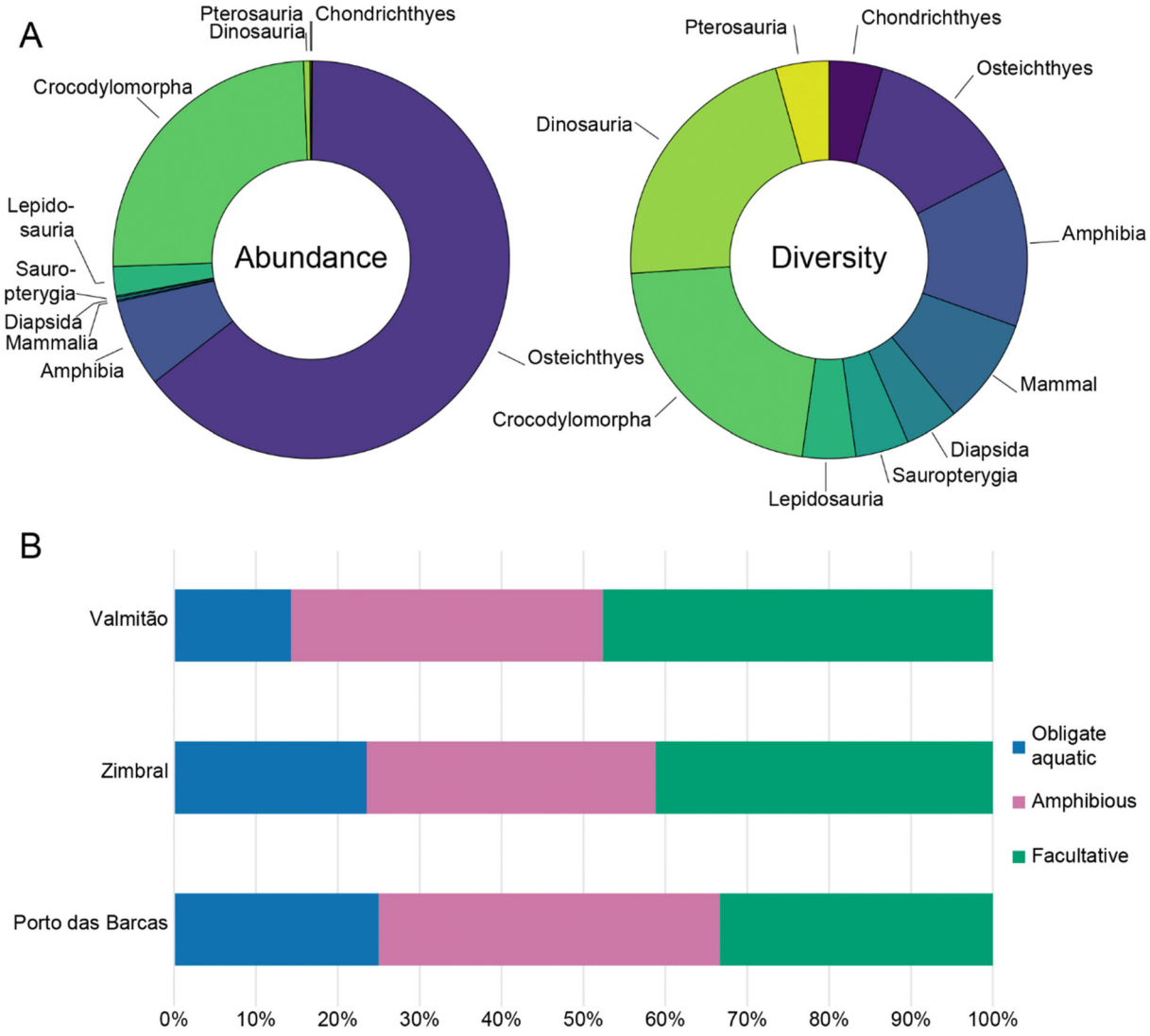


Figure 1. A, taxonomic abundance and diversity in the VMAs from the Lourinhã Formation; and **B**, faunal assemblages between the three assemblages used in this study.

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sharks and the large number of invertebrate shells recovered in the assemblage. This taphonomic signal is shared with Buenache and Las Hoyas, interpreted as swamp and lacustrine environments (Buscalioni et al., 2008, 2018) but Porto das Barcas is relatively less diverse in obligate taxa, which could be a reflection of a much smaller size.

The analysis of the vertebrate microfossil assemblages, coupled with a detailed sedimentological analysis, shows that the degree of marine influence in the late Jurassic paleoenvironments recorded by the Lourinhã Formation is much more marked than previously identified. Interestingly, the dominance of obligate aquatic and amphibious faunas in the VMAs of the Praia Azul member points towards a more transitional environment, excluding the three well known transgression levels.

References

Antunes, M. T., & Mateus, O. (2003). Dinosaurs of Portugal. *Comptes Rendus Palevol, 2*, 77-95.

Buscalioni, A. D., Martín-Closas, C., Delvene, G., Munt, M., Barral, A., Tinner-Grellet, G., Gomez, B., Daviero-Gomez, V., & Chamero, B. (2018). Taphonomy and palaeoecology in the upper Barremian of the SW Iberian chain (Spain): A model to compare taxonomy and diversity of biotas from different coeval basins. *Palaeogeography, Palaeoclimatology, Palaeoecology, 490*, 305-324.

Buscalioni, A. D., Fregenal, M. A., Bravo, A., Poyato-Ariza, F. J., Sanchíz, B., Báez, A. M., Cambra-Moo, O., Martín-Closas, C., Evans, S. E., & Marugán-Lobón, J. (2008). The vertebrate assemblage of Buenache de la Sierra (Upper Barremian of Serrania de Cuenca, Spain) with insights into its taphonomy and palaeoecology. *Cretaceous Research, 29*, 687-710.

Eberth, D. A., Shannon, M., & Noland, B. G. (2007). A Bonebeds Database: Classification, Biases, and Patterns of Occurrence. In R. R. Rogers, D. A. Eberth, & A. R. Fiorillo (Eds.), *Bonebeds: Genesis, analysis, and paleobiological significance* (pp. 103-219). University of Chicago Press.

Fernandes, A. E., Mateus, O., Bauluz, B., Coimbra, R., Ezquerro, L., Núñez-Lahuerta, C., Suteu, C., & Moreno-Azanza, M. (2021). The Paimogo dinosaur egg clutch revisited: Using one of Portugal's most notable fossils to exhibit the scientific method. *Geoheritage, 13*, 1-17.

Gilbert, M. M., Bamforth, E. L., Buatois, L. A., & Renaut, R. W. (2018). Paleoecology and sedimentology of a vertebrate microfossil assemblage from the easternmost Dinosaur Park Formation (Late Cretaceous, Upper Campanian,) Saskatchewan, Canada: Reconstructing diversity in a coastal ecosystem. *Palaeogeography, Palaeoclimatology, Palaeoecology, 495*, 227-244.

Guillaume, A. R., D. (2018). *Microvertebrates of the Lourinhã Formation (Late Jurassic, Portugal)* [Master's thesis, Universidade de Lisboa].

Hill, G. (1988). *The sedimentology and lithostratigraphy of the Upper Jurassic Lourinhã Formation, Lusitanian Basin, Portugal* [Doctoral dissertation, The Open University]. https://doi.org/10.21954/ou.ro.0000d526

Malafaia, E., Ortega, F., Escaso, F., Dantas, P., Pimentel, N., Gasulla, J. M., Ribeiro, B., Barriga, F., & Sanz-López, J. (2010). Vertebrate fauna at the Allosaurus fossil-site of Andres (Upper Jurassic), Pombal, Portugal. *Journal of Iberian Geology, 36*, 193-203.

Martin, T., & Krebs, B. (2000). *Guimarota: A Jurassic ecosystem*. Verlag Dr. Friedrich Pfeil.

Mateus, O. & Milàn, J. (2010). A diverse Upper Jurassic dinosaur ichnofauna from central-west Portugal. *Lethaia, 43*, 245-257.

Oreska, M. P., Carrano, M. T., & Dzikiewicz, K. M. (2013). Vertebrate paleontology of the Cloverly Formation (Lower Cretaceous), I: Faunal composition, biogeographic relationships, and sampling. *Journal of Vertebrate Paleontology, 33*, 264-292.

Rogers, R. R., Carrano, M. T., Rogers, K. A., Perez, M., & Regan, A. K. (2017). Isotaphonomy in concept and practice: an exploration of vertebrate microfossil bonebeds in the Upper Cretaceous (Campanian) Judith River Formation, north-central Montana. *Paleobiology, 43*, 248-273.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 9:00 AM)

THE FAUNA OF THE LOWER BURGERSDORP FORMATION (CYNOGNATHUS ASSEMBLAGE ZONE – LANGBERGIA SUBZONE) OF SOUTH AFRICA

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The Burgersdorp Formation is a non-marine fluvio-lacustrine succession of siliciclastic rocks at the top of the Tarkastad Subgroup (Beaufort Group; Karoo Supergroup) deposited in the main Karoo Basin in South Africa from

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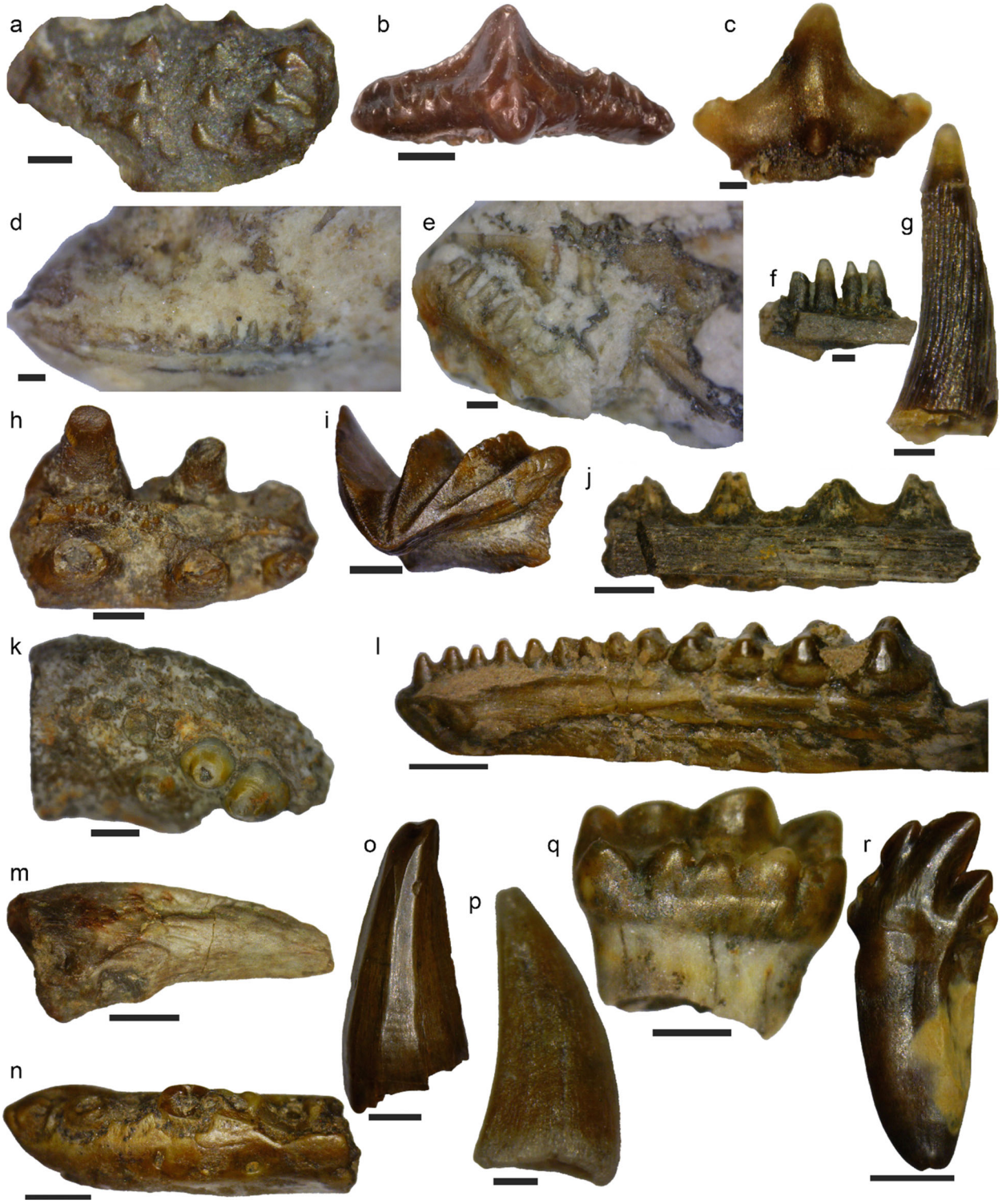


Figure 1. Representative vertebrate fossils from the *Langbergia-Garjainia* subzone of the *Cynognathus* Assemblage Zone, Driefontein, South Africa. a, incomplete jaw fragment with 14 teeth of *Lissodus* n. sp. in occlusal view; b, tooth of *Polyacrodus* n. sp. in occlusal view; c, tooth of a new hybodont in labial view; d-e, close-up views of jaw fragments preserved in coprolites; f, actinopterygian jaw fragment; g, actinopterygian tooth; h, saurchthyiid jaw fragment in occlusal view; i, toothplate of the lungfish *Ptychoceratodus* sp. in occlusal view; j, temnospondyl jaw fragment in side view; k, procolophonid palate fragment in occlusal view; l, nearly complete jaw of the *Palacrodon* in medial view; m, archosauromorph ungual; n, archosauromorph dentary fragment in lateral view; o, archosauriform tooth in labial view; p, archosauriform tooth in labial view; q, bauriid cynodont molariform tooth; R, cynodont sectorial tooth in labial view. Scale bars = 0.2 mm (a, c-g, p); 1.0 mm (b, h, j-k, q), and 2.0 m (I, l-o, r).

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the Early to Middle Triassic. The lowermost part of the Formation records a rich and diverse Early Triassic (upper Olenekian) fauna that is referred biostratigraphically to the *Langbergia-Garjainia* subzone of the *Cynognathus* Assemblage Zone, one of the most durable tetrapod biostratigraphic concepts of the Triassic (Hancox et al., 2020).

The fauna of the *Langbergia-Garjainia* subzone is of particular importance as it documents the recovery of life some three to four million years after the end-Permian mass extinction, an event that dramatically impacted and remodeled global ecosystems.

The fully terrestrial component of the macrofauna includes the cynodonts *Cynognathus craternotus* and *Langbergia modisei*, the therocephalian *Microgomphodon oligocynus*, eucynodont teeth, the enigmatic diapsid *Palacrodon browni*, and as of yet undescribed procolophonoids (Figure 1). It is of interest to note that all are fairly small animals, and most have been previously proposed as burrowers (Smith & Botha, 2005).

The remainder of the macrofauna comprises a relatively high diversity of temnospondyl amphibians, which are also the most abundant fossils found. Taxa include the mastodonsaurids *Kestrosaurus dreyeri* and *K. kitchingi, Parotosuchus haughtoni*, the trematosuchid *Trematosuchus sobeyi* and the brachyopid *Bathignathus poikilops*. Archosauromorphs are currently represented only by the erythrosuchid archosauriform *Garjainia madiba*. All large forms seem to have a dominantly piscivorous diet. Despite extensive collecting, no dicynodonts are yet documented from this subzone.

Archosauromorphs in particular underwent a major phylogenetic diversification in the Olenekian, characterized by significantly elevated evolutionary rates, with the origins or initial diversification of major clades such as rhynchosaurs, archosaurs, erythrosuchids and tanystropheids. Certain localities also fill an important sampling gap in the diapsid fossil record by sampling small members of the assemblage. Study of isolated diapsid teeth from the microvertebrate assemblage provide evidence of seven distinct tooth morphotypes (e.g., Figure 1o-p), only one of which may be attributed to *Garjainia*. Five of the seven morphotypes are faunivorous with the other two potentially omnivorous or piscivorous based on morphological similarities to dentitions of known diet (Hoffman et al., In review). Coupled with studies of other cranial and postcranial material, this work has shown a higher diversity of diapsids than is documented by the other macro-faunal remains.

The remaining microvertebrate fauna remains largely undescribed, however the discovery of this diverse assemblage of small vertebrates is important, as previously only the Czatkowice quarry in Poland and the Arcadia Formation in Australia have produced large samples of Early Triassic microvertebrate remains.

Micro-fossil remains have also shown that a diverse actinopterygian, sarcopterygian and chondrichthyan fish fauna exists in the form of thousands of isolated cranial bones, teeth and scales. At present only the actinopterygian *Saurichthys* sp., the dipnoan *Ptychoceratodus phillipsi* and the chondrichthyan *Lissodus* sp. are documented in the literature (Bender & Hancox, 2004), however, recent work has shown that three hybodontid taxa, including new species of *Lissodus* and *Polyacrodus* occur (Figure 1a-c). Hybodontid material comprises thousands of extremely small ($\leq$ 2.5 mm long and 1.5 mm high) tooth crowns from multiple tooth positions, a few well preserved teeth with roots, and a single jaw fragment, which preserves approximately 12 teeth in parts of four tooth whorls (Figure 1a). Dozens of fin spine fragments and several cephalic spines are assignable to *Lissodus* sp. This new material is particularly important given the rarity of Early Triassic hybodonts in non-marine settings. Additionally, the *Lissodus* species differs from *Lissodus africanus* from the overlying *Trirachodon-Kannemeyeria* subzone and shows that even isolated *Lissodus* teeth may be useful in a biostratigraphic context.

All recovered chondrichthyan, actinopterygian, and sarcopterygian (dipnoan) fossils are diminutive in size. Given the large sample size this cannot be an artefact of sampling and their diminutive nature may represent an ongoing Lilliput effect amongst these taxa following the end Permian extinction event (Romano et al., 2020).

Tens of thousands of vertebrate coprolites of various morphologies have also been collected from the subzone, including the coprotaxa *Alococopros triassicus*, *Eucoprus cylindratus*, *Hyronocopros amhipola* and *Heteropolacopros* sp. These coprolites provide unique information on digestive systems, diets, and ecosystems of extinct animals, including preserved prey items (Figure 1d-e). Despite their broad utility, scientific enquiry into Early Triassic coprolites is relatively scarce. Previous work has shown that these coprolites contain both vertebrate and invertebrate remains, including beetles and the earliest Post-Paleozoic freshwater bivalves, and it is possible that South Central Africa hosted the initial freshwater radiation of the Unionoida. Micro-CT has also recently been used to characterize the coprofabrics and coprolite inclusions, with three different coprofabrics characterized, showing varying digestive strategies amongst the coprolite makers (Montgomery, 2022).

To conclude, collecting over the past three decades in the *Langbergia-Garjainia* subzone in the main Karoo Basin of South Africa has shown that the late Olenekian documents a period of diversification following the end Permian mass extinction, with a marked increase in species

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counts, abundance, and disparity, contemporaneous with global ecosystem stabilisation, but with simultaneous restriction of many nonmarine taxa to small body size.

References

Bender, P. A., & Hancox, P. J. (2004). Newly discovered fish faunas from the Early Triassic, Karoo Basin, South Africa, and their correlative implications. *Gondwana Research, 7*, 185-192.

Hancox, P. J., Neveling, J., & Rubidge, B. S. (2020). Biostratigraphy of the *Cynognathus* Assemblage Zone (Beaufort Group, Karoo Supergroup), South Africa. *South African Journal of Geology, 123*, 217-238.

Montgomery, C. (2022). *Application of Micro Computed-Tomography in the characterisation of Early Triassic coprolite microstructures and microfossils from the Burgersdorp Formation (Tarkastad Subgroup, Beaufort Group) of South Africa* [Doctoral dissertation, University of the Witwatersrand].

Romano, M., Bernardi, M., Petti, F. M., Rubidge, B., Hancox, J., & Benton, M. J. (2020). Early Triassic terrestrial tetrapod fauna: a review. *Earth-Science Reviews, 210*, 103331.

Smith, R., & Botha, J. (2005). The recovery of terrestrial vertebrate diversity in the South African Karoo Basin after the end-Permian extinction. *Comptes Rendus Palevol, 4*, 623-636.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 9:15 AM)

USING THE DIVERSITY AND DISTRIBUTION OF VERTEBRATE BURROWS TO RECONSTRUCT PALEOECOLOGICAL RELATIONSHIPS IN THE LOWER JURASSIC NAVAJO SANDSTONE, SOUTHEASTERN UTAH

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Most of what is known about the paleocommunities and paleoecological relationships between organisms that existed during the deposition of the Navajo Sandstone (Ss) comes from strata that contain co-occurring trace fossils produced by microbes, plants, invertebrates, and vertebrates. These trace fossils, along with body fossils, primary and secondary sedimentary structures, lithofacies associations, and hierarchical bounding surfaces, allow for the reconstruction of the paleoecological settings in which they are preserved and the hydroclimate under which they formed. Most previous studies have focused only on vertebrate tracks and trackways or on the morphologic descriptions of invertebrate trace fossils, neither of which includes much, if any, paleoecological context within or between these disparate groups of organisms. Here we discuss the paleoecological significance of the diversity and distribution of vertebrate burrows to the desert ecosystems preserved in the eolian and non-eolian deposits of the Navajo Ss erg strata. Like their modern analogs, the burrowing activity of the vertebrates in the Navajo Ss had an effect on such environmental and ecological factors as biotic diversity, trophic structure, water infiltration, subsurface aeration, sediment mixing, nutrient distribution, and habitat creation.

Six morphotypes of vertebrate burrows were discovered in the Navajo Ss around the Moab, Utah, area (Figure 1). Their occurrence appears to be mostly mutually exclusive of each other and exact relationships are incomplete based on their limited exposures. Morphotypes are generally numbered and arranged in order of increasing size and complexity. Morphotypes (M) I, II, and III are subhorizontal or gently inclined ($\leq 15^\circ$ angle) and gently curved burrows with elliptical cross sections (Length-to-Width ratio [L:W] of ~2:1). Most well-preserved burrows exhibit a medial ridge along the base. The surficial morphology of these burrows contains thin and elongated, subparallel scratch marks along the floor and walls, with some exhibiting transverse scratch marks on the upper parts of the walls and ceiling. These burrows are tentatively assigned to *Reniformichnus*, with three size ranges of diameter and length that do not overlap in size: 1) M-I is $\leq$ 7 cm in diameter; 2) M-II is $\leq$ 15 cm in diameter; and 3) M-III is $\leq$ 40 cm in diameter. Morphotype IV is inclined at $\leq 30^\circ$ and less gently curved compared with the other traces. The elliptical cross section has a L:W ratio of ~1.4:1 as well as a medial ridge along the base of the burrow that is more subtle compared to M-1–III burrows. The surficial morphology of these burrows also contains thin and elongated, subparallel scratch marks but mostly along the boundary between the floor and walls of the burrow. Morphotype IV burrows are incredible: one burrow example measures over 4 m long with a diameter of ~85 cm wide and 60 cm tall. Morphotypes V and VI exhibit much more complicated architectural morphology compared to morphotypes I–IV. Morphotype V burrows exhibit high-density networks of

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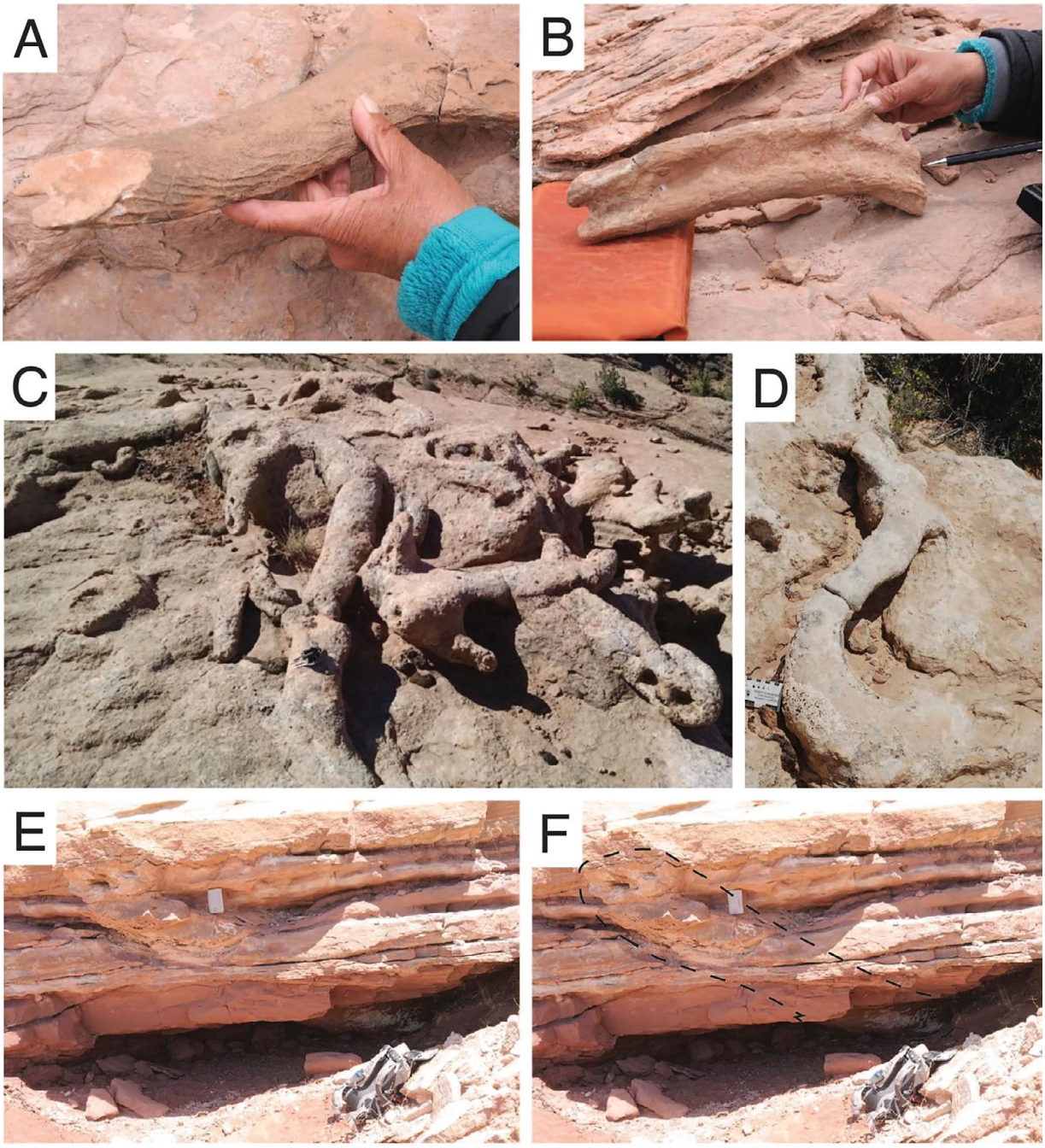


Figure 1. Examples of vertebrate burrow morphologies from the Navajo Sandstone from the Moab, Utah, area. A, B. Morphotype I burrow with W-shaped cross-section and longitudinal scratches; burrow diameter is is 6 cm. C, D. Morphotype V burrow complex with variable burrow diameters, Y- and T-branching, and inclined ramps; scale card in D is 8 cm wide. E, F. Morphotype IV burrow with outline of burrow trace penetrating into the outcrop but exposed by erosion of finer grained material at the base and within the outcrop shown by the dashed line in E. Notebook is 21 cm tall.

subhorizontal to horizontal tunnels, with diameters of ~4 to 21 cm wide in and ~1 to 10 cm tall (average width-to-height ratio 2.2) that are irregularly interconnected at Y- and T-branched tunnels and inclined ramps. The whole of each complex is preserved as differentially weathered circular to elliptical, low-relief mounds ~1-m tall and 40 m by 40 m to 10 m by 15 m in plan view. The surficial morphology of these burrows is mostly smooth but some exhibit paired scalloped features along the walls. Morphotype VI burrows display similar complex morphology as M-V burrows, but overall the tunnels are larger in diameter (15–30 cm wide), fewer in number, with fewer Y- and T-branched connections, and are not associated with any distinct mounds

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The range of architectural morphologies suggests multiple genera and species of burrowing vertebrates that reflect construction by reptiles, therapsids, and/or mammals based on comparison to modern and other ancient burrow morphologies. Morphotypes V and VI were most likely constructed by mammals. Morphotype IV was most likely constructed by a very large therapsid. Morphotypes I–III were likely constructed by reptiles, therapsids, and/or mammals. The body fossil record of non-dinosaurian vertebrates in the Navajo Ss is so scant in comparison to the great diversity and abundance of these burrows that the body fossils not provide much information for the identification of the burrow constructors.

These burrows also provide information about the environments and ecology of the Navajo erg at their time of construction. For the most part, the stratigraphic occurrence of burrows indicate that the landscape was relatively stable in a depositional system dominated by migrating dunes and interdunes. The stabilization of ergs is related to the amount of overall precipitation, which, by today's global climate condition (Icehouse and currently interstadial), would have been > 15 cm in equatorial regions. This stabilization due to the greater presence of water in the system would have had on effect on the trophic structure of the erg ecosystems, beginning with the presence of vegetation, including sparse to abundant ground cover, shrubs, and/or trees. The surfaces where the trace fossils are found also have abundant plant fossil traces and sometimes body fossils. The burrowing reptiles, therapsids, and mammals would have occupied the roles of lower-level carnivores, omnivores, and/or herbivores, feeding on a variety of lower trophic level arthropods and smaller vertebrates, which, in turn, would have been consumers of other arthropods and vegetative matter. The occurrence of the footprints *Grallator* and *Eubrontes* indicate that the top predator in the ecosystem would have been a theropod similar in size to *Dilophosaurus*. Its presence, hypothetically, could have also provided lower-level predators opportunities to prey on eggs and hatchlings.These burrows, themselves, played a major role in pedogenesis and nutrient dynamics within the erg ecosystem, based on studies of burrowing vertebrates in arid and semiarid terrestrial ecosystems as analogs for the ancient settings. Vertebrate burrows, regardless of diameter, length, and depth, improved rainfall infiltration, air exchange between the atmosphere and the soil atmosphere, and biogenic mixing and/or turnover of the near-surface sediment. In terms of habitat modification, these burrows likely provided shelter for smaller vertebrates and much smaller invertebrates, particularly when abandoned by the constructor, as well as for enhanced germination of seeds by providing them a conduit into the subsurface.

Poster Session 2 (Friday, June 9, 2023)

A FRAMEWORK TO CONSTRUCT EOLIAN ICHNOCOENOSES AND ICHNOFACIES: EXAMPLES FROM THE LOWER JURASSIC NAVAJO SANDSTONE, SOUTHEASTERN UTAH

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Research on the distribution of microbial, plant, invertebrate, and vertebrate trace fossils in the Lower Jurassic Navajo Sandstone (Ss) demonstrate that they are intimately associated with bedding planes, bounding surfaces, and sedimentary deposits on and in which they are preserved. These observed relationships can be used to identify unique trace fossil-lithofacies associations that reflect distinct physicochemical controls and may be used to construct ichnofacies. The two previously proposed eolian ichnofacies models defined by the "presence or absence of surface water and climate" are overly generalized and lack the context of patterns and recurrence and well-defined hydrologic and hydroclimatic parameters. Here, we discuss the problems with eolian ichnofacies and potential solutions constructing ichnocoenoses (trace-fossil communities) and ichnofacies to illustrate better the distribution of trace fossils in eolian deposits, and use them to interpret environments, ecology, and hydroclimate.

The concept of ichnofacies was developed by Seilacher (1967) for recurring marine trace fossil-lithofacies associations through geologic time, from the Cambrian and up through the Quaternary, with representatives of these associations to the modern analog environments. These ichnofacies––Skolithos, Glossifungites, Cruziana, Zoophycos, and Nereites––reflected facies-controlled (i.e., environmental) and physicochemical conditions that determined the distribution of epibenthic- and endobenthic-tracemaking organisms. These ichnofacies were originally created to reconstruct paleowater depth; however, they do still represent biophysicochemical trends of organisms from shallow, proximal to deep, offshore settings in basins dominated by marine environments (i.e., depositional systems).

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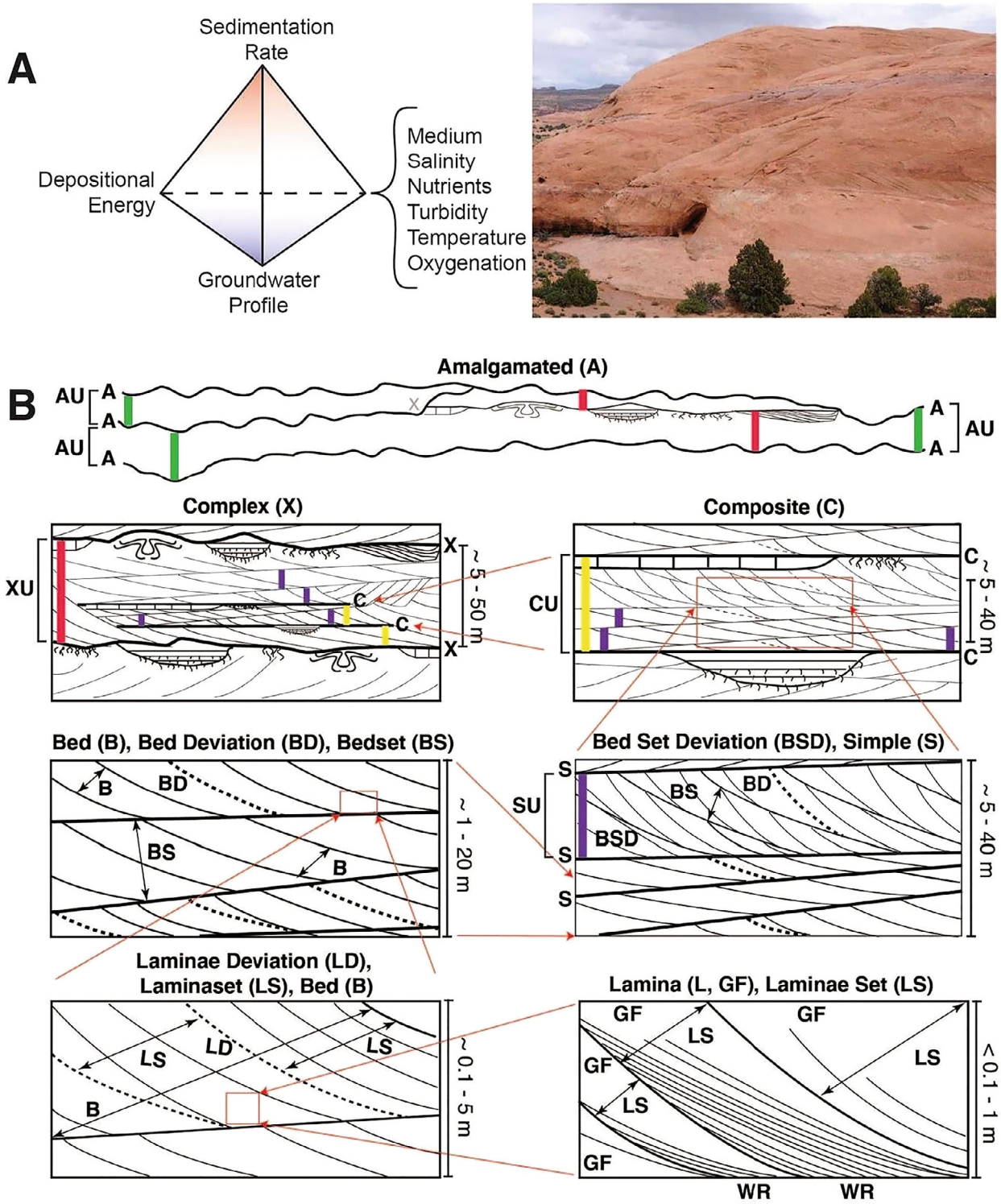


Figure 1. Controls on continental trace fossil distribution and surface hierarchy in erg systems. A. Tetrahedron of physicochemical controls on the distribution of organism behaviors and trace fossils, particularly critical in deserts. B. Hierarchy of surfaces with potential to be used to construct ichnofacies that accurately reflect hierarchies of trace fossil-lithofacies associations; U=units bound by surfaces of similar or higher order (modified from Hasiotis et al., 2021).

Seilacher also created a sole ichnofacies for entirety of continental deposits––the Scoyenia Ichnofacies––based on the trace fossil Scoyenia in Permian fluvial deposits to encompass all "non-marine redbed environments." Since that time, numerous continental (preferred to the use of non-marine, which literally means not marine)

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ichnofacies have been proposed, modified, and remodified for nearly all environments represented by continental depositional systems. However, all of these ichnofacies suffer from being narrowly defined, constructed, and understood poorly in terms of the biophysicochemical controls that they represent. The premise for continental ichnofacies construction is purported to be their recurrent, archetypal or representative nature in the geologic record that parallels the construction of Seilacherian ichnofacies. This approach using inductive reasoning for the parallel construction continues to plague continental ichnology, including the more recently proposed and modified ichnofacies for eolian deposits: the Octopodichnus-Entradaichnus and the Chelichnus ichnofacies.

The physicochemical factors that control the distribution of organisms—and thus trace fossils—in erg settings are spatially and temporally heterogeneous on multiple levels. First and foremost, in the continental realm, the groundwater profile, combined with climate, controls the distribution of continental tracemaking organisms in terrestrial and aquatic environments. Thus, the vast majority of trace fossils are not mainly controlled by sedimentary facies but by the postdepositional, physicochemical conditions of the environment in which they live. This means that the traces of organisms reflect a range of moisture regimes that compose the groundwater profile, which is separate from depositional processes that produce sedimentary facies. Furthermore, distribution of biota is also shaped by the sedimentation rate, depositional energy, the frequency, magnitude, and time between depositional events based on the depositional process in that environment. Therefore, the spatial and temporal heterogeneity in erg systems results in autogenic and allogenic processes that produce a hierarchy of surfaces that bound terrestrial and aquatic erg deposits. These surfaces also bound the trace fossil-lithofacies associations that are used to define ichnocoenoses (i.e., trace-fossil association as a proxy for communities) and used to define ichnofacies, if, and only if a well-defined, recurrent pattern can be determined. Bounding surfaces are important to defining ichnocoenoses and ichnofacies as they reflect the degree of exposure time and stability of a particular part of the landscape (Figure 1).Our research in the Navajo Ss demonstrates that trace fossils-lithofacies associations are defined by a hierarchy of surfaces that bound eolian and non-eolian deposits and that captures the spatial and temporal variability of the landscapes in this erg system. Recognition of these relationships provides a critical starting point to understand the distribution of traces in erg deposits. Trace fossils preserved in eolian and non-eolian deposits are bounded by surfaces that define conterminous and contemporaneous strata formed by the processes related to one or more allogenic changes in the groundwater profile, sedimentation, tectonics, and climate. Because trace fossil preservation, degree of bioturbation, and pedogenesis are ultimately controlled by the local, regional, and basinal hydroclimate, the patterns that result from their associations with bounding surfaces can be used to construct more objective and informative ichnocoenoses that reflect the biological response to autogenic and allogenic processes preserved eolian and non-eolian surfaces and sedimentary units. These ichnocoenoses and their recurrent patterns through geologic time may eventually be used to construct ichnofacies that accurately reflect the biophysicochemical processes of erg systems.

Poster Session 3 (Saturday, June 10, 2023)

LOCATING SUBSURFACE FOSSILS USING STATISTICAL ANALYSIS OF GAMMA DETECTION

Heck, Mariah; Mohler, Sherman; Sickles, Craig; Noviello, Jessica L.; Hoffman, Derek; Thrasher, Larry; Borst, Jenny; Mohler, Benjamin
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During the process of fossilization, a higher proportion of available radioactive elements can mineralize into bone microstructure largely due to apatite's affinity for uranium and rare earth elements. In certain geological circumstances and formations, the proportion of gamma radiation from fossilized bone in the subsurface is distinctly higher than that of the surrounding matrix, making it possible to detect fossils without surface exposure. These high gamma counts could be used as a guide for excavation, saving time and effort of prospecting.

Previous work by R. Jones, D. Burge, and D. J. Chure (1997, 1998) successfully utilized a single tube Geiger counter to locate such fossils in the subsurface, with lead shielding to eliminate background radiation. Our approach is to leverage multiple gamma detecting nodes simultaneously and use statistical methods to remove background radiation, eliminating the need for heavy shielding. This results in a lightweight detector that is easy to carry in the field. The Beautiful Analytical Bone Sensor (BABS) is an assembly of six tubes that detect gamma radiation, driven by microcontrollers that working individually and in clusters to capture radiation. The BABS establishes a baseline sample representing the local

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background radiation and compares subsequent readings in areas of interest using statistical analyses. The output is a table of z-scores and Poisson probabilities representing the likelihood of a fossil present in the substrate underlying the detector.

The immediate result in the field is a rough guide of recommended digging locations, based on variations in radiation levels. In post-processing, the readings can be rendered as a heat map of recorded confidence scores that can be manipulated to exclude values under a certain threshold. Further refinement produces a more precise guide for further exploration. Testing in a controlled lab environment demonstrates that 2.4 Ma fossilized camelid limb bones from the 111 Ranch Beds in Graham County, AZ, can be detected with 95% confidence under more than 30 cm of matrix with a two-node detector. In the field, we have been able to reliably detect the locations of fossils we knew to be under the surface and created heat maps of nearby locations to guide future excavation efforts.

Recent improvements to BABS include the addition of larger gamma detecting tubes producing greater sensitivity. Future upgrades in consideration are: plastic shielding to filter out other radionuclides, which may fluctuate more erratically than gamma radiation and may be a confounding factor in the detector's accuracy; and adjustable supports to keep the detector evenly leveled over rough ground.

References

Jones, R., & Burge, D. (1997). The successful application of radiological survey instruments to map bone locations and aid excavation at a Lower Cretaceous, Cedar Mountain Formation, dinosaur quarry. *New Mexico Museum of Natural History and Science*, *14*, 319-330.

Jones, R., & Chure, D. J. (1998). The recapitation of a Late Jurassic theropod dinosaur: A successful application of radiological surveying for locating subsurface fossilized bone. *Gaia*, *15*, 103-110.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 10:00 AM)

AN EXCEPTIONALLY RICH UPPER TRIASSIC MICROVERTEBRATE SITE FROM THE ?EARLY REVUELTIAN (MID-NORIAN) GARITA CREEK FORMATION OF EAST-CENTRAL NEW MEXICO, USA

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Upper Triassic strata of the American Southwest (?Carnian–Rhaetian) help to reveal the major diversification of amniotes following the end-Permian extinction. These fossiliferous deposits record the radiations of many important groups, including large-bodied archosauromorphs and smaller-bodied forms such as lepidosauromorphs and lissamphibians. Particularly important to documenting these evolutionary events are fossils of small body size. Microvertebrate assemblages from the southwestern USA are known from four biostratigraphic intervals (Otischalkian, Adamanian, Revueltian, and Apachean, in ascending order), but the overwhelming majority are of Adamanian age. Here we describe the stratigraphic context and provide preliminary taxonomic identifications of a new, highly diverse Revueltian microvertebrate assemblage, the "Homestead Site", from the Upper Triassic Garita Creek Formation of east-central New Mexico. With material of at least 20 taxa thus far, the site represents one of the most diverse Revueltian assemblages known and provides insight into the rise of the archosauromorph-dominated assemblages of the Late Triassic.

The Homestead ichthyoassemblage includes teeth of the chondrichthyan *Reticulodus*, numerous actinopterygian scales and teeth, coelacanth cranial fragments, and lungfish tooth plates assigned to *Arganodus*. Tetrapod fossils are abundant and diverse. Fragmentary larger fossils represent temnospondyl amphibians (metoposaurids), phytosaurs, aetosaurs (*Typothorax*) and a rauisuchid. The microvertebrate assemblage is extremely rich, and includes several small temnospondyls, lepidosauromorphs, two drepanosauromorphs, a taxon with tricuspid to pentacuspid teeth of uncertain affinities, and diverse archosauromorphs. Archosauromorphs include early-branching forms such as trilophosaurids and tanystropheids as well as crown-group archosaur taxa such as shuvosaurids, crocodylomorphs, and dinosauromorphs, including probable theropods.

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The Homestead Site occurs low in a red-bed section of rock that is stratigraphically equivalent to, and in a continuous outcrop belt with, the type section of the Garita Creek Formation. These exposures generally consist of fine-grained, slope-forming floodplain deposits interbedded with ledge-forming sandstones and conglomerates that represent channels. The existing vertebrate record of the Garita Creek Formation is sparse but has traditionally been accepted as Adamanian based on a few biostratigraphically important, but fragmentary, fossils. Stratigraphic, revised biostratigraphic, and assemblage evidence, however, indicate a Revueltian age for the Homestead Site. We hypothesize that much of the Garita Creek Formation is actually stratigraphically equivalent to the Bull Canyon Formation, which has yielded abundant fossils, including the type assemblage of the Revueltian.

The Homestead Site yields abundant fossils of the chondrichthyan *Reticulodus*, which is known from youngest-Adamanian assemblages but is much more abundant in strata of Revueltian age. Additionally, the drepanosauromorphs from the site are also more consistent with those from other clearly Revueltian-aged assemblages. The absence of Adamanian index taxa, including *Crosbysaurus, Krzyzanowskisaurus*, *Colognathus* "*Xenacanthus*," and other fossils typical of the Adamanian, also points to a Revueltian age. Furthermore, the absence of the early Revueltian (Barrancan) index fossil *Revueltosaurus callenderi* suggests that the assemblage may even be from the younger part of the Revueltian. To date, the macrofossil assemblage is too fragmentary to assess at the genus level, but abundant osteoderm fragments from the Garita Creek Formation are best assigned to the aetosaur *Typothorax*, and this also suggests a Revueltian age for the assemblage. Detrital zircon ages obtained by LA-ICP-MS are pending, but preliminary data support a Revueltian age for the assemblage. The existing collection consists of >100,000 fossils, most collected by a commercial palaeontologist and subsequently made available for study through acquisition by the Lauer Foundation (LF). As acquired by the LF, the collection consists of both "picked bags," consisting almost entirely of thousands of unsorted, but largely complete and/or identifiable bones and teeth, and "concentrate," comprised of the washed residue of more fragmentary fossils from which the picked bags were compiled. Both the picked bags and the concentrate also contain many thousands of coprolites and coprolite fragments. Comparison of the picked bag content to that of the concentrate reveals that coprolites and osteichthyans are under-represented in the picked bags. Fragmentary elements reassembled from multiple bags and our own preliminary excavations indicate that systematic collection should yield many complete elements, and possibly associated-to-articulated material as well.

Now that the site is owned by the LF, we have begun systematic collections. Vertebrate fossils are derived from both a thin (> 1m exposed thickness) greenish sandy siltstone/silty sandstone as well as an overlying, pedogenically modified, reddish-brown mudstone of similar thickness. Weathering of the latter was probably the primary source for the original collections. Our preferred depositional hypothesis is that the Homestead Site represents multiple accumulations, probably representing a

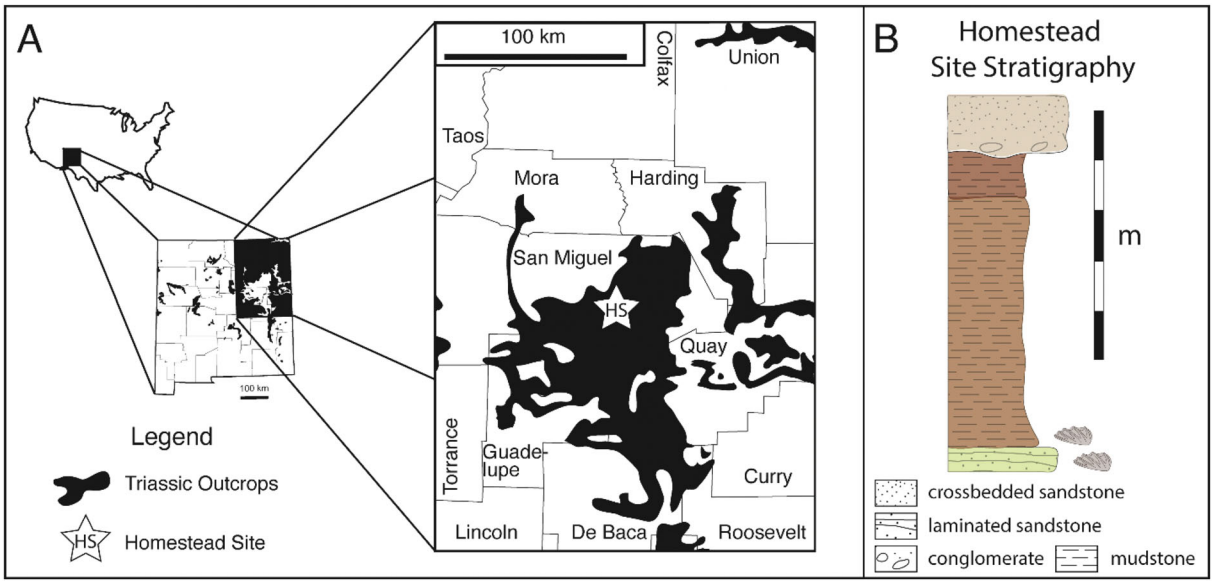


Figure 1. Index map (A) and stratigraphic section (B) showing the location and stratigraphy of the Homestead Site in east-central New Mexico, USA Outlines of lungfish toothplates indicate the fossiliferous horizons.

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time-averaged floodplain assemblage, elements of which were deposited in overbank deposits (siltstone) with subsequent deposition in an oxbow pond and/or other ephemeral body of water. These deposits were then preserved beneath a bench-forming sandstone.The Homestead Site presents a remarkable opportunity for collaboration between a private entity (LF) and diverse academic institutions, including multiple universities and museums. By leveraging resources unique to each contributor, we expect to continue collecting and documenting one of the most diverse Revueltian localities in North America. The microvertebrate assemblage of 20+ vertebrate taxa, many represented by numerous elements, is potentially the best such assemblage of Revueltian age, samples both aquatic and terrestrial environments, and includes multiple new taxa. Further description will doubtless provide greater detail on the diversification of Triassic tetrapods during the Norian.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 11:00 AM)

REASSESSING THE ALPHA-TAXONOMY OF THE OOGENUS *MACROELONGATOOLITHUS* BASED ON A NEW NEST FROM THE CENOMANIAN-AGE MUSSENTUCHIT MEMBER OF THE CEDAR MOUNTAIN FORMATION (UTAH)

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The Mussentuchit Member of the Cedar Mountain Formation is a fossil-rich unit providing spectacular insight into the mid-Cretaceous faunal turnover in the Western Interior Basin. The overwhelming majority of preserved eggshell fragments are referable to Elongatoolithidae, the oofamily directly associated with the dinosaur clade Oviraptorosauria. While there is an overwhelming abundance of Elongatoolithidae eggs in the Mussentuchit Member, the holotype section for the gargantuan eggs of *Macroelongatoolithus*, it does present an ootaxonomic issue. Eggshell for this ootaxon has been known from the unit for over fifty years (Bray, 1998; Jensen, 1970; Zelenitsky et al., 2000), but partial and whole eggs had remained elusive. The discovery of a nest, NCSM 33576, by the North Carolina Museum of Natural Sciences in 2016 at the 'Deep Eddy' locality (Emery County, Utah) has yielded whole eggs within a single nest (n=13; Figure 1) for the first time.

The ootaxonomic history of *Macroelongatoolithus*, and the fossil eggshell from the Mussentuchit Member, has long been contentious. Jensen (1970) referred the first eggshells from the Cedar Mountain Formation of Utah to *Oolithes* based on the rudimentary taxonomic structure of Young (1965), erecting the first North American ootaxon, *O. carlylensis*. By 1975, Zhao had re-assigned the Utah material to *Macroolithus* within the oofamily Elongatoolithidae, under a new parataxonomic system that was not adopted globally for at least two decades. The Utah eggshell was next re-evaluated by Bray (1998), who erected *Boletuoolithus*, within the hadrosaur-affiliated oofamily Spheroolithidae. Subsequent examinations consistently refute an assignment to Spheroolithidae (Simon et al., 2019; Zelenitsky et al., 2000).

In 1995, Li et al. described a clutch of enormous eggs from Henan Province, China that they erected a new ootaxon for, *Macroelongatoolithus xixiaensis*, within a new oofamily of Macroelongatoolithidae, based on their remarkable size. The use of this oofamily in the literature is irregular. Zelenitsky et al. (2000) reassigned the Utah eggshell fragments to *Macroelongatoolithus*, creating a new combination, *M. carlylei*, and reinstating the oogenus to Elongatoolithidae based on comparisons to new discoveries made of comparable whole eggs and nests from Asia. Asian specimens of giant, elongate eggs and nests were reported early in the 21st Century, including two more species of *Macroelongatoolithus*: *M. zhangi* (Fang et al., 2000) and *M. goseongensis* (Kim et al., 2011). Most recently, Simon et al. (2019) revised the diagnosis to incorporate the discovery of two partial eggs from the Wayan Formation of Idaho – a penecontemporenous unit to the Mussentuchit Member – and the first complete specimens of Elongatoolithidae from North America. They synonymized all hitherto described *Macroelongatoolithus* specimens, as well as two of the other massive oogenera from Asia, *Megafusoolithus qiaoxianensis* and *Longiteresoolithus xixiaensis*, under the single oospecies *M. carlylei*. The ootaxon thus currently includes five junior synonyms. The current diagnosis, following Simon et al. (2019), characterizes *M. carlylei* as elongate eggs ranging from 34-61cm in length; laid in pairs as part of a ring-shaped configuration within a nest 2-3 m in diameter; eggshell thickness between 1.38-4.75mm; variable but often prominent ornamentation types; and two eggshell layers separated by an undulating boundary.

NCSM 33576 adds the first non-fragmentary material to the hypodigm for *M. carlylei*, and shows significant differences in gross dimensions to other specimens. It is undoubtedly within Elongatoolithidae, but is somewhat smaller: the eggs in the nest range in length from 265-304mm, and width from 82-102mm, with a resultant elongation index of

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2.98-3.23. One half of the nest is preserved, showing up to thirteen partial to whole eggs, with the likelihood that the complete nest contained between 20 and 30 eggs and was at least 130 cm across. In terms of nest architecture, the eggs are arranged in pairs, concentrically, and in at least two rings, where the blunt end points inwards to a central space akin to that seen for other nests for larger oviraptorosaur nests (Tanaka et al., 2018). The external surfaces of the eggs exhibit highly variable ornamentation from lineartuberculate to dispersituberculate. Quantitative analysis of this ornamentation using the r package 'molaR' reveals high values for Dirichlet Normal Energy (=complexity) and Slope (=relief), more like those of large caenagnathid eggs from China than smaller oviraptorid eggs from Mongolia. Radial thin sections of nest-associated fragments reveal eggshell thickness ranging from 1.87-2.7 mm, with an undulating boundary between the eggshell layers.

Given the potential ambiguity of assigning ootaxa based solely on eggshell fragments, the nest from Deep Eddy is ideally placed for the erection of a neotype for the oogenus *Macroelongatoolithus*, as proposed by Zelenitsky et al., (2000). However, these eggs fall outside the currently recognized size diagnosis for the ootaxon, which can range to significantly greater lengths (the eggs from Henan Province have a reported intra-nest variation of 340-610mm). Incorporating the new egg lengths into this would take the total range for *M. carlylei* from 265-610mm, a difference well-exceeding 200%. As such, the alphataxonomic status of all eggs currently assigned to *M. carlylei* must be taken under consideration once again. Based on our preliminary observations and data collection, it is likely there will be a future formal re-diagnosis of all eggs currently assigned to *M. carlylei*, with likely some division into multiple oospecies or potentially oogenera, reflecting the major size variation that is a key diagnostic differentiator within Elongatoolithidae.



Figure 1. NCSM 33576, the nest of elongatoolithid eggs from the Deep Eddy locality. Eggs are paired, highly ornamented, and laid in a concentric architecture constructed of multiple overlaid rings (at least two are present here).

References:

Bray, E. S. (1998). University of Colorado Museum, CB, 315. Boulder, CO 80309-0315. *Lower and Middle Cretaceous Terrestrial Ecosystems: Bulletin, 14*, 221.

Fang, X., Wang, Y., & Jiang, Y. (2000). On the Late Cretaceous fossil eggs of Tiantai, Zhejiang. *Geological Review, 46*, 105-112.

Jensen, J. (1970). Fossil eggs in the Lower Cretaceous of Utah. *Brigham Young University Geological Studies*, *17*, 51-65.

Kim, J.Y., Yang, S. Y., Choi, H. I., Seo, S. J., & Kim, K. S. (2011). Dinosaur eggs from the Cretaceous Goseong Formation of Tongyeong City, southern coast of Korea. *고생물학회지*, *27*(1), 13-26.

Li, Y. X., Yin, Z. K., & Liu, Y. (1995). The discovery of a new genus of dinosaur egg from Xixia, Henan. *Journal of Wuhan Institute of Chemical Technology*, *17*(1), 38-41.

Tanaka, K., Zelenitsky, D. K., Lü, J., DeBuhr, C. L., Yi, L., Jia, S., Ding, F., Xia, M., Liu, D., Shen, C., & Chen, R. (2018). Incubation behaviours of oviraptorosaur dinosaurs in relation to body size. *Biology letters*, *14*(5), 20180135.

Young, C. (1965). Fossil eggs from Nanhsiung, Kwangtung, and Kanchour, Kiangsi. *Vertebrata PalAsiatica, 9*, 141-189.

Zelenitsky, D. K., Carpenter, K., & Currie, P. J. (2000). First record of elongatoolithid theropod eggshell from North America: The Asian oogenus *Macroelongatoolithus* from the Lower Cretaceous of Utah. *Journal of Vertebrate Paleontology*, *20*(1), 130-138.

Zhao, Z. K. (1975). The microstructure of the dinosaurian eggshells of Nanxiong Basin,Guangdong Province. 1. On the classification of dinosaur eggs. *Vertebrata PalAsiatica*, *13*(2), 105-117.

Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 4:00 PM)

DECIDUOUS OR EVERGREEN? A CASE STUDY ON A NEW SPECIES OF UPPER JURASSIC WOOD FROM THE MORRISON FORMATION OF MONTANA, USA

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1 INTRODUCTION

The paleobotanical record of the Upper Jurassic Morrison Formation preserves a 150-million-year-old terrestrial flora that was highly diverse, in which conifers were one of the most common, diverse, and widespread type of plants (Ash & Tidwell, 1998; Gee, 2020, this volume; Gee & Tidwell, 2010; Hotton & Baghai-Riding, 2010). Paleoenvironmental reconstructions of the Morrison Formation range from a mesic, forested landscape to one dominated by open habitats with xeric or semi-arid vegetation. One important indicator for deciphering the paleoclimate and plant communities of the Morrison Formation is whether the conifer trees were evergreen or deciduous, as evergreen trees are well-adapted to

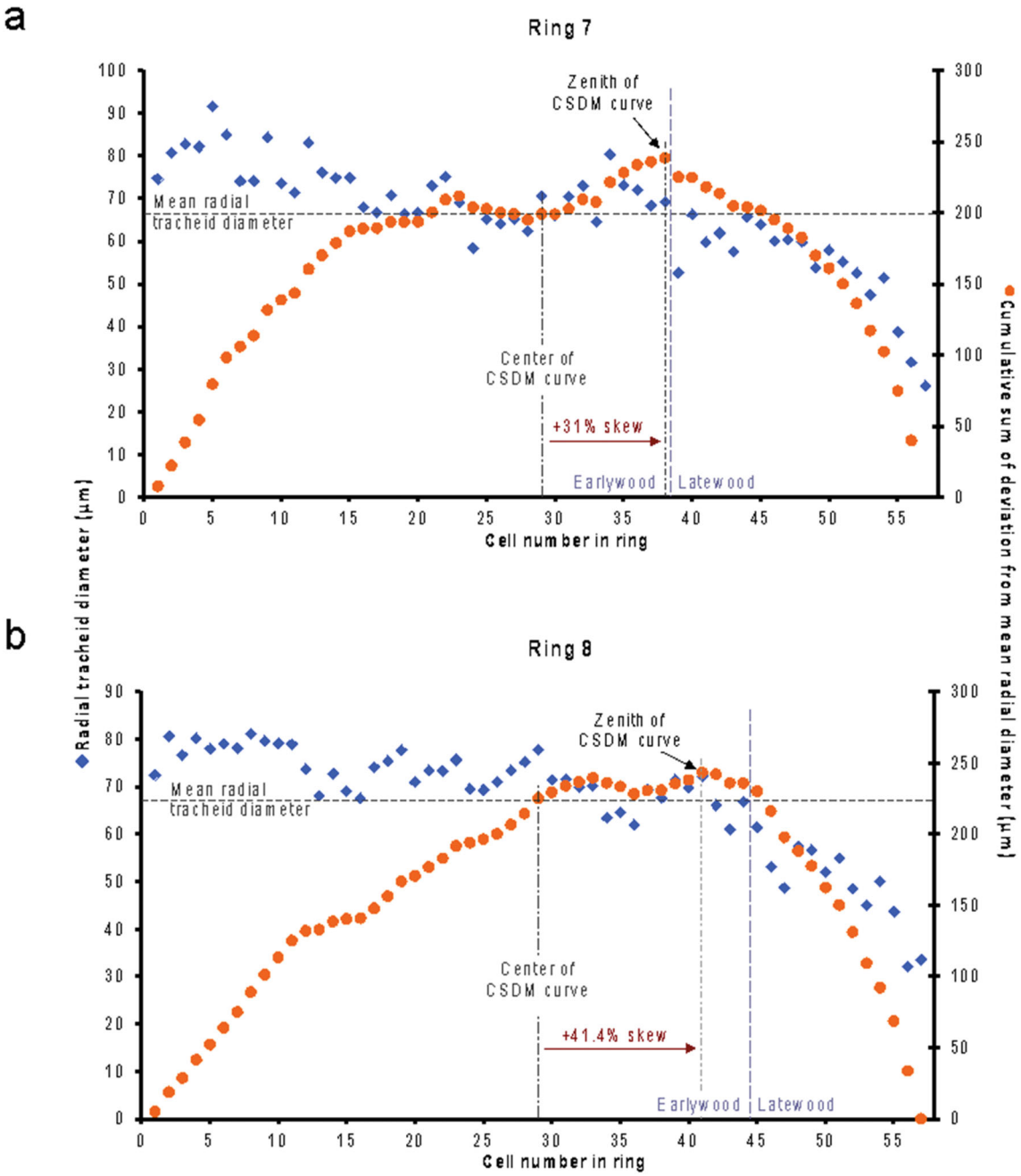


Figure 1. Two graphs showing plotted curves of radial tracheid diameter (blue diamonds) and deviation from mean radial diameter (CSDM curve, orange dots) in two exemplary, consecutive growth rings of similar width in slide CMC-002X, a thin section of silicified wood from the Upper Jurassic Morrison Formation of Montana, USA. Each diamond and dot pair depicts an individual averaged tracheid cell in a complete radial file of cells in a growth ring. The horizontal line shows the value of the mean radial tracheid diameter of the respective growth ring while the differently-dotted vertical lines mark the center and zenith of the CSDM curve and the earlywood/latewood boundary. **(a)** Plotted curves of ring 7 which measures 3.54 mm in width and exhibits a percentage skew value of +31%. **(b)** Plotted curves of ring 8 which measures 3.09 mm in width and exhibits a percentage skew value of +41.4%.

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environments dominated by extreme thermal conditions, such as tropical rainforests, or alpine and boreal terrains with short growing seasons, as well as mesic or semi-arid settings with several months of drought. However, until recently, the distinction between an evergreen or deciduous habit of a tree was based on visual estimations of the amount of latewood rather than quantitative data and calculations. Here we apply a method proposed by Creber and Chaloner (1984) and refined by Falcon-Lang (2000a, b) on a new species of Upper Jurassic conifer wood from the Morrison Formation of Montana, USA (Hoff, 2022), to determine mathematically whether its growth rings indicate an evergreen or a deciduous habit in this tree.

2 MATERIALS AND METHODS

Growth rings were analyzed in cross section in a thin section of a piece of fossil wood. The silicified wood was collected by Glenn W. Storrs (Cincinnati Museum Center in Cincinnati, Ohio, USA) from the Upper Jurassic Morrison Formation on the southwestern slopes of the Pryor Mountains in southcentral Montana, USA. Thin sections of the wood were made, and microscopy was carried out using slide CMC-002X at the University of Bonn in Germany. A continuous transect through 12 growth rings was compiled photographically using a Leica DM2500 compound photomicroscope and the integrated measurement software ImageAccess easyLab 7.

To differentiate between an evergreen and a deciduous habit, two parameters – percentage diminution (the percentage reduction in cell diameter across the growth ring) and percentage latewood – were calculated. To collect data for these parameters, the radial cell diameters of each individual tracheid cell within five adjacent files of cells in each ring were measured. For each tangential row of tracheid cells, the diameter values were averaged to give the mean cell diameters of a single, radial file of cells that is representative for the whole ring. The number of tracheid cells in each file varied slightly, so the data of the shorter sequences were stretched out by adding spaces where the number of cells did not coincide, to ensure that the ring boundaries coincided exactly. These data were plotted as the curves consisting of blue diamonds in Figure 1. To acquire the value for percentage diminution of each growth ring, the difference between the maximum and minimum radial cell diameter was calculated and divided by the maximum cell diameter.

To determine the percentage of latewood, the method outlined in Creber and Chaloner (1984) was used. First, the difference between each of the values of the radial diameters of tracheid cells in an average file of cells as measured above and the mean radial cell diameter of all tracheid cells in a ring was calculated. The resulting numbers represent each cell's deviation from the mean radial cell diameter of its respective growth ring. Then, the cumulative algebraic sum of these values was calculated and plotted as the curves of orange dots in Figure 1, the CSDM curve. The point where this curve turns towards zero for the last time marks the earlywood/ latewood boundary. Based on this, the final value for percentage latewood can be ascertained by calculating the difference between the total number of cells in a growth ring and the number of cells to the left of the CSDM curve, in the portion with the earlywood, then dividing this by the total number of cells in the growth ring.

When the difference between the individual cell diameter and the mean radial cell diameter in the same ring is negative, namely, when the diameter of the cell is smaller than the mean diameter, the value of the difference gets subtracted from the current sum, which results in a drop in the curve. Once cell sizes cease to display minimal variation in the earlywood and gradually decrease in the latewood, the curve approaches zero.

3 EVERGREEN OR DECIDUOUS?

The direction and percentage of the skew of the CSDM curve is derived from the distance and the position of its zenith in relation to its center. In general, a zenith to the right of the center indicates an evergreen tree, while a zenith to the left depicts a deciduous one. As can be observed in the two graphs of two consecutive growth rings in the Montana wood (Figure 1a, b), there is a distinctive trend towards right-skewed CSDM curves.

Based on Falcon-Lang's (2000b) interpretations, CSDM curves that are dominantly right-skewed with a percentage of more than +10% apply only to evergreen trees, while values ranging between -10% and +10% cannot clearly be assigned to either of them and thus represent an intermediate type. Four out of the six analyzed growth rings of the Montana wood display values that are greater than +10%.

Thus, the growth rings of this new conifer species show that it was clearly an evergreen tree and supports the occurrence of evergreen-dominated forests in the more northerly extent of the Morrison Formation during Late Jurassic times.

References

Ash, S. R., & Tidwell, W. D. (1998). Plant megafossils from the Brushy Basin Member of the Morrison Formation near Montezuma Creek Trading Post, southeastern Utah. *Modern Geology*, *22*, 321-339.

Creber, G. T., & Chaloner, W. G. (1984). Influence of environmental factors on the wood structure of living and fossil trees. *The Botanical Review*, *50*, 357-448.

Falcon-Lang, H. J. (2000a). The relationship between leaf longevity and growth ring markedness in modern conifer woods and its implications for palaeoclimatic studies.

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Palaeogeography, *Palaeoclimatology*, *Palaeoecology*, *160*, 317-328.

Falcon-Lang, H. J. (2000b). A method to distinguish between woods produced by evergreen and deciduous coniferopsids on the basis of growth ring anatomy: a new palaeoecological tool. *Palaeontology*, *43*, 775-783.

Gee, C. T. (2020). The conifer forests of the "Jurassic Park" in western North America, Section 6.5 in C. T. Gee (chapter editor and coordinator), Unit 6, Postcards from the Mesozoic: Forest landscapes with giant flowering trees, enigmatic seed ferns, and other naked-seed plants (pp. 165-169). In E. Martinetto, E. Tschopp, & R. A. Gastaldo (Eds.), *Nature through time: Virtual field trips through the nature of the past*. Springer Nature Switzerland AG.

Gee, C. T. (This volume). Paleobotany of the Upper Jurassic Morrison Formation: What's new and what's to come? *The Anatomical Record*.

Gee, C. T., & Tidwell, W. D. (2010). A mosaic of characters in a new whole-plant *Araucaria*, *A. delevoryasii* Gee sp. nov., from the Late Jurassic Morrison Formation of Wyoming, U.S.A (pp. 67-94). In C. T. Gee (Ed.), *Plants in Mesozoic time: Morphological innovations, phylogeny, ecosystems*. Indiana University Press.

Hoff, F. V. (2022). *A new occurrence of the fossil wood genus* Circoporoxylon *from the Upper Jurassic Morrison Formation of Montana, USA: Seasonality, growth ring markedness, evergreen habit, paleoclimate* [Bachelor's thesis, University of Bonn].

Hotton, C. L, & Baghai-Riding, N. L. (2010). Palynological evidence for conifer dominance within a heterogeneous landscape in the Late Jurassic Morrison Formation, USA (pp. 294-328). In C. T. Gee (Ed.), *Plants in Mesozoic time: Morphological innovations, phylogeny, ecosystems*. Indiana University Press.

Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 4:55 PM)

CONTRAST BETWEEN THE PALYNOFLORA AND MEGAFLORA IN THE JURASSIC SALAD BAR SITE, UTAH, USA: IMPLICATIONS FOR THE REGIONAL FLORA

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The Late Jurassic Morrison Formation of the U.S. Western Interior has long produced a rich vertebrate fauna; its dinosaur skeletons grace many prominent museums around the world. The Morrison plant record, especially of compression fossils, is not nearly as rich, but recent exciting discoveries have greatly expanded our understanding of the vegetation (Gee, this volume). Here, we focus on contrasts between the megaflora and palynoflora from an unusual site mere hundreds of meters from the original boundary of the Bears Ears National Monument in southeastern Utah, the "Jurassic Salad Bar" (JSB). The locality, from the middle Brushy Basin Member, represents a likely perennial lake.

The palynoflora is dominated by a gymnosperm of unknown affinities, *Exesipollenites tumulus* (Figure 1) (64%--this and succeeding percentages are out of 300 grains counted). *Exesipollenites* has been attributed either to the extinct Mesozoic group Bennettitales or to taxodioid Cupressaceae (redwoods and the like). The Bennettitales were a group of relatively low-statured plants, possessing many morphological traits suggesting animal pollination. Modern members of the Cupressaceae are generally tall, wind-pollinated trees producing copious pollen, as were likely their Jurassic counterparts. Because canopy sized, wind-pollinated plants overdominate dispersed pollen records, in comparison to animal pollinated plants, we believe that *Exesipollenites* was most likely produced by a tall wind-pollinated, possibly cupressaceous tree. Other common elements in the palynoflora include saccate conifer pollen (18%) representing Pinaceae (Figure 2), and perhaps Podocarpaceae (Figure 5) and Voltziales (a late Paleozoic-early Mesozoic relictual group). Less common conifers include unquestioned Cupressaceae (Figure 4) (3%), Araucariaceae (Figure 8) (5%) and the extinct xerophytic family Cheirolepidiaceae (Figure 3) (2%). Other rare (1% or less) but taxonomically significant pollen forms include *Ephedripites* (Figure 6) (Gnetales) and *Cycadopites* (Figure 7) (ginkgophytes or Bennettitales). Spores comprise about 3% of the palynoflora and represent mostly the family Dicksoniaceae or Cyatheaceae (Figure 9) (Baghai-Riding et al., 2018).

In contrast, ginkgophytes (*Czekanowskia, Ginkgo* and others) make up more than half of the total number of specimens in the compression flora, along with several fern taxa including *Coniopteris* (Dicksoniaceae), as well as small numbers of conifers (Foster et al., this volume). Discordance between palynoflora and megaflora is significant. Ginkgophyte pollen (*Cycadopites*) is present at very low abundance, in contrast to its dominance in the megaflora; this also holds true for the fern genus *Coniopteris*, which is represented by spores of Dicksoniaceae. The compression form genus *Brachyphyllum* may be the parent plant of the Araucariaceae pollen, but the relatively

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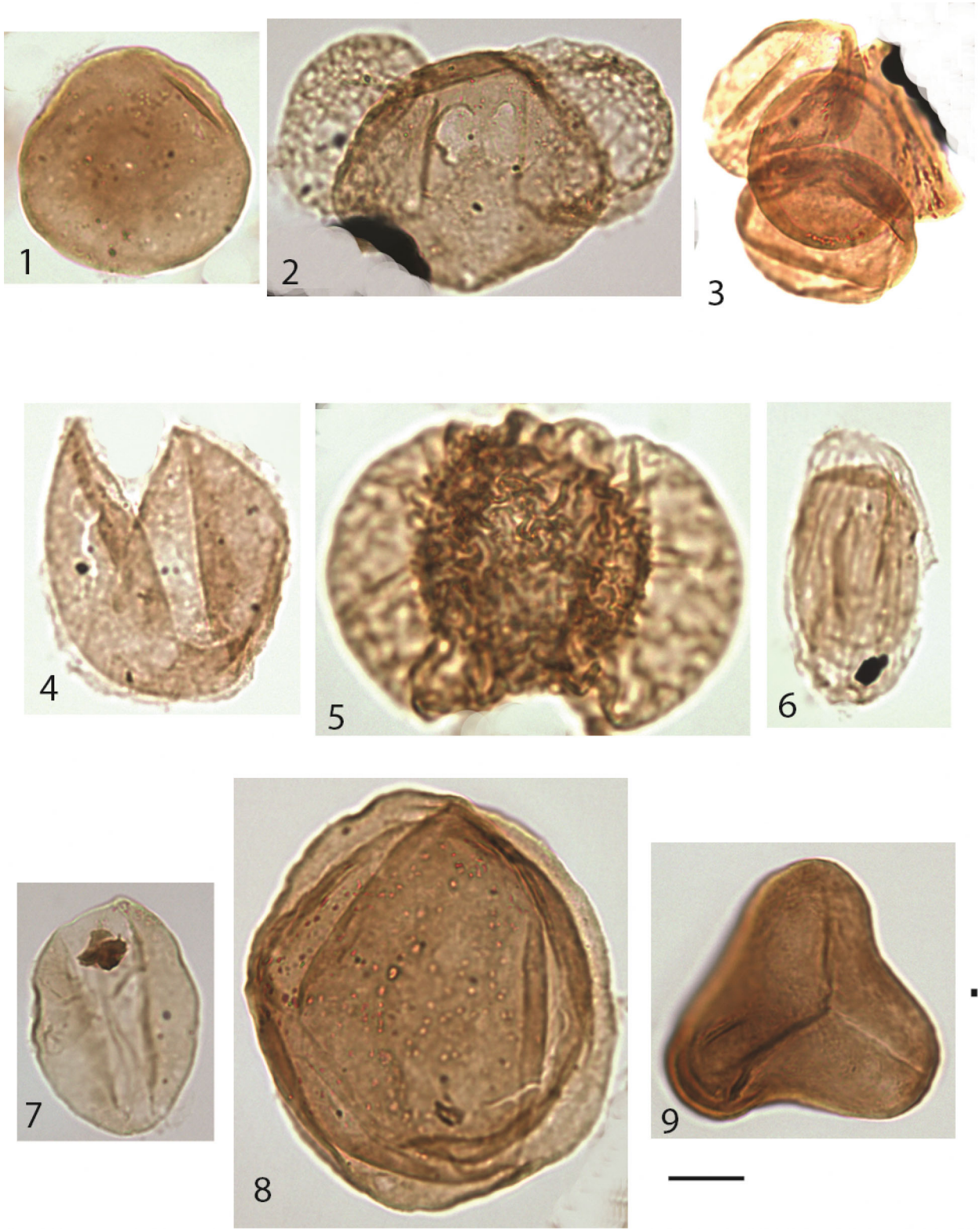


Figure 1. *Exesipollenites tumulus* Balme, 1957; Figure 2. *Pityosporites constrictus* Singh, 1964; Figure 3. *Classopollis* sp. (tetrad); Figure 4. *Perinopollenites elatoides* Couper, 1958; Figure 5. *Podocarpidites florinii* Pocock, 1970; Figure 6. *Ephedripites* sp.; Figure 7. *Cycadopites fragilis* Singh, 1964; Figure 8. *Araucariacites australis* Cookson, 1947; Figure 9. *Cyathidites minor* Couper, 1953. Scale bar = 10 micrometers. All specimens from sample SA1134 unit 20 (plant megafossil bearing unit) provided by J. Kirkland in 2018.

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abundant saccate pollen in the palynoflora is not reflected by any currently known foliage taxa at the JSB. Most notably, no taxodioid or bennettitalean foliage has been identified that might represent the parent plant of *Exesipollenites*. This is particularly baffling because *Exesipollenites* is abundant worldwide in Late Jurassic and Early Cretaceous palynofloras of low and middle latitude regions, often associated with the known xerophytic conifer Cheirolepidiaceae. Yet its parent plant remains unclear.

The discordant megaflora and palynoflora at the JSB is echoed throughout the plant fossil record (for a Jurassic example, see Slater & Wellman, 2015). Differing taphonomic filters through which compression floras and dispersed palynomorphs pass is the most likely cause of this disparity. Generally speaking, leaves and other plant parts (fruits, seeds, etc.) are preserved best in relatively still, water-logged environments, and tend to reflect vegetation growing close to the depositional site (leaves dropping into a pond, for example). They represent a snapshot in time, and are more likely to preserve mesophilic and hydrophilic plants ('taphonomic megabias' *fide* DiMichele et al., 2020). In contrast, dispersed pollen and spores generally reflect both local, aerially dispersed pollen rain and water-borne palynomorphs derived from sediments distant from the depositional basin and may include more xerophilic plants occupying interfluves. (The proportion of each category is heavily facies dependent.) Furthermore, palynofloras may be less sensitive to minor climate fluctuations, as they are time-averaged (drawn from numerous erosional cycles), rather than capturing an instant in time. Unfortunately, as the example of *Exesipollenites* shows, palynomorphs generally display lower taxonomic resolution, complicating interpretations of paleofloras. The megaflora at the JSB suggest ginkgophytes and ferns occupied wetter habitats, whereas the palynoflora reveals that a seed plant (likely a canopy tree) of unknown affinities along with conifers were dominant on a more regional scale. This analysis demonstrates how the plant megafossil and microfossil record complement one another to paint a more complete, though still imperfect, picture of past floras.

References

Baghai-Riding, N. L, Kirkland, J. I., Trujillo, K., Chamberlain, K., Hotton, C. L., Foster, J., & Hunt-Foster, R. (2018). Dispersed palynomorph and cuticle assemblages from the Late Jurassic Morrison Formation, southeastern Utah: Floristic and paleoclimate implications. *Geological Survey of America Annual Meeting, Abstracts with Programs, 50*, 6. doi: 10.1130/abs/2018AM-322649

DiMichele, W. A., Bashforth, A., Falcon-Lang, H. J., & Spencer, L. G. (2020). Uplands, lowlands, and climate: Taphonomic megabiases and the apparent rise of a xeromorphic, drought-tolerant flora during the Pennsylvanian-Permian transition. *Palaeogeography Palaeoclimatology Palaeoecology, 559*, 109965-109965. doi: 10.1016/j.palaeo.2020.109965

Foster, J. R., Gee, C. T., Ash, S. R., & Kirkland, J. I. This volume. Preliminary observations on the Jurassic Salad Bar flora, a new ginkgophyte-dominated flora from the Upper Jurassic Morrison Formation of southeastern Utah, USA. *The Anatomical Record*

Gee, C. T. This volume. Paleobotany of the Upper Jurassic Morrison Formation: What's new and what's to come? *The Anatomical Record*

Slater, S. M., & Wellman, C. H. 2015. A quantitative comparison of dispersed spore/pollen and plant megafossil assemblages from a Middle Jurassic plant bed from Yorkshire, UK. *Paleobiology, 41*(4), 640-660. doi: 10.1017/pab.2015.27

Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 5:10 PM)

PRELIMINARY OBSERVATIONS ON EXPERIMENTALLY PRODUCED PLANT-BASED COPROLITES AS A BASIS TO UNDERSTANDING DINOSAUR HERBIVORY

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1 INTRODUCTION

One of the few direct lines of evidence for the diets of herbivorous dinosaurs is the analysis of plant remains in coprolites. Although not as plentiful as those of carnivores, coprolites of herbivorous dinosaurs have been described from the Jurassic (Hunt & Lucas, 2014) and particularly from the Cretaceous (e.g., Barbacka et al., 2022; Chin & Gill, 1996; Ghosh et al., 2003). In these, leaf

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material usually pertains to gymnosperms, such as conifers, cycads, bennettitaleans, and ginkgophytes (see Sander et al., 2010 for overview), implying that the diets of their producers consisted primarily of these taxa. Fern sporangia have also been documented in coprolites (Chin & Kirkland, 1998), but the authenticity of the fossils has been questioned due to doubt that these fern parts could have survived complete digestion (Sander et al., 2010). However, the degree to which different Mesozoic floral taxa could withstand long periods of microbial digestion and become coprolites has never been explored. Here we show that plant material from five Jurassic-age families can survive up to 96 hours of microbial digestion, but the type of the tissue remaining in an experimentally produced coprolite is taxon-specific.

2 MATERIALS AND METHODS

To simulate herbivore digestion, samples of five living relatives representing the Mesozoic flora were experimentally fermented using a modified Hohenheim gas test



Figure 1. Degradation of *Equisetum hyemale*, *Araucaria araucana*, and *Cycas revoluta* after 0, 24, and 96 hours of *in vitro* digestion. (a) *Equisetum hyemale* before microbial digestion; (b) *Equisetum hyemale* after 24 hours; (c) *Equisetum hyemale* after a full 96-hour digestion period; (d) *Araucaria araucana* before digestion; (e) *Araucaria araucana* after 24 hours of digestion. (f) *Araucaria araucana* after 96 hours; (g) *Cycas revoluta* before digestion; (h) *Cycas revoluta* after the first 24 hours; (i) *Cycas revoluta* after 96 hours.

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(Menke & Steingass, 1988). This *in vitro* method is commonly used to determine the nutrition of livestock feed, but it has also been previously applied to the feeding ecology of Mesozoic herbivores (e.g., Gee, 2011; Howell et al., in revision; Hummel et al., 2008). The green shoots of *Equisetum hyemale*, foliage of the conifers *Podocarpus neriifolia* and *Araucaria araucana*, as well as the fronds of the tree fern *Sphaeropteris* (*Cyathea*) *cooperi* and the cycad *Cycas revoluta* were collected and dried, then cut into one-centimeter pieces. Samples of each species were digested for 24, 48, 72, and 96 hours. Remains were then filtered, preserved in methanol and ethanol, prepared with critical point drying, and weighed. Four replicates of each species at each time point were used and compared to undigested material. The progressive degradation of each species was then observed with both low-magnification stereomicroscopy and SEM. Gas production for each species was also recorded, and chemical fiber analyses performed.

3 RESULTS

Equisetum hyemale was the most degraded of the samples and lost the most biomass (Figure 1a–c). By 96 hours, only some cuticle, isolated sporangia, and leaf sheaths remained; all leaf tissue had been digested. *Araucaria araucana* was the second most decayed species, followed by *Sphaeropteris cooperi*, and *Podocarpus neriifolius*. Leaves of *Araucaria araucana* retained the epidermis, but the cuticle began to peel away after 96 hours of digestion (Figure 1d–f). The interior tissues were also heavily degraded and entirely absent from the cut margins of the leaf fragments. In *Sphaeropteris cooperi*, the edges of some pinnules decayed by 96 hours, leaving only cuticle, but most of the tissue remained intact. The sporangia and their annuli were undamaged. *Podocarpus neriifolius* foliage showed signs of degradation along the cut edges, but both internal and external tissues remained. The least degraded species was *Cycas revoluta*, which lost the least mass and remained almost fully intact after 96 hours, with only minor degradation around the cut edges of tissue (Figure 1g–i).

4 DISCUSSION

Our observations parallel previous findings about the degradability and digestibility of the living relatives of the Mesozoic flora (cf. Gee, 2011; Howell et al., in revision; Hummel et al., 2008). The most digestible species, *Equisetum hyemale*, is also the most degraded. Similarly, the least digestible species in earlier experiments, *Cycas revoluta*, was the least degraded specimen. Furthermore, the results confirm that the most energetically nutritious species are also the ones least likely to survive the digestion process, which creates bias in coprolites. While larger, intact pieces of cycads might survive the entire digestion process, the most likely plant parts of *Equisetum* to be found in coprolites, if any at all, would be the leaf sheaths, isolated sporangia, or possibly cuticle fragments. Meanwhile, the pinnules of *Sphaeropteris cooperi* retained cuticle as well as sporangia with annuli, which demonstrates that it is possible for these structures to endure microbial digestion. As such, dietary reconstruction of herbivorous dinosaurs through analysis of coprolite remains may inordinately exclude the taxa most likely to be fed upon by herbivorous dinosaurs, but it is possible for supposedly delicate structures to persist in coprolites.

ACKNOWLEDGMENTS

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References

Barbacka, M., Górecki, A., Pacyna, G., Pieńkowski, G., Philippe, M., Bóka, K., Ziaja, J., Jarzynka, A., Qvarnström, M., & Niedźwiedski, G. (2022). Early Jurassic coprolites: Insights into palaeobotany and the feeding behaviour of dinosaurs. *Papers in Palaeontology, 8*(2), e1425.

Chin, K., & Gill, B. D. (1996). Dinosaurs, dung beetles, and conifers: Participants in a Cretaceous food web. *PALAIOS*, *11*, 280-285.

Chin, K., & Kirkland, J. I. (1998). Probable herbivore coprolites from the Upper Jurassic Mygatt-Moore Quarry, western Colorado. *Modern Geology, 23*, 249–275.

Gee, C. T. (2011). Dietary options for the sauropod dinosaurs from an integrated botanical and paleobotanical perspective. In N. Klein, K. Remes, C. T. Gee, & P. M. Sander (Eds.), *Biology of the sauropod dinosaurs: Understanding the life of giants* (pp. 34-56). Indiana University Press.

Ghosh, P., Bhattacharya, S. K., Sahni, A., Kar, R. K., Mohabey, D. M., & Ambwani, K. (2003). Dinosaur coprolites from the Late Cretaceous (Maastrichtian) Lameta Formation of India: Isotopic and other markers suggesting a C_3 plant diet. *Cretaceous Research, 24*, 743-750.

Howell, M. M., Gee, C. T., Böttger, C., & Südekum, K.-H. In revision. Digestibility of dinosaur food plants revisited and expanded: Previous data, new taxa, microbe donors, foliage maturity, and seasonality. *PLoS One*.

Hummel, J., Gee, C. T., Südekum, K.-H., Sander, P. M., Nogge, G., & Clauss, M. M. (2008). In vitro digestibility of fern and gymnosperm foliage: Implications for sauropod feeding ecology and diet selection. *Proceedings of the Royal Society B: Biological Sciences*, *275*(1638), 1015-1021.

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Hunt, A. P., & Lucas, S. G. (2014). Jurassic vertebrate bromalites of the western United States in the context of the global record. *Volumina Jurassica*, *12*(2), 151-158.
Menke, K. H., & Steingass, H. (1988). Estimation of the energetic feed value obtained from chemical analysis and in vitro gas production using rumen fluid. *Animal Research and Development*, *28*, 7-55.
Sander, P. M., Gee, C. T., Hummel, J., & Clauss, M. (2010). Mesozoic plants and dinosaur herbivory. In C. T. Gee (Ed.), *Plants in Mesozoic time: Morphological innovations, phylogeny, ecosystems* (pp. 331-359). Indiana University Press.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 11:45 AM)

REVIEW OF DINOSAURS, PTEROSAURS, AND BIRDS OF KOREA

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Korea is one of the best-known regions in the world for the Cretaceous vertebrate ichnology. The abundance of diverse vertebrate tracks with outstanding quality of preservation, the high density occurrences of tracks, and the abundance of track-bearing stratigraphic beds in the Cretaceous of Korea represent a Mesozoic paradise of vertebrates and have been tentatively listed as a UNESCO World Heritage and Global Geopark.

Dinosaur tracks recently named in Korea include: *Hamanosauripus ungulates*, *Koreanosauripus cheongi*, *Dromaeosauripus hamanensis*, *D. jinjuensis*, *Ornithopodichnus masanensis*, *Caririchnium kyoungsookimi*, *C. yeongdongensis*, *Brontopodus pentadactylus*, and *Dromaeosauriformipes rarus*. Ootaxa include *Spheroolithus* sp., *Faveoloolithus* sp., *Dictyoolithus neixiangensis*, *Macroelongatoolithus goseongensis*, *Propagoolithus widoensis*, and *Reticuloolithus acicularis* (see Kim & Huh, 2018).

In contrast to dinosaur tracks and eggshells, dinosaur bones have been rarely reported from the Cretaceous of Korea. In this regard, a new basal ornithopod *Koreanosaurus boseongnesis* (Huh et al., 2011), the first ceratopsian *Koreacertops hwaseongensis* (Lee et al., 2011), and the titanosauriform *Pukyongosaurus millenniumi* (Dong et al., 2001) are paleontologically important. Other sauropod teeth include *Chiayuesaurus asianensis* and *Chiayuesaurus* sp.

Although the ichnotaxonomy of pterosaur tracks has been debated, five ichnogenera, including *Haenamichnus, Pteraichnus, Pubeckopus, Agadirichnus*, and *Rhamphichnus*, are recognized in Korea. *Haenamichnus*, including *H. uhangriensis* (Hwang et al., 2002) and *H. gainensis* (Kim et al., 2012), represent the first reported pterosaur ichnofossils in Asia and the largest pterosaur ichnofossil ever discovered. Two ichnospecies belonging to the ichnogenus *Pteraichnus* from Korea include: *P. koreanensis* (Lee et al., 2008) in the Hasandong Formation and *P. gracilis* (Ha et al., 2022) in the Jinju Formation. In addition, other pterosaur ichnofossils have been recently discovered and are currently being studied.

Diverse and abundant bird tracks from the Cretaceous of Korea include six ichnogenera (*Koreanaornis*, *Jindongornipes*, *Hwangsanipes*, *Uhangrichnus*, *Goseongornipes*, and *Gyeongsangornipes*) and nine ichnospecies including *Koreanaornis hamanensis*, *Jindongornipes kimi*, *Uhangrichnus chuni*, *Hwangsanipes choughi*, *Goseongornipes markjonesi*, *Ignotornis yangi*, *I. gajinensis*, *I. seoungjoseoi*, and *Gyeongsanornipes lockleyi*. This is the most diverse record of avian ichnospecies in the world and much more diversity than those of any other country. The Gajin tracksite from the Early Cretaceous Haman Formation of the Gajin area, Jinju, Korea includes more than 2500 well-preserved bird tracks associated with theropod and sauropod tracks. Bird tracks from the Gajin tracksite include *Koreanaornis hamanensis, Goseongornipes markjonesi*, *Aquatilavipes*, and *Ignotornis gajinensis. Ignotornis gajinensis* represents a semi-palmate bird track associated with arcuate to semi-circular, double-grooved impressions resulting from spoonbill-like feeding behavior. The Gajin tracksite represents a record of one of the world's richest and most diverse Cretaceous bird assemblages and has been dubbed "A paradise of Mesozoic birds."

In addition to dinosaurs, pterosaurs, and birds, other diverse vertebrate fossils are present in the Cretaceous deposits of Korea, including: turtle tracks (*Chelonipus* ichnosp.), lizard tracks (*Neosauroides koreaensis*; *N. innovates*; and *Sauripes hadongensis*), crocodile tracks (*Batrachopus grandis*; and *Crocodylopodus* ichnosp.), anuran tracks (*Ranipes* isp.; and *Ranipes saokensis*), and mammaliform tracks (*Koreasaltipes jinuensis*). Especially lizard skeleton (*Asprosaurus bibongriensis*) has a significant scientific value related to dinosaur fossils in Korea and Asia (Park et al., 2015).

The abundance of vertebrate tracks in Korea can be estimated on the basis of comparisons of tracks, trackways,

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and tracksites. The world's largest tracksite in terms of the exposed surface was the Upper Cretaceous dinosaur tracksite at Cal Orckó of Bolivia, exposing more than 5,000 tracks. However, unfortunately, the track-bearing surface collapsed in 2010. Eleven tracksites of Spain and Portugal for the nomination of the World Heritage designation include nearly 13,640 tracks. Recent studies indicate that more than 20,000 dinosaur tracks have been reported from the Cretaceous at ~90 tracksites in Korea. Compared with Spain and the USA, Korea is a region with one of the most abundant and highly dense occurrences of dinosaur tracks and trackways in the world.

References

Dong, Z., Paik, I. S., & Kim, H. J. (2001). A preliminary report on a sauropod from the Hasandong Formation (Lower Cretaceous), Korea. In *Proceeding of the 8th Annual Meeting of the Chinese Society of Vertebrate Paleontology* (pp 41-53). China Ocean Press.

Ha, S., Kim, K. S., Lim, H. S., Lockley, M. G., Yoo, J. S., & Lim, J. D. (2022). Diminutive pterosaur tracks and trackways (*Pteraichnus gracilis* ichnosp. nov.) from the Lower Cretaceous Jinju Formation, Gyeongsang Basin, Korea. *Cretaceous Research, 131*, 105080.

Huh, M., Lee, D.-G., Kim, J.-K., Lim, J.-D., & Godefroit, P. (2011). A new basal ornithopod dinosaur from the Upper Cretaceous of South Korea. *Neues Jahrbuch für Geologie und Paläontologie – Abhandlungen, 259*(1), 1-24.

Hwang, K.-G., Huh, M., Lockley, M. G., Unwin, D. M., & Wright, J. L. (2002). New pterosaur tracks (Pteraichnidae) from the Late Cretaceous Uhangri Formation, southwestern Korea. *Geological Magazine, 139* (4), 421-435.

Kim, J. Y., & Huh, M. (2018). *Dinosaurs, birds, and pterosaurs of Korea: A paradise of Mesozoic vertebrates* (1st ed.). Springer.

Kim, J. Y., Lockley, M. G., Kim, K. S., Seo, S. J., & Lim, J. D. (2012). Enigmatic giant pterosaur tracks and associated ichnofauna from the Cretaceous of Korea: Implication for the bipedal locomotion of pterosaurs. *Ichnos, 19*, 50-65.

Lee, Y.-N., Lee, H.-J., Lü, J., & Kobayashi, Y. (2008). New pterosaur tracks from the Hasandong Formation (Lower Cretaceous) of Hadong County, South Korea. *Cretaceous Research, 29*, 345-353.

Lee, Y.-N., Ryan, M. J., & Kobayasi, Y. (2011). The first ceratopsian dinosaur from South Korea. *Naturwissenschaften, 98*, 39-49

Park, J.-Y., Evans, S. E., & Huh, M. (2015). The first lizard fossil (Reptilia: Squamata) from the Mesozoic of South Korea. *Cretaceous Research, 55*, 292-302.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 9:30 AM)

THE EARLY CRETACEOUS ORNITHOMIMOSAUR RECORD IN NORTH AMERICA

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Ornithomimosaurs are well known from Asia during the Early Cretaceous but are more enigmatic during the same time in North America. The oldest known ornithomimosaur from North America is represented by *Nedcolbertia justinhofmanni* from the Valanginian-aged, upper portion of the Yellow Cat Member of the Cedar Mountain Formation of eastern Utah (Joeckel et al., 2019, 2023; Kirkland et al., 1998, 2016). Both the holotype and paratype specimens preserve numerous individuals from a single horizon just above a marker calcrete unit at the base of the upper Yellow Cat Member, including subadult and juvenile individuals. These discoveries allow the study of the species ontogeny, especially neoteny. Although it was considered a type of basal coelurosaur when originally described, additional published material has allowed for a more detailed comparison of this species with other known North American and Asiatic ornithomimosaurs, revealing this species to be a valid member of the Ornithomimosauridae clade on the presence of a subarctometatarsalian condition of the third metatarsal (Hunt & Kirkland, 2017). Additional larger, undescribed remains, including cranial remains with evidence of dentition, from stratigraphically higher in the Yellow Cat Member still await more detailed work (Scheetz et al., 2010). Two additional undescribed ornithomimosaur specimens have also been noted from the Yellow Cat Member of the Cedar Mountain Formation at the Dalton Wells Quarry, north of Moab, Utah (Britt et al., 2009).

Additional younger Early Cretaceous North American ornithomimosaurs include *Arkansaurus fridayi* from the late Aptian-Lower Albian Trinity Group of Arkansas (Hunt & Quinn, 2018; Suarez et al., 2021), "*Ornithomimus*" *affinis* from the latest Aptian - more probably lower Albian Arundel Formation of Maryland (Frederickson et al., 2018; Gilmore, 1921; Lull, 1911; Marsh, 1888; Weishampel & Young, 1996), as well as fragmentary material from the lower Albian Cloverly Formation of Montana (Carrano et al., 2022; Ostrom, 1970), all of which appear to be unique species.

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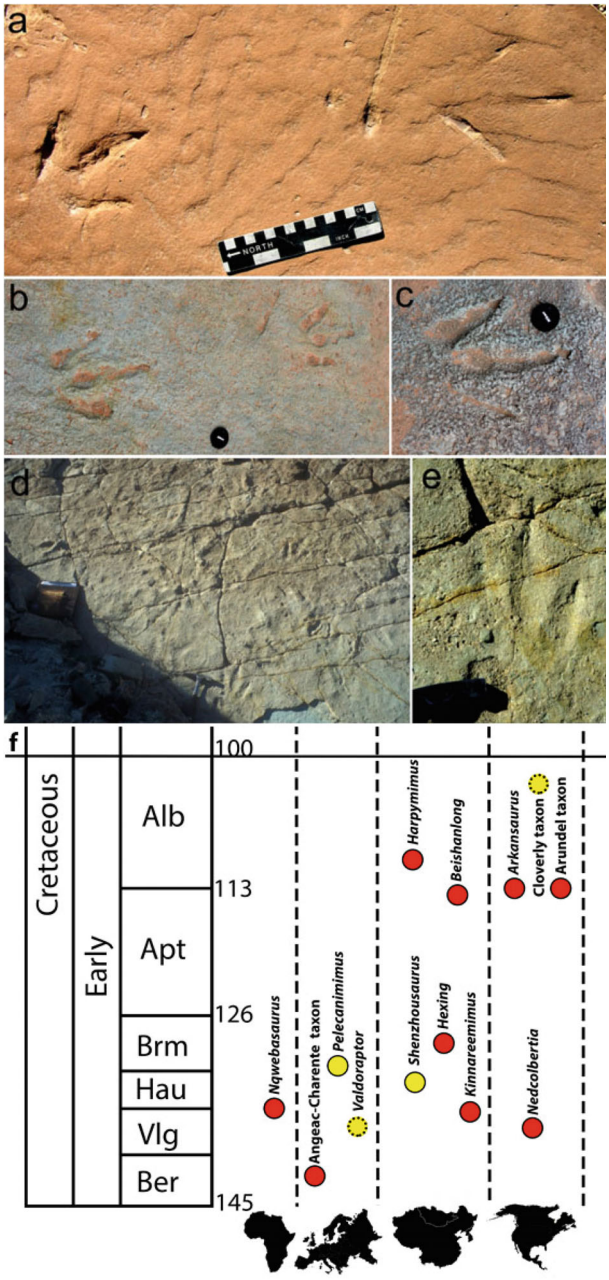


Figure 1. Temporally calibrated chart of the Early Cretaceous members of the Ornithomimosauria along with possible Lower Cretaceous ornithomimid tracks from the Cedar Mountain Formation of eastern Utah. a) Tracks from the Valanginian bird track level at Utahraptor Ridge, upper Yellow Cat Member. b-c) Possible ornithomimid tracks from the Mill Canyon Track site, middle Aptian, upper Ruby Ranch Member. d-e) possible ornithomimid tracks from the Delicate Arch track site, lower Aptian, lower Ruby Ranch Member. f) Ornithomimosauria continental distribution of taxa, as well as the metatarsal condition: subarctometatarsalian condition indicated by red circles, absence of pes material indicated by yellow circles, and unknown condition indicated by yellow broken circles. Abbreviations: Alb, Albian; Apt, Aptian; Ber, Berriasian; Brm, Barremian; Cen, Cenomanian; Cmp, Campanian; Con, Coniacian; Hau, Hauterivian; Maa, Maastrichtian; San, Santonian; Tur, Turonian; Vlg, Valanginian.

Arkansaurus is known from a single specimen consisting of a nearly complete right foot, which can be distinguished from other ornithomimosaurs based on differentiated pedal unguals, a laterally compressed third metatarsal that is ovoid in proximal view, and a distal ungual with a very weak flexor tubercle, lacking spurs (Hunt & Quinn, 2018). The Arundel material is known from several sites located around Maryland and New Jersey, most notably from Dinosaur Park, Maryland. Most of this fragmentary material is based off pedal and leg elements, with some associated and isolated vertebrae. The Arundel material has been assigned to *Archaeornithomimus affinis* by Russell (1972) on the basis of a recurved pedal ungual, and later referred to as *'Ornithomimus' affinis* (Gilmore, 1921; Weishampel & Young, 1996). It has also been considered by some to represent another theropod, possibly *Dryptosaurus* (Smith & Galton, 1990), with other authors noting its similarity to other ornithomimosaurs, such as *Kinnareemimus* (Buffetaut et al., 2009; Weishampel & Young, 1996). The comparable elements for the Arundel taxa and *Arkansaurus* are very similar to one another, and both possess the subarctometatarsalian condition, and possibly represent an evolutionary change between the two taxa.

As noted by Ostrom (1970), the Cloverly material strongly resembles the Late Cretaceous *Ornithomimus velox*, known from the Hell Creek and Lance Formations (Claessens & Loewen, 2016), and is quite different from *Arkansaurus* and the Arundel taxa. This fragmentary material from the Himes Member (Unit VII of Ostrom, 1970), has been dated to the younger Albian (Carrano et al., 2022; D'Emic et al., 2019). Very little information on additional ornithomimid material from the Cloverly has been published to date.

Somewhat older middle Aptian tracks have been attributed to ornithomimosaurs at the Mill Canyon Dinosaur Tracksite in southeastern Utah (Cedar Mountain Formation, Ruby Ranch Member; Hunt & Quinn, 2018; Kirkland et al., this volume; Lockley et al., 2014a; Suarez et al., 2021, this volume) and even older tracks are present in the lower Ruby Ranch Member at Arches National Park, but the oldest possible ornithomimid tracks are associated with bird tracks near the top of the Yellow Cat Member in the Valanginian (Joeckel et al., 2023; Lockley et al., 2014b). These sites represent the oldest tracks of this type from the Early Cretaceous of North America. These tracks also indicate that ornithomimosaurs were a regular part of the fauna, which also included large theropods, dromaeosaurs, sauropods, ankylosaurs, and iguanodontian dinosaurs.

By the Early Cretaceous the majority of coelurosaur clades (including Ornithomimosauria) appear to have been widespread geographically (Makovicky et al., 2004;

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Choiniere et al., 2012). The basal-most Early Cretaceous ornithomimosaur *Nqwebasaurus* is known from the Valanginian/Hautterivian of Africa (Choiniere et al., 2012; de Klerk et al., 2000; McPhee et al., 2016), followed by the problematic and fragmentary "*Valdoraptor*" from the Valanginian of England (Allain et al., 2014; Austen & Batten, 2018), *Kinnareemimus* from the Valanginian of Thailand (Buffetaut et al., 2009; Naish, 2011; Tucker et al., 2022), the Angeac-Charente taxon from the Berriasian-early Valanginian of France (Allain et al., 2014; Rozada et al., 2021; which may also be more closely related to the Noasauridae), *Shenzhousaurus* in the Lower Valanginian - Lower Barremian of Asia, and *Pelecanimimus* of Spain (Hauterivian to Barremian) and *Hexing* from Barremian of China (Jin & Godefroit, 2012; Zhong et al., 2021). In the Aptian, *Beishanlong* from China appears, along with *Harpymimus* from Mongolia in the Albian.

Nedcolbertia and *Arkansaurus* are more basal than other Asiatic ornithomimosaurs of similar age, and correlate more strongly with the European Wealden faunas, indicating that dispersal from Laurasia took place during the Early Cretaceous. During the Valanginian through Aptian, species would have been able to move east-west across southern North America, which was not yet bisected into the ancestral Laramidia and Appalachia by the influx of the Skull Creek Seaway (Blakey, 2014; Scott et al., 2009). This paleogeographic situation allows for the co-mingling of species across southern North America during the Early Cretaceous and could have allowed for the ornithomimosaur *Nedcolbertia* to disperse back to ancestral Appalachia, where later forms evolved into *Arkansaurus*, or an existing Appalachian ornithomimosaur, more distantly related to *Nedcolbertia*, evolved into the *Arkansaurus*.

Ji et al. (2003) pointed out that many derived members of other dinosaur clades, mainly known from Asia and North America, have Early Cretaceous basal members from Europe. The presence of Early Cretaceous ornithomimosaurs in the Valanginian-Lower Barremian of Europe ("*Valdoraptor*", Angeac-Charente taxon, *Pelecanimimus*), and in the late Barremian of North America (*Nedcolbertia*), strengthen the argument of a periodic trans-Laurasian connection between North America and Europe during the early Barremian (Brikiatis, 2016; Liyong et al., 2012). Brikiatis (2016) notes that a land connection during this time (~131-129 Ma) between North America and Fennoscandia was present through the Barents Shelf and was contemporaneous with the regressive stages present in central Europe through the Russian Platform. This would have created a wider land connection, spanning from Eastern Eurasia to North America during the early Barremian, allowing for a greater faunal mixing between Asia, Europe, and North America. This connection lasted until the Aptian (120 Ma), when the initiation of seafloor spreading in the Newfoundland-Iberia rift led to the breakup of the area, represented by the magnetic J anomaly (e.g., Bronner et al., 2011; Eddy et al., 2017; Kirkland et al., 2013). By the Late Aptian to early Albian in North America, ornithomimosaurs would potentially have been widely dispersed (Hunt & Quinn, 2018; Hunt-Foster & Kirkland, in prep.; Kirkland et al., 2016; Lockley et al., 2014).

The differences seen between the Cloverly specimen, and the other North American Early Cretaceous taxa could possibly represent a separate dispersal by a different form into northern Laramidia, or a younger form, in the transitional stages of the subarctometatarsalian to arctometatarsalian condition, seen in all Late Cretaceous forms. D'Emic (2019) proposed an older Asian–North American biogeographic connection, taking place in the Aptian, in the 124-109 Ma range (Zanno & Makovicky, 2011). Continued work in these units will help to resolve these issues.

References

Allain, R., Vullo, R., Le Loeuff, J., & Tournepiche J. F. (2014). European ornithomimosaurs (Dinosauria, Theropoda): an undetected record. *Geologica Acta, 12*(2), 127-135.

Allain, R., Vullo, R., Rozada, L., Anquintin, J., Bourgeais, R., Goedert, J., Lasseron, M., Martin, J. E., Perez-Garcia, A., Peyre de Fabregues, C., Royo-Torres, R., Augier, D., Bailly, G., Cazes, L., Despresy, Y., Galliegue, A., Gomez, B., Goussard, F., Lenglet, T., Vacant, R., Mazan, & Tournepiche, J.-F. (2022). Vertebrate paleobiodiversity of the Early Cretaceous (Berriasian) Angeac-Charente Lagerstätte (southwestern France): Implications for continental faunal turnover at the J/K boundary. *Geodiversitas, 44* (25), 683-752.

Austen, P. A., & Batte, D. J. (2018). English Wealden fossils: an update. *Proceedings of the Geologists' Association, 129*(2), 171-201.

Blakey, R. C. (2014). Paleogeography and Paleotectonics of the Western Interior Seaway, Jurassic-Cretaceous of North America. *AAPG Search and Discovery Article* #30392

Brikiatis, L. (2016). Late Mesozoic North Atlantic land bridges. *Earth Science Reviews, 159*, 47-57.

Britt, B. B., Eberth, D. A., Scheetz, R. D., Greenhalgh, B. W., & Stadtman, K. L. (2009). Taphonomy of debris-flow hosted dinosaur bonebeds at Dalton Wells, Utah (Lower Cretaceous, Cedar Mountain Formation, USA). *Palaeogeography, Palaeoclimatology, Palaeoecology, 280*, 1-22.

Buffetaut, E., Suteethorn, V., & Tong, H. (2009). An early 'ostrich dinosaur' (Theropoda: Ornithomimosauria) from

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

the Early Cretaceous Sao Khua Formation of NE Thailand. *Geological Society, London, Special Publications, 315*(1), 229-243.

Carrano, M. T., Oreska, M. P. J., Murch, A., Trujillo, K. C., & Chamberlain, K. R. (2022). Vertebrate paleontology of the Cloverly Formation (Lower Cretaceous), III: A new species of Albanerpeton, with biogeographic and paleoecological implications. *Journal of Vertebrate Paleontology*, *41*, e2003372. DOI: 10.1080/02724634.2021.2003372

Choiniere, J. N., Forster, C. A., & de Klerk, W. J. (2012). New information on *Nqwebasaurus thwazi*, a coelurosaurian theropod from the Early Cretaceous Kirkwood Formation in South Africa. *Journal of African Earth Sciences, 71-72*, 1-17.

Claessens, L. P. A. M., & Loewen, M. A. (2016). A redescription of *Ornithomimus velox* Marsh, 1890 (Dinosauria, Theropoda*). Journal of Vertebrate Paleontology, 36*, e1034593

De Klerk, W. J., Forster, C. A, Sampson, S. D., Chinsamy, A., & Ross, C. F. (2000). A new coelurosaurian dinosaur from the Early Cretaceous of South Africa. *Journal of Vertebrate Paleontology, 20*(2), 324-332.

Frederickson, J. A., Lipka, T. R., & Cifelli, R. L. (2018). Faunal composition and paleoenvironment of the Arundel Clay (Potomac Formation; Early Cretaceous), Maryland, USA. *Palaeontologia Electronica, 21.2.31A*, 1-24. https://doi.org/10.26879/847palaeo-electronica.org/content/2018/2290-arundel-fauna-of-maryland-usa

Gilmore, C. W. (1921). The fauna of the Arundel Formation of Maryland. *Proceedings of the United States Natural Museum, 59*, 581-594

Hunt, R. K. & Quinn, J. (2018). A new, primitive ornithomimosaur from the Early Trinity Group of Arkansas. *Journal of Vertebrate Paleontology, 38*(1), e1421209. DOI: 10.1080/02724634.2017.1421209

Hunt-Foster, R. K., & Kirkland, J. I. (2017). Evaluating the enigmatic Early Cretaceous ornithomimosaur record in North America. *Journal of Vertebrate Paleontology, Program and Abstracts, 2017*, 133-134.

Ji, Q., Norell, M. A., Makovicky, P. J., Gao, K. Q., Ji, S., & Yuan, C. (2003). An early ostrich dinosaur and implications for Ornithomimosaur phylogeny. *American Museum Novitates, 3420*, 1-19

Jin L., Jun, C., & Godefroit, P. (2012). A new basal ornithomimosaur (Dinosauria: Theropoda) from the early Cretaceous Yixian formation, Northeast China. *Bernissart Dinosaurs and Early Cretaceous Terrestrial Ecosystems*, 467.

Joeckel, R. M., G.A. Ludvigson, A. Moller, C.L. Hotton, M.B. Suarez, C.A. Suarez, B. Sames, J.I. Kirkland, and B. Hendrix. (2019). Chronostratigraphy and terrestrial palaeoclimatology of Berriasian-Hauterivian strata of the Cedar Mountain Formation, Utah, USA. In M. Wagreich, M. B. Hart, B. Sames, & I. O. Yilmaz (Eds.), *Cretaceous climate events and short-term sea-level changes. Geological Society of London, Special Publications, 498*, https://doi.org/10.1144/SP498-2018-133

Joeckel, R. M., Suarez, C. A., McLean, N. M., Möller, A., Ludvigson, G. A., Suarez, M. B., Kirkland, J. I., Andrew, J., Kiessling, S., & Hatzell, G. A. (2023). Berriasian-Valanginian Geochronology and Carbon-Isotope Stratigraphy of the Yellow Cat Member, Cedar Mountain Formation, Eastern Utah. USA. *Geosciences, 13*, 32. https://doi.org/10.3390/geosciences13020032

Kirkland, J. I., Alcalá, L., Loewen, M. A., Espılez, E., Mampel, L., & Wiersma, J. P. (2013). The basal nodosaurid Ankylosaur *Europelta carbonensis* n. gen., n. sp. from the Lower Cretaceous (Lower Albian) Escucha Formation of Northeastern Spain. *PLoS ONE, 8*(12), e80405. doi:10.1371/journal.pone.0080405

Kirkland, J. I., Britt, B. B., Whittle, C. H., Madsen, S. K., & Burge, D. L. (1998). A small coelurosaurian theropod from the Yellow Cat Member of the Cedar Mountain Formation (Lower Cretaceous, Barremian) of Eastern Utah. In S. G. Lucas, J. I. Kirkland, & J. W. Estep (Eds.), *Lower and Middle Cretaceous Terrestrial Ecosystems. New Mexico Museum of Natural History and Science Bulletin, 14*, 239-248.

Kirkland, J. I., Suarez, M., Suarez, C., & Hunt-Foster, R. K. (2016). The Early Cretaceous in East-Central Utah - The Cedar Mountain Formation and its Bounding Strata. *Geology of the Intermountain West, 3*, 1-117.

Liyong, J., Jun, C., & Godefroit, P. (2012). A New Basal Ornithomimosaur (Dinosauria: Theropoda) from the Early Cretaceous Yixian Formation, Northeast China. In P. Godefroit (Ed.), *Bernissart dinosaurs and Early Cretaceous terrestrial ecosystems* (pp. 467-487). Indiana University Press.

Lockley, M. G., Gierlinski, G. D., Houck, K., Lim, J. D., Kim, K. S., Kim, D. Y., Kim, T. H., Kang, S. H., Hunt-Foster, R. K., Li, R., Chesser, C., Gay, R., Dubicka, Z., Cart, K., & Wright, C. (2014a). New excavations at the Mill Canyon Dinosaur Track Site (Cedar Mountain Formation, Lower Cretaceous) of Eastern Utah. In M. G. Lockley & S. G. Lucas (Eds.), *Fossil footprints of western North America. New Mexico Museum of Natural History and Science Bulletin, 62*, 287-300

Lockley, M. D., Buckley, L. G., Foster, J. R., Kirkland, J. I., & Deblieux, D. D. (2014b). First report of bird tracks (*Aquuatilavipes*) from the Cedar Mountain Formation (Lower Cretaceous), eastern Utah. *Palaeogeography, Palaeoclimatology, Palaeoecology, 420*, 150-162

Lull, R. S. (1911). Systematic paleontology of the Lower Cretaceous deposits of Maryland: Vertebrata. *Maryland Geological Survey: Lower Cretaceous* 183-211

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Marsh, O. C. (1888). Notice of a new genus of Sauropoda and other new dinosaurs from the Potomac Formation. *American Journal of Science, Series 3, 35*, 89-94

McPhee, B. W., Mannion, P. D., de Klerk, W. J., & Choiniere, J. N. (2016). High diversity in the sauropod dinosaur fauna of the Lower Cretaceous Kirkwood Formation of South Africa: implications for the Jurassic-Cretaceous transition. *Cretaceous Research, 59*, 228-248

Naish, D., & Sweetman, S. C. (2011). A tiny maniraptoran dinosaur in the Lower Cretaceous Hastings Group: evidence from a new vertebrate-bearing locality in southeast England. *Cretaceous Research, 32*, 464-471.

Ostrom, J. H. (1970). Stratigraphy and paleontology of the Cloverly Formation (Lower Cretaceous) of the Bighorn basin area, Wyoming and Montana. *Bulletin of the Peabody Museum of Natural History, 35*, 1-234

Prieto-Márquez, A., Erickson, G. M., & Ebersole, J. A. (2016). A primitive hadrosaurid from southeastern North America and the origin and early evolution of 'duck-billed' dinosaurs. *Journal of Vertebrate Paleontology, 36*, e1054495

Rozada, L., Ronan, A., Vullo, R., Goedert, J., Augier, D., Jean, A., Marcha, J., Peyre de Fabrègues, C., Qvarnström, M. & Royo-Torres, R. (2021). A Lower Cretaceous Lagerstätte from France: A taphonomic overview of the Angeac-Charente vertebrate assemblage. *Lethaia, 54* (2), 141-165.

Russell, D. A. (1972). Ostrich dinosaurs from the Late Cretaceous of western Canada. *Canadian Journal of Earth Sciences, 9*, 375-402

Scheetz, A., Britt, B., Scheetz, R., Rauhut, O., & Chure, D. (2010). An ornithomimid-like basal coelurosaur from the early Cretaceous (Aptian) Cedar Mountain Formation of Utah. *Society of Vertebrate Paleontology Annual Meeting, Program and Abstracts*, 158A

Scott, R. W., Oboh-Ikuenobe, F. E., Benson, Jr., D. G., & Holbrook, J. M. (2009). Numerical age calibration of the Albian/Cenomanian boundary. *Stratigraphy, 6*, 17-32

Sprinkel, D. A., Madsen, S. K., Kirkland, J. I., Waanders, G. L., & Hunt, G. J. (2012). Cedar Mountain and Dakota Formations around Dinosaur National Monument—evidence of the first incursion of the Cretaceous Western Interior seaway into Utah. *Utah Geological Survey Special Study, 143*, 1-21

Suarez, M. B., Mclean, M. N., Mueller, A., Ludvigson, G., Kirkland, J. I., Montgomery, E., & Paige, M. (2021). Combined CA-ID-TIMS and carbon isotope chemostratigraphy to correlate Cretaceous continental strata of the Ruby Ranch Member of the Cedar Mountain Formation. *Geological Society of America Abstracts with Programs*, 53 (6). doi: 10.1130/abs/2021AM-370386

Suarez C. A., J. Frederickson, R.L. Cifelli, J.G. Pittman, R.L. Nydam, R.K. Hunt-Foster, and K. Morgan. (2021). A new vertebrate fauna from the Lower Cretaceous Holly Creek Formation of the Trinity Group, southwest Arkansas, USA. *PeerJ, 9*, e12242. DOI 10.7717/peerj.12242

Tucker, R. T., Hyland, E. G., Gates, T. A., King, M. R., E.M. Roberts, E. M., Foley, E. K., Berndt, D., Hanta, R., Khansubha, S., Aswasereelert, W., & Zanno, L. E. (2022). Age, depositional history, and paleoclimatic setting of Early Cretaceous dinosaur assemblages from the Sao Khua Formation (Khorat Group), Thailand. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *601*, 111107. https://doi.org/10.1016/j.palaeo.2022.111107

Weishampel, D. B. & Young, L. (1996). *Dinosaurs of the East coast*. John Hopkins University Press

Zhong, Y., Huyskens, M. H., Yin, Q. Z., Wang, Y., Ma, Q., & Xu, Y. G. (2021). High-precision geochronological constraints on the duration of 'Dinosaur Pompeii' and the YixianFormation. *National Science Review, 8*(6), nwab063.

Poster Session 2 associated with the Theme Session: Laramidia to Asia: biota and biogeography of interconnected iconic Late Cretaceous ecosystems (Friday, June 9, 2023)

NEW PALEOBIOTIC ELEMENTS OF THE WILLIAMS FORK FORMATION (CAMPANIAN–MAASTRICHTIAN) OF NORTHWESTERN COLORADO AND NORTHEASTERN UTAH, USA

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Institutional Abbreviations: FHPR, Utah Field House of Natural History State Park Museum, Vernal, Utah, USA; MWC, Museums of Western Colorado, Fruita, Colorado, USA; UCM, University of Colorado Museum, Boulder, Colorado, USA.

The Williams Fork Formation (WFF) is an Upper Cretaceous unit representing river channel, floodplain, swamp, estuary, and shallow nearshore marine environments of a coastal delta setting on a Laramidian shore of the Western Interior Seaway. The unit is as much as 580 m thick and preserves fossil material that helps fill a

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paleobiogeographic gap between Campanian–Maastrichtian units to the north in Montana and Canada and to the south in southern Utah, New Mexico, and western Texas and Mexico.

Forty years of intermittent paleontological study produced a fragmentary fauna of mostly dinosaurs and mammals (Archibald, 1987; Diem, 1999; Lucas & Kihm, 1982; Lucas & Rasmussen, 1983; Yun, 2022). Paleobiotic additions and results noted here represent our field studies since 2009.

The WFF is mapped in the northern part of the Piceance Basin, northwestern Colorado, and in the northeastern part of the Uinta Basin, northeastern Utah. The WFF lies stratigraphically above the Campanian Iles Formation and unconformably below the Eocene Wasatch Formation. The coastal lowland sediments comprising the WFF were transported generally eastward (Noll, 1988) in largely fluvial deposits of sandstone, conglomeratic sandstone, siltstone, and shale (Hettinger & Kirschbaum, 2002). The lower two-thirds of the WFF represents a barrier plain and coastal plain, which in turn is overlain by a marine shale tongue capped by nearshore marine sandstones (Roberts & Kirschbaum, 1995). The upper "undifferentiated" part of the WFF may in part correlate to the Tuscher Formation found in the Book Cliffs of the southern Uinta Basin.

The WFF spans seven ammonite biozones, from the *Didymoceras cheyennense* to the *Baculities baculus* Zone (Diem & Archibald, 2005; Meek & Hayden, 1861; Newman, 1987). These ammonite biozones indicate a Campanian to lower Maastrichtian age. Lillegraven and Ostresh (1990) correlated these strata to the "Edmontonian" North American Land Mammal Age (NALMA), and the fauna is consistent with the Kirtlandian to early Edmontonian land-vertebrate "ages" of the Upper Cretaceous of North America (Sullivan & Lucas, 2006).

Our field studies since 2009 have focused on two major outcrop areas of the WFF: south of Rangely, Colorado, Douglas Creek Arch (Archibald, 1987; Noll, 1988), and southeast of Jensen, Utah, along Snake John Reef (Ward, 2017). Most fossil localities appear to be in the middle third of the formation (Noll, 1988).

Several localities in the Douglas Creek Arch and Snake John Reef areas have produced previously unreported fossil plant taxa, including the horsetail *Equisetum* sp. (Figure 1a); ferns (similar to Late Cretaceous morphotype HC241; Figure 1b; e.g., Labandeira et al., 2002); conifers *Geinitzia* sp., *Elatides longifolia*, and possibly *Metasequoia*? (Figure 1c–e); plus several angiosperm morphotypes. The latter include the palm *Sabalites* sp. and *Salix*-like (Figure 1f) and *Marmarthia*-like forms (Figure 1g), among others (Figure 1h). Additional plant fossils include amber and petrified to coalified wood and logs.

Invertebrates include small to large, probably freshwater to brackish, bivalves (Figure 1i; *Corbula* sp., *Corbicula* sp.) and a large, freshwater, unidentified ?unionid. Gastropods are mostly small, high-spired forms (e.g., *Campeloma* sp.; Figure 1j).

Among new vertebrate taxa, our group identified a number of chondrichthyans (the sharks *Lonchidion*, *Cantioscylium*, *Chiloscyllium* and the rays *Cristomylus* and *Pseudomyledaphus*), as well as the bony fish (*Parabula)*, and small teeth referred to an amioid (*Melvius)* (Brand et al., 2022). The presence of *Melvius* is supplemented here by large characteristic vertebrae and a large jaw element found by our crew in 2021 (Figure 1k, l).

New amphibians include the salamander *Prodesmodon* and the albanerpetontid *Albanerpeton* (Figure 1m, n). These taxa, and other microvertebrates, are generally found in screen-washing concentrates among abundant gar scales, fish teeth, and other fragments.

The lizards *Leptochamops* sp. (Figure 1o) and *Peneteius* sp. were reported recently by Vaughn et al. (2015) and Brand et al. (2022), respectively. Recent work produced many of the turtle types reported by Archibald (1987), but one shell fragment appears to represent the baenid *Denazinemys* (Figure 1p). Our work also produced several additional (Archibald, 1987) small vertebrae of *Champsosaurus*. In 2021, we found an additional specimen of the giant neosuchian crocodyliform taxon first reported by Foster and Hunt-Foster (2015). Teeth of smaller, durophagous crocodilians were also found in abundance.

Dinosaur taxa are mostly identified from teeth (Diem, 1999) and include several genera of theropods (tyrannosaurs, dromaeosaurs, and others), ceratopsians, hadrosaurs, and ankylosaurs. A chasmosaurine ceratopsian skull collected in 1988 (Diem & Archibald, 2005) was referred to *Pentaceratops* by Diem (1999) and Lucas et al. (2006). The few fragmentary skeletons of hadrosaurs remain mostly unidentified to genus.

Our new dinosaur finds include a left humerus of the first oviraptorosaur from the WFF (MWC 8248, Figure 1q). North American oviraptorosaur discoveries were previously restricted to the south in Texas, New Mexico, and central and southern Utah, and South Dakota, Montana, and Alberta to the north. We interpret MWC 8248 as a smaller, basal relative of the oviraptorids.

Among the mammals, we report the occurrence of a large pediomyid metatherian based upon a left dentary fragment containing m1–m3 (Figure 1r–u). The molars on MWC 9744 are morphologically similar to *Protolambda florencae* described by Davis (2007), but are approximately 20–25% larger than those of *P. florencae* measured by Clemens (1966), making this WFF taxon among the largest known metatherians from the Late Cretaceous.

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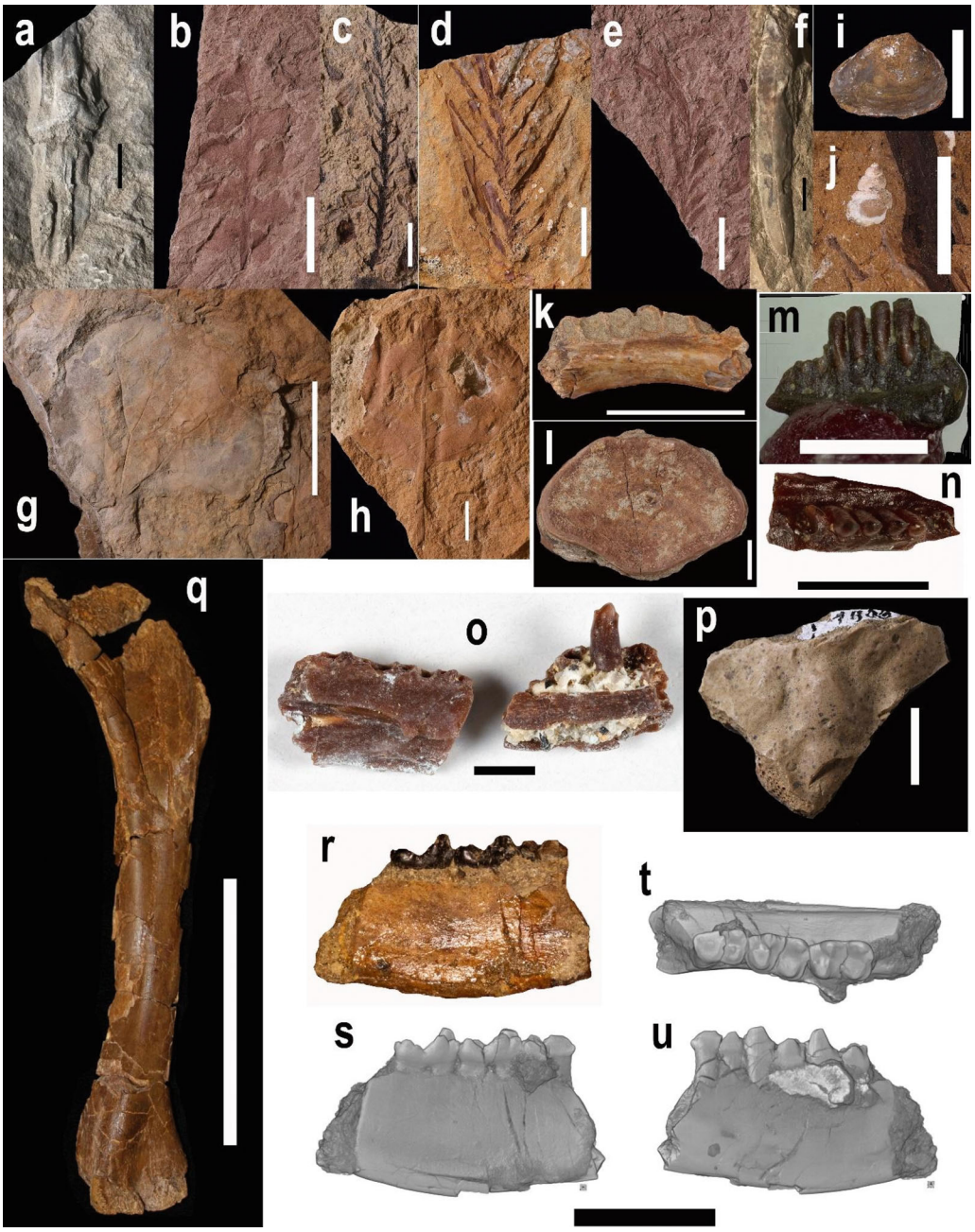


Figure 1. Taxa new to the Williams Fork Formation (Campanian–Maastrichtian), northwestern Colorado (Douglas Creek Arch) and northeastern Utah (Snake John Reef). **a)** Horsetail *Equisetum* sp., stem, FHPR 11049, from Andy's Plants locality (DCA). **b)** Fern morphotype HC241, pinna, FHPR 14723, from Spring Hollow locality (SJR). **c)** Conifer *Geinitzia* sp., twig, FHPR 10995, from Pine Barren locality (SJR). **d)** Conifer *Elatides longifolia*, twig, FHPR 17090, from Andy's Plants locality (DCA). **e)** Conifer *Metasequoia*?, twig, FHPR 10935, from Spring Hollow locality (SJR). **f)** *Salix*-like angiosperm, leaf, FHPR 18069, from Andy's Plants locality (DCA). **g)** *Marmarthia*-like angiosperm, leaf, FHPR 18067, from Andy's Plants locality (DCA). **h)** Unidentified angiosperm, leaf, FHPR 10957, from Booter's Saddle locality (DCA). **i)** Bivalve *Corbula* sp., steinkern, FHPR 11047, from J&M Lateral Swamp locality (DCA). **j)** Gastropod *Campeloma* sp., shell, FHPR 10983, from Booter's Saddle locality (DCA). **k)** Amioid fish *Melvius* sp., dentary fragment, FHPR 11191, from Arrowhead Fish Jaw locality (DCA). **l)** Amioid fish *Melvius* sp., vertebra, UCM 108102, from Hairpin locality (DCA). **m–n)** Amphibian *Albanerpeton* sp., jaw fragment, UCM 108110, from Bounty locality (DCA) in **m)** lingual view and **n)** occlusal view. **o)** Lizard *Leptochamops* sp., jaw fragments, UCM 107397, from Dinomunge locality (DCA). **p)** Turtle *Denazinemys*?, shell fragment, FHPR 17806, from Dead Cow Badlands 5 locality (DCA). **q)** Unidentified oviraptorosaurian dinosaur, left humerus, MWC 8248, from Tom's Camp-O-Saur locality (DCA). **r–u)** Photo and XRM images of unidentified, large pediomyid metatherian mammal, left dentary fragment with m1–m3, MWC 9744, from J&M locality (DCA); **r)** Photo of lingual view; **s)** XRM image of lingual view; **t)** XRM occlusal view; **u)** XRM labial view. Scale bars = 1 cm (a–f, h–j, l, p, r–t); 5 cm (g, k); 1 mm (m–o); 10 cm (q).

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Laramidia in general is known for its endemic southern and northern macrovertebrate faunas, highlighted by studies in the Upper Cretaceous Kaiparowits (Utah) and Dinosaur Park (Alberta) formations. Geographically transitional discoveries between the two could represent an area of faunal mixing or cline as suggested by Sampson et al (2010).

Although most plant types from the WFF are yet unidentified, many appear to be taxa at least similar to those known from Campanian–Maastrichtian units to the south and north. The possible presence of *Denazinemys* among turtles demonstrates some faunal links with the southern province of Laramidia, as it is mostly known from the Kirtland and Kaiparowits formations of New Mexico and southern Utah, respectively.

Oviraptorosaurs are unknown from Wyoming, eastern Utah, and, until now, Colorado, within the enigmatic transition between the southern and northern biogeographic provinces of Laramidia. New specimens from this region are of interest in that they provide additional insights into the development, extent, and possible biotic mixing that existed in upper Campanian–lower Maastrichtian biogeographic zones.

Although the genus *Protolambda* is known from Judithian–Lancian time, the presence of a large pediomyid morphologically most similar to Lancian *P. florencae* seems consistent with an "Edmontonian" age for the WFF fauna that has been suggested by others (Archibald, 1987; Diem, 1999), as the "Edmontonian" shares many faunal affinities with Lancian faunas.

Future collecting in the WFF and other mid-latitude Laramidia formations of the time (e.g., Farke, this volume) should begin to refine this biogeographic puzzle, results should be forthcoming with current sampling efforts by a number of institutions.

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References

Archibald, J. D. (1987). Late Cretaceous (Judithian and Edmontonian) vertebrates and geology of the Williams Fork Formation, N.W. Colorado. In P. J. Currie, & E. H. Koster (Eds.), *Fourth Symposium on Mesozoic Terrestrial Ecosystems, Short Papers*, 7-11.

Brand, N. A., Heckert, A. B., Sanchez, I., Foster, J. R., Hunt-Foster, R. K., & Eberle, J. J. (2022). New Late Cretaceous microvertebrate assemblage from the Campanian-Maastrichtian Williams Fork Formation, northwestern Colorado, USA, and its paleoenvironmental implications. *Acta Palaeontologica Polonica*, *67*, 579-600.

Clemens, W. A. (1966). Fossil mammals of the type Lance Formation, Wyoming. Part II. Marsupialia. *University of California Publications in Geological Sciences*, *62*, 1-122.

Davis, B. M. (2007). A revision of "pediomyid" marsupials from the Late Cretaceous of North America. *Acta Palaeontologica Polonica*, *52*, 217-256.

Diem, S. D. (1999). *Vertebrate faunal analysis of the Upper Cretaceous Williams Fork Formation, Rio Blanco County, Colorado* [Master's thesis, San Diego State University].

Diem, S. D., & Archibald, J. D. (2005). Range extension of southern chasmosaurine ceratopsian dinosaurs into northwestern Colorado. *Journal of Paleontology*, *79*, 251-258.

Farke, A. (This volume). Vertebrate paleontology and biostratigraphy of the Mesaverde Formation (middle Campanian) in the Bighorn Basin of Wyoming, USA. *The Anatomical Record*, this volume.

Foster, J. R. & Hunt-Foster, R. K. (2015). First report of a giant neosuchian (Crocodyliformes) in the Williams Fork Formation (Upper Cretaceous: Campanian) of Colorado. *Cretaceous Research*, *55*, 66-73.

Hettinger, R. D., & Kirschbaum, M. A. (2002). Stratigraphy of the Upper Cretaceous Mancos Shale (upper part) and Mesaverde Group in the southern part of the Piceance and Uinta Basins, Colorado and Utah. *U.S. Geological Survey Geologic Investigations Series I-2764*, 1-21.

Labandeira, C. C., Johnson, K. R., & Lang, P. (2002). Preliminary assessment of insect herbivory across the Cretaceous-Tertiary boundary: major extinction and minimum rebound. *Geological Society of America Special Paper*, *361*, 297-327.

Lillegraven, J. A., & Ostresh Jr., L. M. (1990). Late Cretaceous (earliest Campanian/Maastrichtian) evolution of western shorelines of the North American Western Interior Seaway in relation to known mammalian faunas. In T. M. Bown & K. D. Rose (Eds.), *Dawn of the age of mammals in the northern part of the Rocky Mountain Interior, North America. Geological Society of America Special Paper, 243*, 1-30.

Lucas, S. G., & Kihm, A. J. (1982). *Paleontological resource study and inventory of part of the White River Resource Area and vicinity, Piceance Creek Basin, northwestern Colorado*. Prepared for the Craig District of the Bureau of Land Management.

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Lucas, S. G., & Rasmussen, T. E. (1983). Fossil vertebrates from the Upper Cretaceous Williams Fork Formation (Mesaverde Group), Piceance Creek Basin, northwestern Colorado. *Geological Society of America, Rocky Mountain and Cordilleran Sections Meeting, Abstracts with Programs*, *15*(5), 292.

Lucas, S. G., Sullivan, R. M., & Hunt, A. P. (2006). Re-evaluation of *Pentaceratops* and *Chasmosaurus* (Ornithischia: Ceratopsidae) in the Upper Cretaceous of the Western Interior. *New Mexico Museum of Natural History and Science Bulletin*, *35*, 367-370.

Meek, F. B. & Hayden, F. V. (1861). Descriptions of some Lower Silurian (Primordial), Jurassic, Cretaceous and Tertiary fossils collected in Nebraska by the exploring expedition under the command of Captain W. F. Reynolds, U.S. Topographical Engineer, with some remarks on the rocks from which they were obtained. *Proceedings of the Academy of Natural Sciences of Philadelphia*, *12*, 175-185.

Newman, K. R. (1987). Biostratigraphic correlation of Cretaceous-Tertiary boundary rocks, Colorado to San Juan Basin, New Mexico. In J. E. Fassett & J. K. Rigby Jr. (Eds.), *Cretaceous-Tertiary Boundary in the San Juan and Raton Basins, New Mexico and Colorado*. *Geological Society of America Special Paper, 209*, 151-163.

Noll, M. D. (1988). *Sedimentology of the Upper Cretaceous Williams Fork Formation, Rio Blanco County, northwestern Colorado* [Master's thesis, San Diego State University].

Roberts, L. N. R., & Kirschbaum, M. A. (1995). Paleogeography of the Late Cretaceous of the Western Interior of Middle North America coal distribution and sediment accumulation. *U.S. Geological Survey Professional Paper 1561*.

Sampson, S. D., Loewen, M. A., Farke, A. A., Roberts, E. M., Forster, C. A., Smith, J. A., & Titus, A. L. (2010). New horned dinosaurs from Utah provide evidence for intracontinental dinosaur endemism. *PLoS ONE*, *5*(9), e12292. doi:10.1371/journal.pone.0012292

Vaughn, M. C., Foster, J. R., Nydam, R. L., Heckert, A. B., & Hunt-Foster, R. K. (2015). Newly reported lissamphibian and squamate taxa from the Williams Fork Formation (Upper Cretaceous, Campanian), Colorado: Closing the gap. *Journal of Vertebrate Paleontology, SVP Program and Abstracts Book*, *2015*, 230.

Ward, C. J. (2017). *Stratigraphy, petrology, and paleontology of the Late Cretaceous (Campanian) Mesaverde Group in northeastern Utah* [Master's report, Utah State University].

Yun, C. G. (2022). A tyrannosaurid pedal ungual from the Williams Fork Formation (Campanian) of Colorado and its implications for the biogeography of Laramidian dinosaurs. *Acta Geologica Polonica*, *73*(1), 63-72. Warszawa. DOI: 10.24425/agp.2022.140433

Poster Session 1 (Thursday, June 8, 2023)

PLANT FOSSIL LOCALITY IN THE SHINARUMP CONGLOMERATE MEMBER OF THE CHINLE FORMATION (UPPER TRIASSIC) OF SOUTHWESTERN UTAH (WASHINGTON COUNTY)

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A newly discovered plant fossil locality in the Chinle Formation (Upper Triassic) in Washington County broadens the distribution of known plant fossil localities to now include southwestern Utah. Previously reported plant fossil localities in the Chinle Formation are from southeastern Utah, Arizona, and equivalent strata in New Mexico (Ash, 1975; Milner, 2006). The majority of the known plant fossil localities are from upper units of the Chinle Formation. However, the Washington County plant fossil locality is from an older, basal unit, the Shinarump Conglomerate Member, which makes it one of the oldest plant fossil localities known from the formation. Plant fossil localities have been studied from the Chinle Formation of southeastern Utah, but not the southwestern part of the state –despite the extensive outcropping of the formation. The discovery of this locality encourages further excavation and investigation of new plant fossil localities, and further exploration of the Chinle Formation in southwestern Utah, particularly in sandstone lenses of the Shinarump Member.

The plant fossils identified from the new locality include fronds of the fern *Phlebopteris* sp., fertile specimens of the fern *Cynepteris* sp., and an undetermined species of conifer represented by a branch and a three-dimensionally preserved cone. The fern, *Cynepteris*, is not previously known from the Shinarump Member –which makes

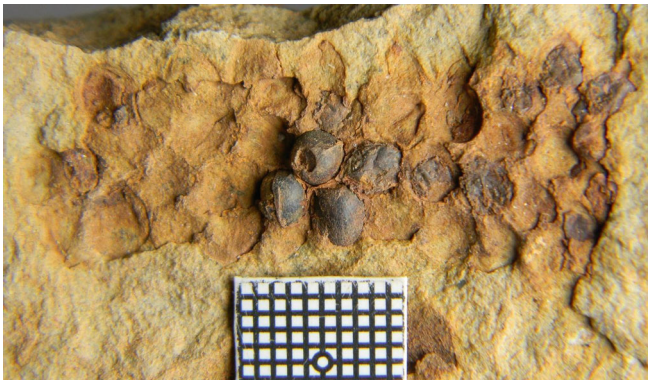


Figure 1. Coniferales cone preserving three-dimensional seeds (UMNH PB 1967) 12 MP with cm scale

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these specimens some of the oldest. The diversity of species found at the Washington County plant fossil locality correlates with other known floral assemblages from the Chinle Formation, suggesting general homogeneity of Chinle Formation floras (Tidwell & Ash, 1994). These plant fossil assemblages support interpretations of basal Chinle Formation paleoclimates as humid and warm.

References

Lucas, S. G. (1993). The Chinle Group: Revised stratigraphy and biochronology of Upper Triassic nonmarine strata in the western United States. *Museum of Northern Arizona Bulletin, 59*, 27-50.

Milner, A. M. (2006). *Plant fossils from the Owl Rock or Church Rock Members, Chinle Formation, San Juan County Utah. New Mexico Museum of Natural History and Science Bulletin F37.*

Tidwell D. W., & Ash, S. R. (1994). A review of selected Triassic to Early Cretaceous Ferns. *Journal of Plant Research, 107*, 417-442.

Poster Session 3 (Saturday, June 10, 2023)

THE DIVERSITY OF DINOSAUR EGG FOSSILS FROM KOREA AND THE PRELIMINARY STUDY ON THE NEW DINOSAUR EGGS FROM SHINAN, JEOLLANAM-DO PROVINCE

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The first record of the dinosaur fossils from South Korea were dinosaur eggs and nests discovered from Hadong in 1972 (Yun & Yang, 1997). Subsequently, assorted dinosaur eggs have been found and studied from at least 15 eggsites from the Cretaceous non-marine deposits (see Kim & Huh, 2018). Among these eggsites, Boseong (Huh & Zelenitsky, 2002) and Hwaseong (Lee et al., 2000) are well-known as massive dinosaur eggsites (egg number >100) in addition to giant theropod eggs in a nest were reported in Aphae Island, Shinan. Six oofamilies have been reported from the Korean Peninsula (Faveoloolithidae, Spheroolithidae, Dendroolithidae, Ovaloolithidae, Elongatoolithidae, and Prismatoolithidae). The age of the egg-bearing formations ranges from Aptian to Campanian-Maastrichtian (Kang & Paik, 2013).

Here we report previously unreported egg fossil sites and additional samples of eggs from the southwestern Korean Peninsula. One new dinosaur eggsite is in Jaeun Island of Shinan, Jeollanam-do Province, and additional samples were unearthed from Aphae Island of Shinan, where the giant theropod egg nest was found. The age of the Shinan eggsites ranges about 84 – 82 Ma at the Jaeun Island eggsite and 83 – 77 Ma at the Aphae Island eggsite (Rhee et al., 2012). Both eggsites are preserved in reddish sandstones/mudstones intercalated with pyroclastic deposits. The eggsite of Jaeun Island includes 20 eggs contained within four nests. They belong to Faveoloolithidae because the radial thin section shows the filispherulithic morphotype and multicanaliculate pore system. In addition, some egg exhibit tiny and compact concentrated fragments inside, likely to be related to hatching fragments rather than fossilization. At the Aphae Island eggsite of two different ootaxa were newly found at the same site where the giant theropod eggs (Macroelongatoolithus) were reported. The four eggs, maintaining their original shape, with lots of fragments, were found at the lower layer and considered dendroolithid, given the rough and irregular surface ornamentation and protocanaliculate pore system. Also, some disarticulated vertebrate bones were found in the vicinity. Another type of egg shows exceptionally thin eggshells, representing Laevisoolithidae, previously unreported in Korea. They have a very smooth surface and are interpreted as eggs of tiny theropod dinosaurs or birds. The dinosaur oofauna of Shinan indicates a high diversity of dinosaur fauna within a nesting area for various dinosaurs in the Late Cretaceous terrestrial ecosystem of Korea.

References

Huh, M., Kim, B. S., Woo, Y., Simon, D. J. D., Simon, J., Paik, I. S., & Kim, H. J. (2014). First record of a complete giant theropod egg clutch from Upper Cretaceous deposits, South Korea. *Historical Biology: An International Journal of Paleobiology, 26*(2), 218-228.

Huh, M., & Zelenitsky, D. K. (2002). Rich dinosaur nesting site from the Cretaceous of Boseong
county, Chullanam-do province, South Korea. *Journal of Vertebrate Paleontology, 22*(3), 716-718.

Kang, H.-C., & Paik, I. S. (2013). Review on the geological ages of the formations in the Gyeongsang Basin, Korea. *Journal of the Geological Society of Korea, 49*(1), 17-29.

Kim, J. Y., & Huh, M. (2018). *Dinosaurs, birds, and pterosaurs of Korea: A paradise of Mesozoic vertebrates* (1st ed.). Springer.

Lee, Y.-N., Jeong, K. S., Chang, S. K., Choi, M. Y., & Choi, J. I. (2000). The preliminary research on the dinosaur eggs and nests found in the reclaimed area south to the Siwha Lake, Gyeonggi Province, Korea. *Journal of the Paleontological Society of Korea, 16*(1), 27-36

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Rhee, C., Kim, B. S., Kim, M. G., & Kim, C. B. (2012). K-Ar ages of dinosaur egg nest found in Cretaceous Formation of Aphaedo, Jeollanam-do, Korea. *Journal of Korean Earth Science Society, 33*(4), 329-336.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 12:00 PM)

THE PTEROSAUR TRACKS OF KOREA: THE DIVERSITY AND ECOLOGY OF THE CRETACEOUS PTEROSAURS THROUGH THE FOOTPRINTS

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Subsequent to the first report of pterosaur footprints in Asia from the Upper Cretaceous Uhangri Formation of South Korea (Hwang et al., 2002), numerous pterosaur ichnofossils have been found and studied in the Cretaceous non-marine deposits of the Korean Peninsula. Although the pterosaur fossil records in Korea are strongly biased toward ichnofossils, their quantity, and diversity are exceptional. Pterosaur ichnofossils have been reported at about twenty tracksites in Korea, and their total number is approximately 4,000 (Ha et al., 2018). Diverse footprint types have led to the recognition of four novel pterosaurian ichnotaxa (e.g., *Haenamichnus uhangriensis* (Hwang et al., 2002), *H. gainensis* (Kim et al., 2012), *Pteraichnus koreanensis* (Lee et al., 2008), and *P. gracilis* (Ha et al., 2022) and the recent improvements in analysis and sampling have led to the new interpretations of existing controversial tracks.

The pterosaur tracksites of Korea are restricted to the Cretaceous and range in age from the Aptian-Albian (118 ± 2.6 to 112.4 ± 1.3 Ma) Hasandong Formation (Lee et al., 2008) to the Santonian-Campanian (84-79 Ma) deposits on Saok Island (Park et al., 2018). Given this range includes Late Cretaceous deposits in which the body fossil records of pterosaurs decreased rapidly, it can help to answer questions about the diversity and ecology of pterosaurs.

In several tracksites, such as the Hwasun Seoyuri trackside, pterosaur footprints tend to be preserved at very high densities on a single layer with size variation (Jung et al., 2022). Considering their size distributions, the tracks may represent pterosaur flock(s) of sub-adult individuals. A similar tendency has been found in other pterosaur tracksites, and further quantitative analysis of these footprints may reveal their ecologies, such as size, age, and species structure of the pterosaur flocks.

The pterosaur tracksites in Korea were discovered along with various vertebrate footprints, including dinosaurs, birds, turtles, crocodiles, lizards, amphibians, and mammalians. This diverse ichnofauna will play an essential role in understanding the Cretaceous non-marine ecosystems of Korea.

References

Ha, S., Chae, Y.-U., Lim, J. D., Kim, C.-B., Lim, H.-S., & Kim, K. S. (2018). Cretaceous pterosaur tracks in Daegok-ri, Ulju-gun, Ulsan: Spatio-temporal distribution of pterosaur in the Korean Peninsula. *Journal of the Korean Earth Science Society, 39*(5), 458-472.

Ha, S., Kim, K. S., Lim, H. S., Lockley, M. G., Yoo, J. S., & Lim, J. D. (2022). Diminutive pterosaur tracks and trackways (*Pteraichnus gracilis* ichnosp. nov.) from the Lower Cretaceous Jinju Formation, Gyeongsang Basin, Korea. *Cretaceous Research, 131*, 105080.

Hwang, K.-G., Huh, M., Lockley, M. G., Unwin., D. M., & Wright, J. L. (2002). New pterosaur tracks (Pteraichnidae) from the Late Cretaceous Uhangri Formation, southwestern Korea. *Geological Magazine, 139*(4), 421-435.

Jung, J., Huh, M., Unwin, D. M., Smyth, R. S. H., Hwang, K.-G., Kim, H.-J., Choi, B.-D., & Xing L. (2022). *Scientific Reports, 12*, 10707.

Kim, J. Y., Lockley, M. G., Kim, K. S., Seo, S. J., & Lim, J. D. (2012). Enigmatic giant pterosaur tracks and associated ichnofauna from the Cretaceous of Korea: Implication for the bipedal locomotion of pterosaurs. *Ichnos, 19*, 50-65.

Lee, Y.-N., Lee, H.-J., Lü, J., & Kobayashi, Y. (2008). New pterosaur tracks from the Hasandong Formation (Lower Cretaceous) of Hadong County, South Korea. *Cretaceous Research, 29*, 345-353.

Park, W. M., Lockley, M. G., Kim, J. Y., & Kim, K. S. (2018). Anuran (frog) trackways from the Cretaceous of Korea. *Cretaceous Research, 86*, 135-148.

Poster Session 3 (Saturday, June 10, 2023)

REASSESSMENT OF *YURGOVUCHIA* PELVIC MATERIAL AND THEROPOD DIVERSITY IN THE LOWER YELLOW CAT MEMBER OF THE CEDAR MOUNTAIN FORMATION OF CENTRAL UTAH

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The Doelling's Bowl Quarry in the lower Yellow Cat Member of the Lower Cretaceous Cedar Mountain Formation is the oldest fossil producing quarry in the Cedar Mountain Formation and is likely Berriasian in age ~140Ma (Joeckel et al., 2020, 2023). The quarry has produced several important dinosaurs including the turiasaurian sauropod *Mierasaurus bobyoungi*, an undescribed new species of polacanthid ankylosaurian, and a growth series for an undescribed basal steracosternid onithopod (Kirkland et al., 2016; Royo-Torres, 2016). The quarry has produced the oldest putative dromaeosaurid material including *Yurgovuchia doellingi* (UMNH VP 20211), a single associated individual including cervical, dorsal, and caudal vertebrae and what was identified as a proximal left pubis lacking a pubic tubercle along with a second distinct pubis (UMNH VP 21752) found three meters from the type of *Yurgovuchia* identified as an unnamed velociraptorine (Senter et al., 2012).

Continued excavation at Doelling's Bowl has revealed additional theropod material. Isolated teeth indicate the presence of a large allosauroid. An incomplete theropod ilium (UMNH VP 26013) was found 3 meters from the type of *Yurgovuchia* that is consistent in size with the pubis UMNH VP 21752. Finally, a complete pelvis (UMNH VP 26015) was found nine meters from the type of *Yurgovuchia*. An isolated one cm long tooth (UMNH VP 26016) indicates the presence of therizinosauria in the quarry. Assessment of these specimens has resulted in a reevaluation of the type of *Yurgovuchia* and suggests the diversity of the theropod fauna in Doelling's Bowl may be greater and more interesting than initially thought.

UMNH VP 26015 represents the complete left pelvis of a medium sized theropod dinosaur. The left ilium of UMNH VP 26015 is composed of a sub-rectangular blade that measures 321 cm in length. The preacetabular blade is shorter and three times taller compared to the postacetabular blade. The cuppedicus fossa is well developed and continues onto the medial ventral half of the preacetabular blade forming a pronounced preacetabular hook on the anterior iliac blade. The brevis fossa is completely obscured in lateral view and extends from a point 1/3 of the length of the postacetabular blade to the posterodorsal tip of the medial surface of the postacetabular blade. The anteroventral pubic peduncle and posteroventral ischial peduncle are relatively dorsoventrally tall with the pubic peduncle twice as long as the ischial peduncle. The pubic peduncle has a ventral flange that articulates lateral to the pubis and the ischial peduncle is peg shaped. The acetabulum is 154 mm long includes a laterally projecting supraacetabular hood originating on the pubic peduncle. The ilium appears to have a supraacetabular ridge, but this is an artifact of postdepositional deformation as the ilium was preserved on top of the pubic shaft.

The pubic shaft of UMNH VP 26015 is straight and propubic ventral to the articulation with the ischium. Distally, the pubis is posteriorly elongated into a triangular, postpubic boot oriented at 68° from the pubic shaft. The pubis does contribute to the acetabulum, but part of the ischial peduncle is not preserved. There is no preacetabular tubercle on the proximal pubis An interpubic apron lamina is present on the distal 2/3rds of the element. The pubis is 33.7 cm long with a midshaft circumference of 183 mm and is mediolaterally elongated and ellipsoidal cross-section.

The ischium of UMNH VP 26015 is overall a blade-like element with an expanded distal end. The iliac peduncle has a deep socket for articulation with the ischial peduncle of the ilium. The ischium measures 178 mm in length and 30 mm in minimum midshaft anteroposterior length diameter. The ischium is posterodorsally and laterally concave. The distal end is expanded posteriorly and also includes an distal anterior obturator process that is broken and of unknown extent.

UMNH VP 26015 represents a previously unrecognized theropod taxon in Doelling's Bowl. The lack of a supraacetabular ridge on the ilium differentiates it from ornithomimids and tyrannosauroids. The anteroventral process of the ilium, the supraacetabular hood and the shape of the cuppedicus and brevis fossae are most similar to *Falcarius*. The pubis is similar to allosaurids, ornithomimids, tyrannosaurids, *Falcarius*, and *Achillobator* in the propubic orientation of the pubis but differs from allosaurids, ornithomimids, tyrannosaurids, *Falcarius, Deinonychus, Achillobator, Adasaurus*, and *Velociraptor* in lacking a prepubic component to its pubic boot. The blade-like ischial shaft with a distal anterior obturator process of UMNH VP 26015 is similar to *Falcarius*, *Deinonychus*, and most known dromaeosaurids and differs from allosauroids, compsognathids, tyrannosauroids, and *Achillobator* which have rod-shaped ischial shafts. The socket on the ischium for articulation with the ilium is most similar to the condition in *Falcarius*.

Closer inspection of the holotype pelvis of Y*urgovuchia* (UMNH VP 20211.18) reveals that it is not a proximal left pubis but instead is a distal right pubis possessing a pubic boot with a slight anterior component and large posterior component. We compared UMNH VP 20211.18 with the

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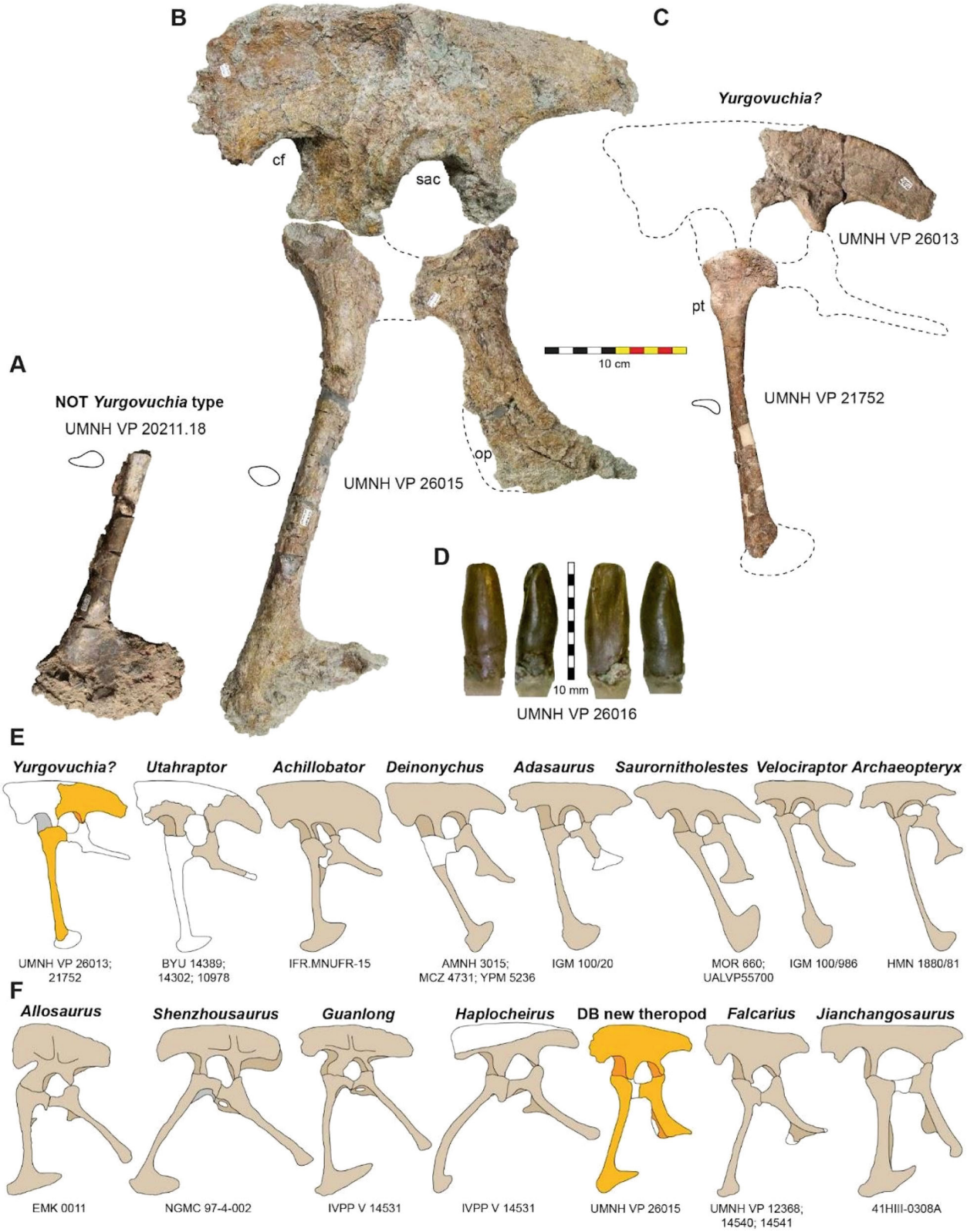


Figure 1. Theropod pelvic material from Doelling's Bowl. A. Misidentified right pubis (photoreversed) of *Yurgovuchia*. B. UMNH VP 26015 in left lateral view. C. Doelling's Bowl dromaeosaurine pelvis (photoreversed). D. Large therizinosaurine tooth (UMNH VP 26016). E.-F. Comparisons of theropod pelves, with missing in black and white. Midshaft cross-section indicated. cf, cappedicus fossa; pt, pubic tubercle; op, obturator process; sac, supraacetabular crest. Scale bar equals 10 cm.

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pubis of UMNH VP 26015 and they differ in that the pubic boot of UMNH VP 26015 has no anterior component and the angle of the boot is oblique rather than at right angles to the pubic shaft. The cross-sectional shapes of both pubic shafts also are different. Both UMNH VP 26015 and 20211.8 are roughly the same size suggesting that UMNH VP 20211.8 is too large to be the same individual as the type specimen of *Yurgovuchia* as it implies sacral vertebrae that are at least 64 mm and the longest vertebrae preserved in *Yurgovuchia* is 42 mm. The pubis UMNH VP 20211.18 should be excluded from the type of *Yurgovuchia*. The pubis of UMNH VP 21752 has a straight opisthopubic shaft with a slight expansion of the distal end that is similar to *Saurornitholestes* and velociraptorines likely does represent a dromaeosaurine pubis. UMNH VP 26013 is an ilium with a long medially placed brevis fossa on the postacetabular blade that lacks a supraacetabular hood. UMNH VP 26013 is similar in outline, proportions, and the form of the brevis fossa to an ilium from the upper Yellow Cat Member of the Cedar Mountain Formation assigned to *Utahraptor* (BYU 14389). UMNH VP 26013 and UMNH VP 21752 are from a pelvis (likely the same individual) of the same size as, and may actually belong to the type of *Yurgovuchia*, but at present there is no way to definitively assign them to that individual or material.

The theropod diversity of the lower Yellow Cat Member is unsurprising because the upper Yellow Cat Member also includes the therizinosaurine *Martharaptor*, a dromaeosaurine with hemicaudothecan tail in *Utahraptor* (CEUM 1250) and dromaeosaurine a distinct caudothecan tail in UMNH VP 20209 from the same stratigraphic level. The three distinct pubes present in the quarry suggest that there is a basal maniraptoran, a dromaeosaurine, and a third theropod taxon are present in the Doelling's Bowl assemblage in addition to the large allosauroid, and more work needs to be done to reveal their affinities.

References

Joeckel, R., Ludvigson, G. A., Moller, A., Hotton, C. L., Suarez, M. B., Suarez, C. A., Sames, B., Kirkland, J. I., & Hendrix, B. (2020). Chronostratigraphy and terrestrial palaeoclimatology of Berriasian–Hauterivian strata of the Cedar Mountain Formation, Utah, USA. In M. Wagreich, M. B. Hart, B. Sames, & I. O. Yilmaz (Eds.), *Cretaceous climate events and short-term sea-level changes*. *Geological Society, London, Special Publications 498*. https://doi.org/10.1144/SP498-2018-133

Joeckel, R. M., Suarez, C. A., McLean, N. M., Möller, A., Ludvigson, G. A., Suarez, M. B., Kirkland, J. I., Kiessling, S., & Hatzell, G. 2023 (in press). Berriasian–Valanginian geochronology and carbon-isotope stratigraphy of the Yellow Cat Member, Cedar Mountain Formation, Eastern Utah, USA. In G. A. Ludvigson, R. M. Joeckel, & M. B. Suarez (Eds.), *Terrestrial paleoclimatology and paleohydrology of the Cretaceous greenhouse world*. *Geosciences, 13*(23), 224. https://doi.org/10.3390/geosciences1986224

Kirkland, J. I., Suarez, M., Suarez, C., & Hunt-Foster, R. (2016). The Lower Cretaceous in east-central Utah—The Cedar Mountain Formation and its bounding strata. *Geology of the Intermountain West, 3*, 101-228. doi: 10.31711/giw.v3.pp101-228.

Royo-Torres, R., Upchurch, P., Kirkland, J. I., DeBlieux, D. D., Foster, J. R., Cobos, A., & Alcalá, L. (2017). Descendants of the Jurassic turiasaurs from Iberia found refuge in the Early Cretaceous of western USA. *Scientific Reports, 7*, 14311, DOI:10.1038/s41598-017-14677-2.

Senter, P., Kirkland, J. I., DeBlieux, D. D., Madsen, S., & Toth, N. (2012). New dromaeosaurids (Dinosauria: Theropoda) from the Lower Cretaceous of Utah, and the evolution of the dromaeosaurid tail. *PLoS One, 7*(5), e36790. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0036790

Poster Session 1 (Thursday, June 8, 2023)

PCO_2 CALCULATIONS FROM CLOVERLY FORMATION IN NORTHERN WYOMING USING PEDOGENIC CARBONATE NODULES

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The Early – Late Cretaceous transition in Western North America recorded a period of rapid climatic and tectonic change in Earth's history. Major climate events associated with large igneous province eruptions caused several instances of ocean anoxic events (OAE) and perturbations to the global carbon (C) – cycle. These perturbations to the global C-cycle are recorded in the bulk organic C record of both marine and terrestrial deposits and can be used to correlate units across major depositional basins. Major efforts are being made to generate time-constrained palaeontologic and paleoclimate information

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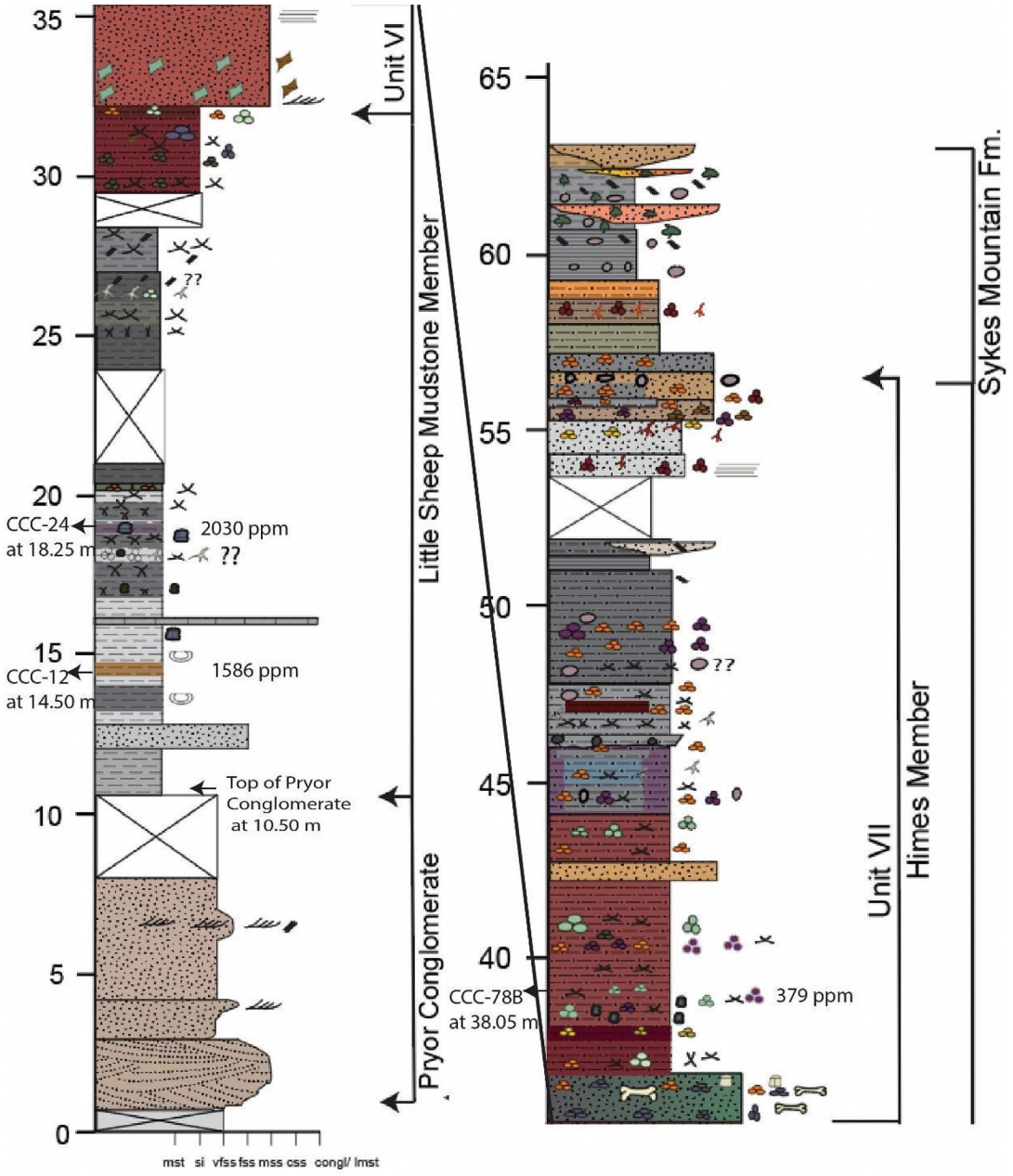


Figure 1. Stratigraphic section of Cloverly Formation at Crooked Creek section, northern Wyoming, showing pCO_2 values from carbonate nodules at CCC-12, CCC-24, CCC-78B.

from the Cordilleran foreland basin and C-isotope chemostratigraphy can aid in making these correlations. Higher atmospheric CO_2 during most of the Cretaceous contributed to higher temperature, productivity, and biotic distribution, although details of these connection are not fully understood. Here, we apply the soil carbonate paleobarometer equation to calculate paleoatmospheric carbon dioxide (pCO_2) concentrations captured in the Cloverly Formation of the Big Horn Basin at Crooked Creek.

Currently, three pedogenic carbonates nodules (two from the Little Sheep Member (CCC-12 and CCC-24) and one from the overlying Himes Member (CCC-78B)) have been analyzed for both $\delta^{13}C_{organic}$ and $\delta^{13}C_{carbonate.}$ These samples will be placed within a high-resolution, bulk organic C-isotopic chemostratigraphic profile constrained by detrital zircon geochronology. This C-isotope chemostratigraphic profile will allow time constraints of calculated pCO_2 values. Carbonate nodules were micro-sampled and facing billets were thin sectioned to examine carbonate fabric to insure samples of micrite only for pCO_2 calculations. The Little Sheep Mudstone Member carbonate nodules have $\delta^{13}C$ values that range between -6.52 ‰ and -7.32 ‰. CCC-12 average $\delta^{13}C = -6.57$ ‰ $\pm$ 0.06 and

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CCC-24 average $\delta^{13}C$ = -7.32 ‰ ± 0.23. For the Himes Member carbonate nodules (CCC-78B), values range between -10.90 ‰ and -12.14 ‰ with the average $\delta^{13}C$ = -11.46 ± 0.6 ‰. The occluded organic C isotopic values of the carbonate nodules are -26.27 ‰ for CCC-12, -25.97 ‰ for CCC-24 and -26.39 ‰ for CCC-78B.

To calculate pCO_2, we assumed a temperature of 25 °C, using -5.7 as $\delta^{13}C$ of atmosphere. The S(z) values were estimated to be between 1000 – 3000 ppm, typical of micro-high vertic soils. At the minimum S(z) value (1000ppm) pCO_2 values at 4 m above the Pryor Conglomerate are 676 ppm, decrease slightly to 528 ppm and then decrease further within the Himes Member (27.55 m above the Pryor Conglomerate) to 126 ppm. At the maximum S(z) values (3000 ppm), pCO_2 values at 4 m above the Pryor Conglomerate are 2030 ppm, decrease slightly to 1586 ppm and then decrease further within the Himes Member to 379 ppm. Using Arens et al., (2000) equation for calculation of $\delta^{13}C$ of atmosphere, we calculated individual $\delta^{13}C$ of atmosphere values for CCC-12, CCC-24, and CCC-78B. At the maximum S(z) values (3000 ppm), pCO_2 values at 4 m above the Pryor Conglomerate are 2319 ppm at CCC-12, 1742 ppm at CCC-24 and then decrease further within the Himes Member to 417 ppm at CCC-78B.

Given the maximum depositional ages of the Little Sheep Member (129.4 ± 0.12 Ma) from D'Emic et al., (2019) and a maximum depositional age for the lower Himes Member at Crooked Creek of 103.6 ± Ma (D'Emic et al., 2019), the high pCO_2 values of the Little Sheep Member might correlate to the Ontong Java large igneous province. The lower values for the Himes pCO_2 value may be related to decreased atmospheric pCO_2 values due to increased silicate weathering rates and resulting in cooling or a "cold snap" within the Late Albian (McAnena et al., 2013). Our expected high-resolution organic C-isotope chemostratigraphic profile will help to place pCO_2 values in a higher resolution chronostratigraphic location.

References

Arens, N. C., & Jahren, A. H. (2000). Carbon isotope excursion in atmospheric CO_2 at the Cretaceous-Tertiary boundary: evidence from terrestrial sediments. *Palaios, 15*(4), 314-322.

Cotton, J. M., & Sheldon, N. D. (2012). New constraints on using paleosols to reconstruct atmospheric pCO_2. *Geological Society of America Bulletin, 124*(9-10), 1411-1423.

D'Emic, M. D., Foreman, B. Z., Jud, N. A., Britt, B. B., Schmitz, M., & Crowley, J. L. (2019).

Chronostratigraphic Revision of the Cloverly Formation (Lower Cretaceous, Western Interior, USA). *Bulletin of the Peabody Museum of Natural History, 60*(1), 3-40. https://doi.org/10.3374/014.060.0101

Ekart, D. D., Cerling, T. E., Montañez, I. P., & Tabor, N. J. (1999). A 400 million year carbon isotope record of pedogenic carbonate: implications for paleoatmospheric carbon dioxide. *American Journal of Science, 299*, 805-827.

McAnena, A., Flögel, S., Hofmann, P., Herrle, J. O., Griesand, A., Pross, J., & Wagner, T. (2013). Atlantic cooling associated with a marine biotic crisis during the mid-Cretaceous period. *Nature Geoscience, 6*(7), 558-561.

Ostrom, J. H. (2020). *Stratigraphy and paleontology of the Cloverly Formation (Lower Cretaceous) of the Bighorn Basin area, Wyoming and Montana*. Yale University Press. https://doi.org/10.2307/j.ctvxkn7tk

Poster Session 1 (Thursday, June 8, 2023)

A CRETACEOUS FROG FOOTPRINT FORUM: A HIGHLY DIVERSE ICHNOFAUNA FROM THE JINJU FORMATION (CRETACEOUS) OF KOREA HIGHLIGHTS THE PALEOECOLOGICAL IMPORTANCE OF RARE TRACKS

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It is now well-known that the Cretaceous (Albian) Jinju Formation of the Jinju City area, Korea has yielded the most diverse tetrapod ichnofauna currently known anywhere (ichnogenus diversity ~16), which is double that of most Mesozoic formations. Among known ichnotaxa those representing small frogs, lizards, diminutive dinosaurs and mammals were previously considered rare. However, the characterization of the ichnofauna as a Konservat-Lagerstätten is based, in part, on the excellent preservation of small tetrapod tracks at many sites and many levels at each site (Kim et al., 2019a). Although only one frog tracksite had been reported prior to 2022 (Kim et al., 2019b), a newly-discovered site, named Sindang-ri, with hundreds of frog tracks including clear trackways at multiple levels was recently discovered and given the popular label the "Frog Footprint Forum" site. It reveals the greatest concentration of frog tracks presently known (Figure 1A-C, H).

The frog-trackway bearing layers are associated with a diverse tetrapod ichnofauna, including tracks of small

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non-avian theropods, birds (*Jindongornipes*), large sauropods (*Brontopodus*), small quadrupedal and large bipedal crocodylomorphs (*Crocodylopodus* and *Batrachopus* respectively), pterosaurs (*Pteraichnus* with pes scale traces), turtles (*Chelichnus*) and frogs (*Ranipes*), other unnamed tetrapods, some with skin impressions, and diverse invertebrate traces including *Cochlichus*, *Protovirgularia* and a high diversity of different arthropod trackways. We conservatively estimate a total diversity of at least 15 distinct ichnotaxa (Figure 1D-J).

The track-rich sequence typically includes fine grained lacustrine mudstones with intercalated sandstones including a variety of current and wave ripples which indicate frequent recharging of the lake basins(s) with fresh water. Such heterolithic sequences facilitate weathering and splitting of thinly bedded strata, especially where depositional cycles fine upwards into thin, laminated and / or clay draped sequences. Skin traces and small tracks of birds, lizards and frogs help identify true tracks, and distinguish them from the transmitted tracks of larger trackmakers.

Collectively the Jinju ichnofauna is a 'window' into the ecology of the lacustrine basin ecosystem represented by the Jinju Formation in the outcrop area. The ichnofauna

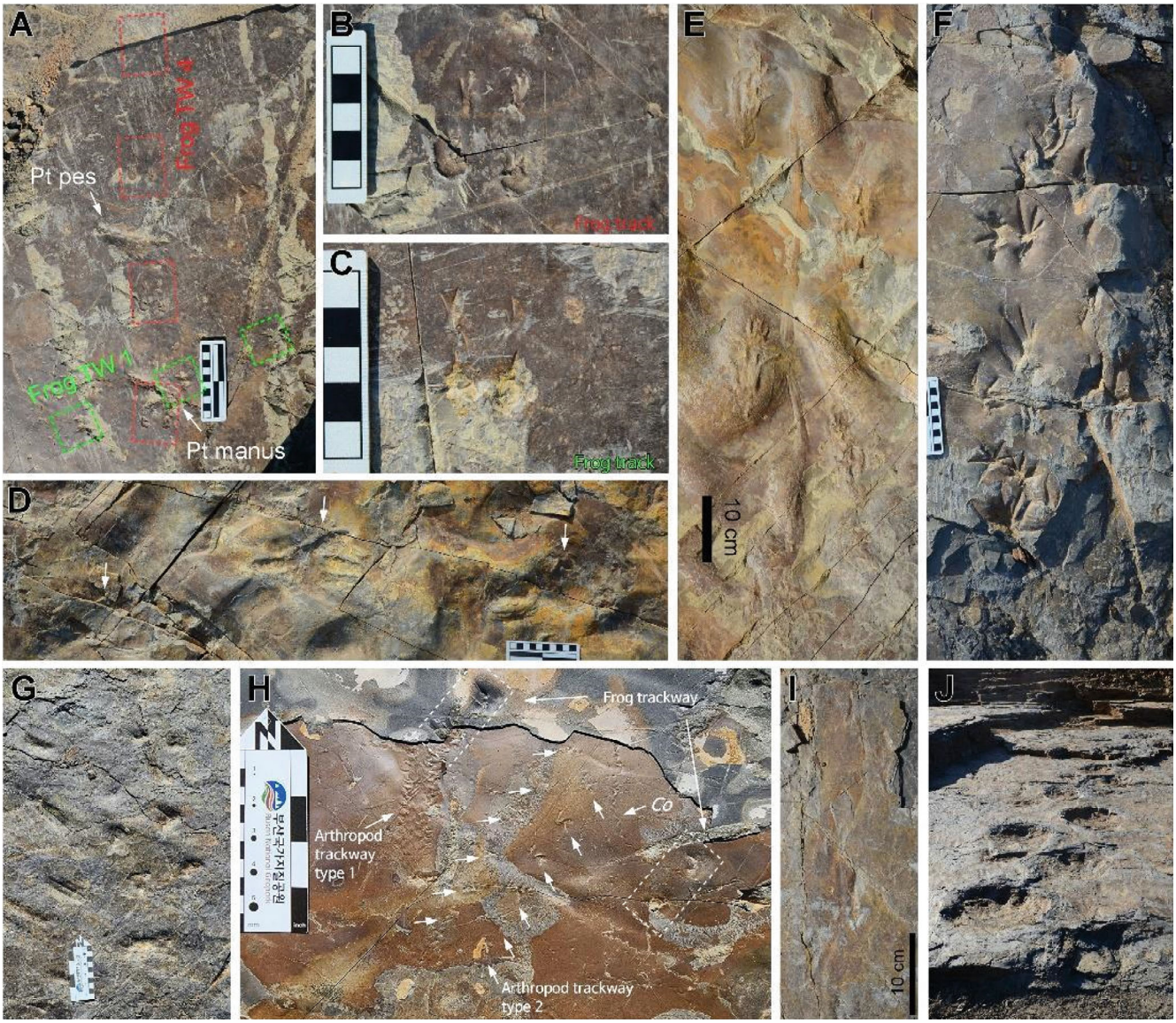


Figure 1. Diverse tetrapod tracks/trackways and invertebrate traces from the Sindang-ri tracksite, Jinju City, South Korea. A. main frog track location showing two frog trackways and pterosaur manus and pes (representing Pt pes and Pt manus); B-C. two types of frog tracks; D. large bipedal crocodylomorphs (*Batrachopus*) trackway; E. quadrupedal crocodylomorph (*Crocodylopodus*) trackways with tail drag mark; F. quadrupedal crocodylomorph (*Crocodylopodus*) trackway without tail drag mark; G. turtle swimming tracks (*Chelichnus*); H. two types of arthropod trackway, one frog trackway and invertebrate traces (*Co*: *Cochlichnus*); I. amphibian? trackway with tail drag mark; J. large sauropod trackway (*Brontopodus*).

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has a mixture of tracks representing pre-modern elements such as sauropods, non-avian theropods, bipedal crocodylomorphs and pterosaurs. These contrast with the tracks of modern elements such as small, hopping mammals, lizards, diverse shorebird-like birds and frogs. Given the conventional wisdom that track assemblages represent *in situ* signatures of permanent and transitory biota, the ichnofauna invites inferences about the Jinju ecosystem. Bacteria, algae and plants represented foundational trophic levels providing food for invertebrate tracemakers, including nematodes (*Cochlichnus* trace maker) and arthropods (e.g., insect trace makers) as well as larger for herbivores. It can be inferred that invertebrates in turn provided food sources for frogs, lizards and birds, which in turn were likely preyed upon by larger carnivores such as various crocodylomorphs, pterosaurs and non-avian theropods.

The abundance of frog trackways provides the opportunity to distinguish between different modes of progression: e.g., walking versus long or short hopping. Differences in size and gauge of trackways suggests that multiple frog taxa / morphotypes may have been present. The sheer abundance of frogs may indicate that the assemblages represent seasonal breeding cycles, and / or increased periods of rainfall. However, given that there are multiple frog track levels, the Sindang-ri site represents high levels of frog activity for extended periods, probably representing more than a single season or pluvial event: i.e., the lake basin paleoenvironment supported a diverse lake margin biota suggesting that establishment of healthy lake ecosystems for extended time periods.

When it was first recognized that lake margin track assemblages from the Cretaceous of Korea, and various Cenozoic lake basins were dominated by shorebird and /or shorebird-like assemblages, the "shorebird ichnofacies" was named (Lockley et al., 1994). At this time almost none of the representative Cretaceous or Cenozoic assemblages had yielded a significant number of tracks of other small tetrapods such as frogs, lizards or mammals. Hunt and Lucas (2007, 2016) proposed that the shorebird ichnofacies could be dissolved or divided into different ichnocoenoses, and could be subsumed under the global or archetypal *Grallator* ichnofacies, which was characterized by "medium-high diversity ichnofaunas (5–8 ichnogenera) with tracks (usually dominant) of bipedal tridactyl avian and non-avian theropods."

The Jinju Formation and over-lying Haman and Jindong formations have yielded multiple assemblages dominated by shorebird-like trackmakers, often in association with abundant tracks of quadrupedal pterosaurs, and rarer tracks of frogs, lizards and mammals. Not surprisingly these rarer elements have occasionally been reported from Cenozoic shorebird assemblages, however none show the high diversities recorded for the Jinju assemblages. While such evidence suggests consistency between Cretaceous and Cenozoic lake basin community structure inferred to indicate an example of "community convergence" (Lockley et al., 2020), it also suggests that the absence or rarity of small tracks represents a preservational bias. Thus, diversity of the shorebird ichnocoenoses (*Grallator* ichnofacies sensu Hunt & Lucas 2007, 2016) may be double that inferred by these authors under optimal preservation conditions: i.e., 10-16 rather than 5-8.

It has recently been noted that shoreline fluctuation causes much intercalation or overprinting of shoreline and shallow lake vertebrate ichnofaunas or ichnocoenoses. This is evident at the Sindang-ri site where tracks of walking and swimming tetrapods represent "shorebird" and swim track ichnofacies respectively. This is to be expected, where certain trackmakers, e.g., bird, crocodylomorph, turtles and dinosaur cross the strict strandline divide between emergent and shallow subaqueous settings.

In conclusion, the discovery of the new Sindang-ri site underscores the potential for preservation of small tetrapod tracks, particularly those of frogs, that were previously considered rare. Such tracks are associated with other small tetrapod tracks that help us better understand the true diversity of shoreline assemblages (so-called "shorebird ichnocoenoses") and how they relate to shallow lake assemblages. These shoreline ichnocoenoses naturally vary locally and through time: for example, containing pterosaur tracks in the Cretaceous, and larger mammal tracks in the Cenozoic.

References

Hunt, A. P., & Lucas, S. G. (2007). Tetrapod ichnofacies new paradigm. *Ichnos, 14*(1-2), 59-68. https://doi.org/10.1080/10420940601006826.

Hunt, A. P., & Lucas, S. G. (2016). The case for archetypal vertebrate ichnofacies. *Ichnos, 23*(3-4), 237-247. https://doi.org/10.1080/10420940.2016.1164153

Kim, K. S., Lim, J. D, Lockley, M. G., Kim, D. H., Pinuela, L., & Yoo, J. S. (2019a). Largest Cretaceous lizard track assemblage, new morphotypes and longest trackways comprise diverse components of an exceptional Korean Konservat-Lagerstätten ichnofauna. *Scientific Reports, 9*, 13278 https://doi.org/10.1038/s41598-019-49442-0

Kim, K. S, Lockle, M. G., Lim, J. D., & Kim, D. H. (2019b). The oldest known Anuran (frog) trackways from the Jinju Formation, Lower Cretaceous, Korea. *Cretaceous Research, 96*, 142-148

Lockley, M. G., Hunt, A. P., & Meyer, C. (1994). Vertebrate tracks and the ichnofacies concept:

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Implications for paleoecology and palichnostratigraphy. In S. Donovan (Ed.), *The paleobiology of trace fossils* (pp. 241-268). Wiley and Sons, Inc,

Lockley, M. G., Kim, K. S., Lim, J. D., & Romilio, A. (2020). Bird tracks from the Green RiverFormation (Eocene) of Utah: Ichnotaxonomy, diversity, community structure and convergence. *Historical Biology, 33*(10), 2085-2102. DOI: 10.1080/08912963.2020.1771559

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 8:45 AM)

THE DAWN OF THE CRETACEOUS IN EASTERN UTAH

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Deposition of the Upper Jurassic Morrison Formation was followed by approximately 25-30 my of erosion and sediment bypass along the western Cordillera from Mexico northward into Canada (Kirkland et al., 2016) during an interval of tectonic quiescence at the end of the Jurassic between the Elko and Sevier orogenies (Thorman, 2011). Research on the microfossils (ostracodes and charophytes) and radiometric dating of paleosols in Lower Cretaceous Yellow Cat Mbr. (YCM) of the Cedar Mountain Fm. (CMF) in the Paradox Basin (PB) of eastern Utah indicates that deposition in this area began near the base of the Cretaceous in the Berriasian stage (Joeckel et al., 2019; 2023); much earlier than previously proposed. We have proposed that salt tectonics resulted in local subsidence and deposition of the basal YCM in the northern Paradox Basin in eastern Utah (Kirkland, 2017).

YCM in the PB of eastern Utah is divided into an upper and lower sequence based on distinct dinosaur faunas separated by a prominent calcrete or caprock marking the first occurrence of carbonate in CMF paleosols (Kirkland et al., 2016). The oldest U/Pb age from detrital zircons in YCM paleosols is 142.5 $\pm$ 2.7 Ma from a ferruginous paleosol interval near the base of the YCM at Utahraptor Ridge (UR) (Joeckel et al., 2019, 2023). Given U/Pb ash dates from near the top of the underlying Morrison Fm. of 150 -149 Ma (Kirkland et al., 2020). The J/K unconformity in this area spans only 7-8 my suggesting that more of the Jurassic (entire Tithonian) is missing than in the Cretaceous (basal 2-3 my of the Berriasian). However, in Europe on the Iberian Peninsula, a Morrison "style" fauna dominated by diverse sauropods (diplodocids, camarasaurids and brachiosaurids), stegosaurs, and diverse large theropods (*Allosaurus* and *Torvosaurus*) continued up through the Tithonian possibly into the basal Berriasian (Foster, 2021; Russo and Mateus, 2021; Allain et al., 2022). The medial YCM calcrete may reflect the first evidence of a rain shadow with the beginnings of the Sevier orogeny in western Utah following a considerably wetter interval across the Jurassic-Cretaceous (J/K) boundary (Suarez, et al., 2014) as indicated by the underlying ferruginous paleosols (Kirkland, 2016).

The basal Cretaceous of eastern Utah preserves a succession of Wealden "style" dinosaur faunas dominated by styracosternid grade iguanodonts, polacanthine ankylosaurs, turiosaur and possibly European derived brachiosaurid sauropods (all characterized by broad, spatulate teeth), and large dromaeosaurs, with possible carcharodontosaurid allosauroids (Kirkland et al., 2016; Mannion et al., 2013; McDonald, 2010; Royo-Torres et al., 2017). These Wealden "style" faunas characterize the entire YCM and overlying Poison Strip Mbr. (PSM) of the CMF (Kinneer et al., 2016; Kirkland et al., 2016). The dating of the PSM is not very precise and could be anytime from the Hauterivian through the Barremian. Similar iguanodonts and polacanthines ankylosaurs suggest a correlation with the Lakota Fauna of the Black Hill region and the upper Wealden of southern England (Kirkland et al., 2016). Thus Wealden "style" dinosaur faunas characterize 20-25 my of time spanning the lower half of the Early Cretaceous. These data strongly support a significant extinction within the dinosaurs faunas of North America and Europe across the J/K boundary although the precise timing and causes of this faunal turnover are not yet clearly understood.

Another significant faunal turnover occurs near the base of the Ruby Ranch Member (RRM) of the CMF as indicated by the absence of styracosternid grade iguanodonts, polacanthine ankylosaurs, sauropods with broad, spatulate teeth, and large dromaeosaurines. Few RRM dinosaur sites have been excavated in eastern Utah, as carbonate nodule debris makes the identification of sites difficult and carbonate encrusting bones makes excavation and preparation of bones difficult and a number of potentially significant dinosaur sites still await excavation. The lowest skeletal remains in the RRM in the Paradox Basin are about 10 meters above the base of member south of Green River, Utah and consist of a large nodosaurine ankylosaur and fragments of tenontosaurid iguanodonts (primitive taxa replacing the more derived styracosternid grade iguanodonts). Elsewhere in eastern Utah, sauropod remains are restricted to narrow toothed titanosauriform sauropods and theropod remains are rare

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(Kirkland et al., 2016). A pending, highly resolved age, from a volcanic ash in a localized lacustrine unit (Lake Carpenter) at the top of the RRM along the west side of the Salt Valley anticline on the west side of Arches Nat. Park is evidence of an Aptian interval of more local subsidence due to salt tectonics and suggests that the entire RRM in the Paradox Basin maybe no younger than Aptian in age (Suarez et al., 2021). To the west and north, the upper RRM yields a similar fauna from the Upper Albian (Kirkland et al., 2016). Although, both older Aptian and younger late Albian dinosaur faunas are known in the RRM of eastern Utah, no Early Albian

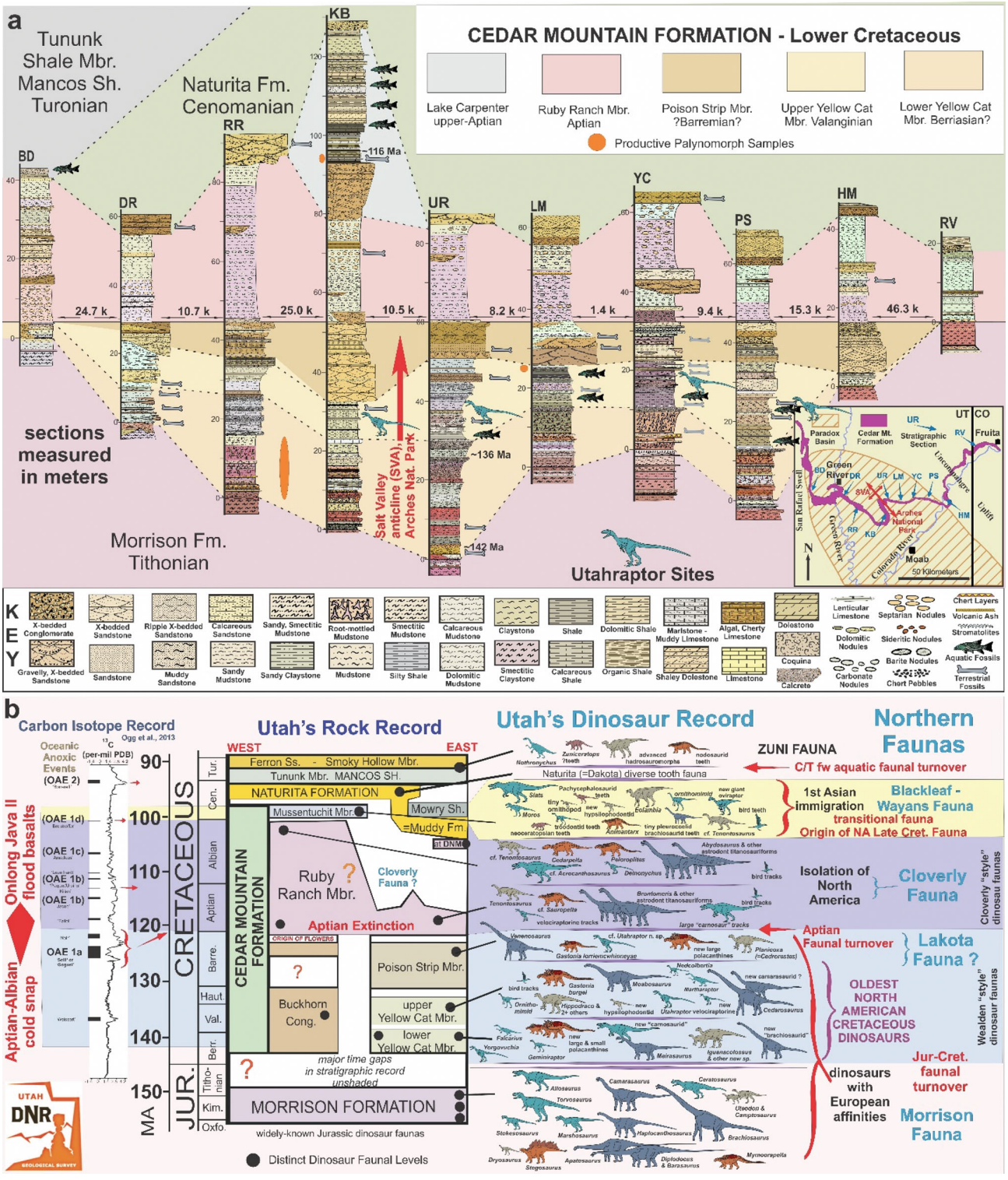


Figure 1. a) Correlation of Cedar Mountain Formation across the Paradox Basin, Grand County, Utah. b) Distribution of Dinosaur through the Cedar Mountain Formation in central and eastern Utah. Both, modified from Kirkland et al., 2016; Kirkland, 2017.

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faunas temporally correlative to the Cloverly fauna of southern Montana have been identified. Given, the presence of similar dinosaurs throughout the RRM, these faunas are identified as Cloverly "style" faunas.

The lower Aptian faunal turnover among dinosaurs was more significant in North America than that in the rest of the Northern Hemisphere. While polacanthine ankylosaurs are replaced by nodosaurine nodosaurids in North America and by struthiosaurine nodosaurids in Europe, styracosternid grade iguanodonts continue to dominate the ornithischian herbivores in Europe (Kirkland et al., 2013). At this time, the extensive Onlong Java flood basalts were erupting in the southeastern Pacific basin likely producing an intense Aptian cooling event. Additionally, flowering plants were undergoing rapid diversification significantly altering the base of the food chain. The base of the Aptian also marks the last evidence of faunal interchange with Europe making North America largely an isolated island continent until the end of the Early Cretaceous (Kirkland et al., 2013, 2016). Any or all of these perturbations, may have resulted in the reorganization of dinosaur faunas recorded in eastern Utah at the base of the Aptian.

Foreland basin development to the west in central Utah resulting from the Sevier orogeny resulted in the deposition of a thick sequence of younger Albian and basal Cenomanian strata while in eastern Utah sediment bypass resulted an unconformity between the top of the Aptian aged CMF and the base the Upper Cretaceous (Cenomanian) Naturita Fm. These "middle" through Upper Cretaceous foreland basin strata have also been undergoing intensive investigation by other teams, who will be presenting their research at this conference.

References

Allain, R., Vullo, R., Rozada, L., Anquintin, J., Bourgeais, R., Goedert, J., Lasseron, M., Martin, J.E., Perez-Garcia, A., Pefre de Fabregues, C., Royo-Torres, R., Augier, D., Bailly, G., Cazes, l., Despresy., Galliegue, A., Gomez, B., Goussard, F., Lenglet, T., Vacant, R., Mazan, & Tournepiche, J.-F. (2022). Vertebrate paleobiodiversity of the Early Cretaceous (Berriasian) Angeac-Charente Lagerstätte (southwestern France): implications for continental faunal turnover at the J/K boundary. *Geodiversitas, 44* (25), 683-752. https://sciencepress.mnhn.fr/en/periodiques/geodiversitas/44/25

Foster, J. (2021). *Jurassic west—The dinosaurs of the Morrison Formation and their world* (2nd ed.). Indiana University Press.

Joeckel, R. M., Ludvigson, G. A., Moller, A., Hotton, C. L., Suarez, M. B., Suarez, C. A., Sames B., Kirkland, J. I., & Hendrix, B. (2019). Chronostratigraphy and terrestrial palaeoclimatology of Berriasian–Hauterivian strata of the Cedar Mountain Formation, Utah, USA. In M. Wagreich, M. B. Hart, B. Sames, & I. O. Yilmaz (Eds.), *Cretaceous climate events and short-term sea-level Changes. Geological Society of London, Special Publications, 498*. https://doi.org/10.1144/SP498-2018-133

Joeckel, R. M., Suarez, C. A., McLean, N. M., Möller, A., Ludvigson, G. A., Suarez, M. B., Kirkland, J. I., Andrew, J., Kiessling, S., & Hatzell, G. A. (2023). Berriasian–Valanginian geochronology and Carbon-isotope stratigraphy of the Yellow Cat Member, Cedar Mountain Formation, Eastern Utah, USA. *Geosciences, 13*, 32. https://doi.org/10.3390/geosciences13020032

Kinneer, B., Carpenter, K., & Shaw, A. (2016). Redescription of *Gastonia burgei* (Dinosauria: Ankylosauria, Polacanthidae), and description of a new species. *Neues Jahrbuch für Geologie und Paläontologie – Abhandlungen, 282*, 37-80. doi:10.1127/njgpa/2016/0605

Kirkland, J. I. (2017). Does Utah preserve North America's oldest Cretaceous dinosaurs because of ancient salt deposits? *Utah Geological Survey. Survey Notes, 49*(1), 4-5. https://ugspub.nr.utah.gov/publications/survey_notes/snt49-1.pdf

Kirkland, J. I., Alcalá, L., Loewen, M. A., Espılez, E., Mampel, L., & Wiersma, J. P. (2013). The basal nodosaurid ankylosaur *Europelta carbonensis* n. gen., n. sp. from the Lower Cretaceous (Lower Albian) Escucha Formation of northeastern Spain. *PLoS ONE, 8*(12), e80405. doi:10.1371/journal.pone.0080405

Kirkland, J. I., DeBlieux, D., Hunt-Foster, R., Foster, J., Trujillo, K., & Finzel, E. (2020). The Morrison Formation and its bounding strata on the western side of the Blanding basin, San Juan County, Utah. *Geology of the Intermountain West, 7*, 137-195. https://giw.utahgeology.org/giw/index.php/GIW/article/view/73

Kirkland, J. I., Suarez, M., Suarez, C., & Hunt-Foster, R. (2016). The Lower Cretaceous in east-central Utah—the Cedar Mountain Formation and its bounding strata. *Geology of the Intermountain West, 3*, 101-228. https://giw.utahgeology.org/giw/index.php/GIW/article/view/11/15

Mannion, P. D., Upchurch, P., Barnes, R. N., & Máteus, O. (2013). Osteology of the Late Jurassic Portuguese sauropod dinosaur *Lusotitan atalaiensis* (Macronaria) and the evolutionary history of basal titanosauriforms. *Zoological Journal of the Linnean Society, 168*, 98-206. doi:10.1111/zoj.12029

McDonald, A. T., Kirkland, J. I., DeBlieux, D. D., Madsen, S. K., Cavin, J., & Milner, A. R. C., & Panzarin, L. (2010). New basal iguanodonts from the Cedar Mountain Formation of Utah and the evolution of thumb-spiked dinosaurs. *PLoS ONE, 5*(11), e14075. https://doi.org/10.1371/journal.pone.0014075

Ogg, J. G., & Hinnov, L. A. (2012). Cretaceous. In F. M. Grandstein, J. G. Ogg, M. D. Schmitz, & G. M. Ogg (Eds.), *The geologic time scale* (pp. 793-853). Elsevier.

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Royo-Torres, R., Upchurch, P., Kirkland, J. I., DeBlieux, D. D., Foster, J. R., Cobos, A., & Alcalá, L. (2017). Descendants of the Jurassic turiasaurs from Iberia found refuge in the Early Cretaceous of western USA. *Scientific Reports, 7*, 14311. DOI:10.1038/s41598-017-14677-2

Russo, J., & Mateus, O. (2021). History of the discovery of the ankylosaur *Dracopelta zbyszewskii* (Upper Jurassic), with new data about the type specimen and its locality. *Comunicações Geológicas, 108*(1), 27-34. DOI: https://doi.org/10.34637/dmdm-5w12

Suarez, C. A., Gonzalas, L. A., Ludvigson, G. A., Kirkland, J. I., Cifelli, R. A., & Kohn, M. J. (2014). Multi-taxa isotopic investigation of paleohydrology in the Lower Cretaceous Cedar Mountain Formation, eastern Utah, USA; Deciphering effects of the Nevadaplano Plateau on regional climate. *Journal of Sedimentary Research, 84*, 975-987. https://doi.org/10.2110/jsr.2014.76

Suarez, M. B., Mclean, M. N., Mueller, A., Ludvigson, G., Kirkland, J. I., Montgomery, E., & Paige, M. (2021). Combined CA-ID-TIMS and carbon isotope chemostratigraphy to correlate Cretaceous continental strata of the Ruby Ranch Member of the Cedar Mountain Formation. *Geological Society of America Abstracts with Programs, 53* (6). doi: 10.1130/abs/2021AM-370386

Thorman, C. H. (2011). The Elko orogeny — a major event in eastern Nevada-western Utah. In D. A. Sprinkle, W. A. Yonkee, & T. C. Chidsey (Eds.), *Sevier thrust belt: Northern and central Utah and adjacent areas. Utah Geological Association Publication, 40*, 117-129.

Poster Session 2 (Friday, June 9, 2023)

PRELIMINARY REPORT ON A PARTIAL NODOSAUR SKELETON FROM THE WAYAN FORMATION OF IDAHO

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Nodosaurs are a rare but distinct component of the fossil assemblage of the middle Cretaceous (Late Albian to Early Cenomanian) Wayan Formation of eastern Idaho. Up to this point, no specimens have been described beyond a few isolated teeth. Other elements recently recovered include very rare isolated axial elements. Most of these elements consist of vertebrae and armor scutes recovered from the multi-taxic Robison Bonebed of eastern Bonneville County. These isolated elements of are of little taxonomic utility. The most important specimen consists of a partial nodosaur skeleton discovered in 2004 by a field party from the Museum of the Rockies in Bozeman, Montana. This specimen is the largest dinosaur skeleton known from Idaho, is by far the most complete ankylosaur known from Idaho and is the only significant dinosaur skeleton known from Idaho excluding comparatively abundant skeletons of the ornithopod *Oryctodromeus cubicularis*. Preparation of this specimen is currently ongoing with the goal of an eventual complete description.

The skeleton was found in a small roadcut outcrop in the upper third of the 1,344-meter thick Wayan Formation, occurring at approximately 1,036 meters above section base in the Tincup Canyon area of Caribou County. The lithology of the fossil quarry consists of a coarsening-upward sequence of fine-grained silty gray sandstone with reworked caliche clasts and associated abundant millimeter to centimeter scale bone fragments. In association with the nodosaur elements are theropod, mammal, and crocodyliform teeth, as well as some dinosaur eggshell fragments. The depositional environment is interpreted as a crevasse-splay deposit within the larger pedogenically imprinted fluvial/floodplain system.

Both axial and appendicular elements are currently known from this specimen, with only a small portion of multiple (~8) field jackets having been prepared so far. Axial elements prepared to this point consist of caudal and dorsal vertebrae, as well as a chevron and ribs. Appendicular elements recognized and prepared so far consist of a partial tibia, fibula, and femur, as well as phalanges and a metatarsal. Extremely abundant small dermal ossifications, (generally less than 1 cm in size) float throughout the matrix associated with the skeleton. Less common larger dermal ossifications are also known, including a few large ridged and ventrally concave dermal plates.

This specimen exhibits a complex taphonomic history. The femur, tibia, and fibula were found in rough articulation. However, these elements are poorly preserved and very fragmentary, with some elements missing articular ends. Vertebrae, ribs, and armor scutes occur mixed together in general anatomical proximity to each other but are compressed together making preparation more challenging. Damage to the skeletal elements indicates some degree of weathering and abrasion prior to final burial and diagenesis. The presence of the theropod, mammal, and crocodyliform teeth in the matrix

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associated with this specimen are interpreted to be reworked clasts not originally associated with the skeleton.

Due to features of the caudal vertebrae and dermal ossifications, initial assessment of this specimen suggested this is a taxon similar to *Sauropelta*, known from the slightly older (Aptian-Albian) Cloverly Formation of Wyoming and Montana. However, much more preparation and comparison to other taxa from coeval units such as the Mussentuchit Member of the Cedar Mountain Formation, which produces the nodosaur *Animantarx*, remain to be done. Once preparation and study are completed on this specimen, it will add to the growing diversity of middle Cretaceous ankylosaurs from Laramidia.

Theme Session: Global Perspectives on Mesozoic Lacustrine Ecosystems (Thursday, June 8, 2023, 4:45 PM)

ARTHROPODA BODY FOSSILS FROM THE JURASSIC SALAD BAR SITE IN THE UPPER JURASSIC MORRISON FORMATION IN SOUTHEASTERN UTAH, USA

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The Upper Jurassic Morrison Formation (~151 Ma) in western North America is well known for its dinosaur fauna. However, the formation also preserves a significant and diverse biota of plants, non-dinosaurian vertebrates (e.g., fishes, amphibians, turtles, crocodylomorphs, pterosaurs, and mammals, invertebrates (e.g., spinicaudatans, ostracods, crayfishes, gastropods, bivalves, insects) and insect traces, most of which have been only preliminarily studied. In the last years, new field trips to Jurassic Salad Bar, a plant-producing locality in southeastern Utah, have produced new arthropod body fossils, such as additional crayfishes, spinicaudatans, and insects, and we summarize and briefly describe these new specimens reposited in the Utah Field House of Natural History State Park Museum, Vernal, Utah, USA (FHPR) here.

The Jurassic Salad Bar, was discovered in 2016 near Bears Ears National Monument, west of the town of Blanding in San Juan County, southeastern Utah, USA. The site contains an abundant flora consisting of ferns, a horsetail, a seed fern, four types of ginkgophytes, a cycadophyte, and up to six different types of conifers (Foster et al., this volume; Kirkland et al., 2022). In addition, the locality preserves spinicaudatan carapaces, rare amioid fishes, and amphibians (Foster et al., 2022). The Jurassic Salad Bar site (hereafter JSB) consists of a several-decimeter thick layer of soft, finely-laminated shale containing most of the plant and occasional small bone material. The site probably represents a freshwater pond or a small lake deposit. The fossiliferous interval occurs near the middle of an ~80 m-thick section of the Brushy Basin Member of the Morrison Formation in southeastern Utah.

Specimens include impressions/compressions of insects and crustaceans (e.g., crayfishes, spinicaudatans). A thin, brown organic film somewhat similar to the color and preservational appearance of the plant material is observed on JSB fossil arthropods (Lara et al., 2020).

The JSB fossil insect fauna is limited but promising, having not been recognized from the site until 2019. The first recognized and formally described insect specimen (Figure 1a, b) from JSB was a nepomorph hemipteran, *Morrisonnepa jurassica*, with broad similarities to modern giant water bugs (Lara et al., 2020). *Morrisonnepa jurassica* (FHPR 17299) is a relatively large insect, with preserved length of 25.4 mm. The insect consists of an incomplete specimen in dorsal view, with mostly disarticulated elements including a forewing (hemelytra), clavus, possible head, and scutellum, five (articulated) abdominal segments, and a pair of short and tubular structures (similar to respiratory processes observed in true water bugs [Lara et al., 2020]).

The most recent findings from the JSB include a new crayfish, spinicaudatans, a beetle, and other unidentified arthropods. The small crayfish (FHPR 11301 [Figure 1c]) appears to be a different form from those previously reported and described by Hasiotis and Kirkland (1997) and is not associated with burrows. The specimen (total length ~30 mm) is preserved in ventral view and consists of cephalothorax, abdomen, and telson. The morphological structures partly preserved include: carapace, rostrum, ?maxillipeds, cephalothorax sternum, five pairs of thoracic appendages (pereiopods: the first three pairs are chelate), and uropods.

Interestingly, the spinicaudatans include at least ten specimens (e.g., FHPR 10861) preserved as shells but not yet identified (Figure 1d). Spinicaudatans are also common at the Montezuma Creek locality east of Bluff, Utah. There are at least four possible caddisfly cases (?*Tektonargus*, e.g., FHPR 10844) from the Jurassic Salad Bar and

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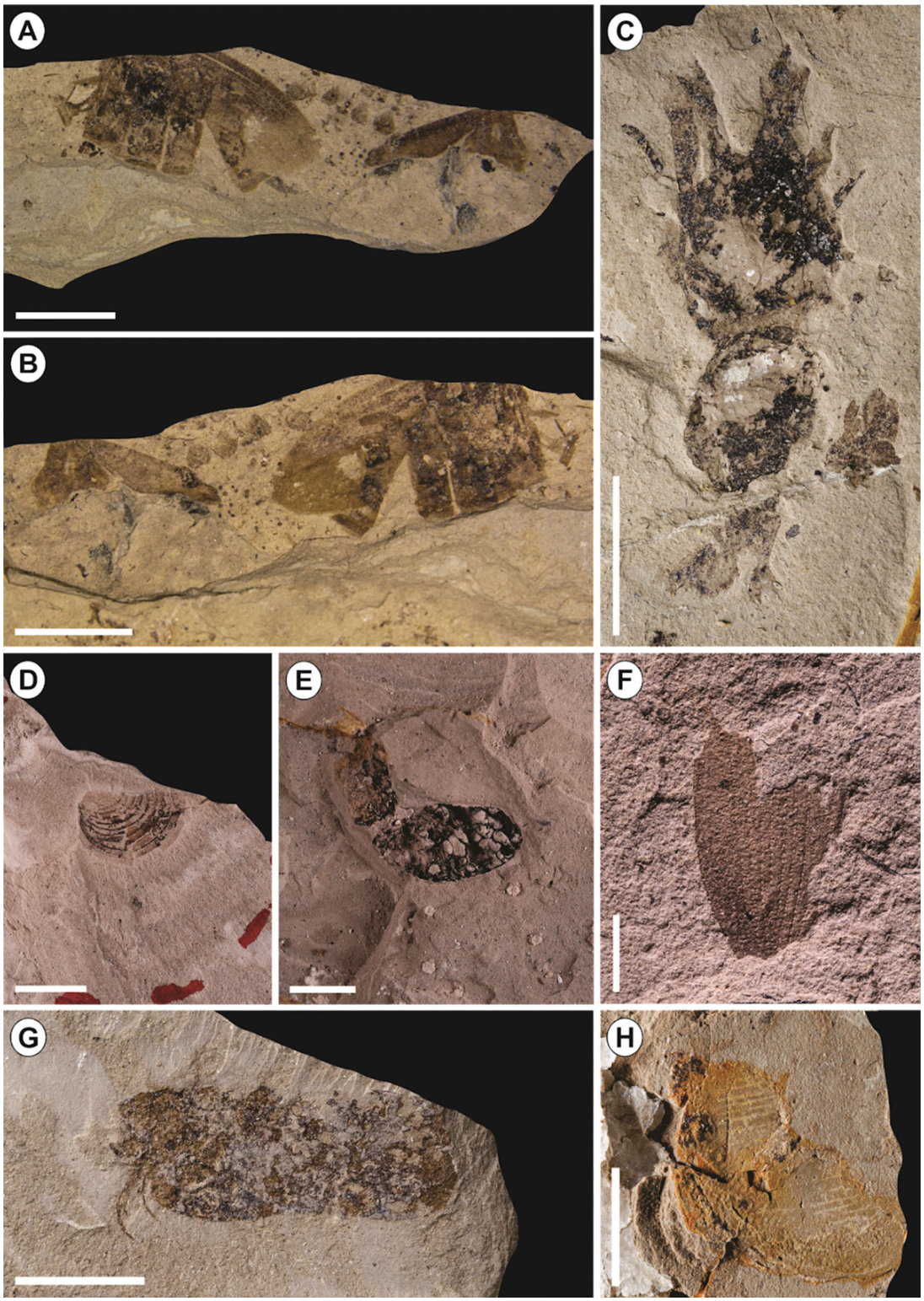


Figure 1. Fossil arthropods at the Jurassic Salad Bar (JSB) locality, Morrison Formation, San Juan County, southeastern Utah, USA. **a)** Nepomorph hemipteran *Morrisonnepa jurassica* Lara et al., 2020, holotype, FHPR 17299, part. **b)** *Morrisonnepa jurassica* Lara et al., 2020, holotype, FHPR 17299, counterpart. **c)** Crayfish body fossil, FHPR 11301, part. **d) S**pinicaudatan carapace, FHPR 10861. **e)** Caddisfly case (? *Tektonargus*), FHPR 10844. **f)** Coleoptera isolated elytra, FHPR 18689, counterpart. **g)** Decapod crustacean?, FHPR 11308. **h)** Fragmentary arthropod?, FHPR 18672. Scale bars A–C, 10 mm; D, E, G, H, 5 mm; F, 2mm.

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all appear to have been lined exteriorly with unidentified fecal pellets (Figure 1e).

A beetle (Figure 1f) is represented by an isolated and elongated elytra (FHPR 18689), 8.0 mm long by 5.5 mm, showing ~12 longitudinal rows of small striae, which show up best as positive-relief natural casts on the counterpart. The striae run parallel to each other and the margins. The elytra is punctate, with striae composed of rows of small indentations.

Finally, FHPR 11308 is ~14.3 mm long, and preserves structures similar to eyes on stalks, antennae, and a cheliped (Figure 1g). This specimen is likely close to decapod crustaceans (freshwater ?hermit crabs). Futures studies will give us a more accurate taxonomic position. FHPR 18672 also appears to be a fragmentary arthropod fossil with some exoskeletal structure preserved as impressions in the matrix (Figure 1h).

These fossils represent the first arthropod records at the Jurassic Salad Bar locality, Morrison Formation (Upper Jurassic), San Juan County (Utah, USA). The presence of multiple species of insect body fossils is so far unique within the Morrison Formation. Likewise, these findings add new anatomical information to different arthropod groups and allow us to better understand how the arthropod assemblages were integrated during the Late Jurassic in this part of the Laurasian continent.

References

Foster, J. R., Hunt, A. P., & Kirkland, J. I. (2022). Significance of a small regurgitalite containing lissamphibian bones, from the Morrison Formation (Upper Jurassic), within a diverse plant locality deposit in southeastern Utah, USA. *Palaios*, *37*, 433-442.

Foster, J. R., Gee, C. T., Ash, S. R., & Kirkland, J. I. (This volume). Preliminary observations on the Jurassic Salad Bar, a new ginkgophyte-dominated flora from the Upper Jurassic Morrison Formation in southeastern Utah, USA. *The Anatomical Record*.

Hasiotis, S. T., & Kirkland, J. I. (1997). Crayfish fossils and burrows from the Upper Jurassic Morrison Formation, Colorado Plateau, USA: Implications for crayfish evolution. *Freshwater Crayfish*, *11*, 106-120.

Kirkland, J. I., Foster, J. R., DeBlieux, D. D., & Hunt-Foster, R. K. (2022). New discoveries of Morrison Formation plant fossils expand our knowledge of Jurassic ecosystems. *Utah Geological Survey: Survey Notes*, *54(2)*, 6-7.

Lara, M. B., Foster, J. R., Kirkland, J. I., & Howells, T. F. (2020). First fossil true water bugs (Heteroptera, Nepomorpha) from Upper Jurassic strata of North America (Morrison Formation, southeastern Utah). *Historical Biology*, *33*, 1996-2004.

Poster Session 2 (Friday, June 9, 2023)

ACQUIRING THE HOMESTEAD UPPER TRIASSIC SITE: AN INTERNATIONAL COLLABORATION THAT PROVIDES EDUCATIONAL, RESEARCH AND PUBLICATION OPPORTUNITIES

Lauer, René[1], Lauer, Bruce[1], Ward, David J.[1,2,3], Ward, Alison E. M.[1,3]

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The Lauer Foundation acquires, curates, and provides access to a collection of scientifically important paleontological specimens. The collection is available to the scientific community for research, publication, exhibition, and educational outreach. An updated list of publications is available on the Foundation website (https://www.lauerfoundationpse.org/). The core collection is locality based, including the lagerstättes of the late Carboniferous at Mazon Creek, Illinois, USA, and the late Jurassic of Solnhofen, Bavaria, Germany. Individual specimens and collections from other localities have been acquired for educational outreach or research purposes.

Paleontologists are facing increasing legal, financial, and bureaucratic barriers to gain access to fieldwork localities for student teaching, specimen collection and research. Many deposits are located on privately owned land which is largely inaccessible or publicly owned lands such as state and national parks or BLM land. Although rightly protected and preserved for future generations, localities on publicly owned land in the USA can be particularly difficult to use due to the amount of paperwork and number of regulations. Bruce and René Lauer, Directors of the Lauer Foundation, were contacted by a commercial fossil dealer with an offer to sell a scientifically important collection of approximately 100,000 upper Triassic field picked macrofossils and screen washed microvertebrate fossils. The fossils were collected on a plot of land owned by the fossil dealer in east central New Mexico. The Lauer Foundation initially declined the offer as this was not the focus of the Foundation. However, an alternative option was proposed; to purchase the entire microvertebrate site and the existing collection. This option would solve provenance issues and could also provide site access to facilitate both education and research. Further, it would save the collection from being sold or dispersed, with the inevitable loss of provenance-based scientific data.

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Figure 1. A) The Homestead Site in east-central New Mexico, USA, B) the Homestead cabin.

The plot of land, now referred to as "the Homestead site" is a small (2 hectare/5 acre) area of unfenced semi-desert badland in New Mexico. This region has been relatively inaccessible, so minimal geological, sedimentary and paleontological study has taken place. It contains a rich deposit of Triassic macro- and microvertebrate fossils which provide a wealth of possibilities for research and publication. Several leading paleontologists with an expertise in Triassic vertebrate fossils helped to evaluate the collection and the site. The Lauer Foundation undertook a feasibility, cost/risk/benefit analysis, which included consideration of the value of the collection and the land for geological field training, research, and publication. Initial investigation confirmed both the collection and the parcel of land were scientifically important; they could be a valuable resource for teaching and research, and could provide students with sound field experience and laboratory training. Additionally, the collection was thought likely to yield new species and fill gaps in museum collections worldwide. The Foundation set up a limited liability corporation to purchase the property and the collection, and updated the Foundation by-laws to meet the requirements for scientific publication and the storage of type and figured specimens. The Foundation assembled an international team of partner institutions who could commit to use the collection and the site. A memorandum of understanding (MOU), which details the terms of use, access, liability, insurance, and responsibilities was drafted and signed by representatives of Appalachian State University, Virginia Tech University and the Natural History Museum, UK. Each team member provides unique expertise, resulting in a multidisciplinary approach to the study of this rich microvertebrate fossil assemblage. Access is coordinated within the group, which can be expanded to allow further participants as required. Together, these institutional partners can use the collection and have access to the Homestead site for student fieldwork and geological research.

Fieldwork began in late 2020 and student visits took place in the Springs of 2021 and 2022. Talks and poster presentations have been conducted by the staff and students of the institutional partners at SVP (2021, 2022) and at IPC6 (2022).

Ongoing research continues with the aim of reconstructing the sedimentological and paleoenvironmental context of the site with an emphasis on the determination of its precise stratigraphic position and age. The Lauer Foundation and partner institutions will continue to collect, identify, and publish on the taxa assemblage in addition to building a reference collection within the Foundation to provide the scientific community with research material. New taxa can be housed within the Foundation, added to the NHM UK collection, or deposited wherever is thought appropriate. The site and the fossil collection will continue to be used for teaching and student projects without the need for permits or lengthy negotiation.The Lauer Foundation has successfully secured an important upper Triassic microvertebrate site for student teaching, collection, research, and publication. It has provided a novel solution for any conflict of interest between the commercial fossil collector and the academic community and serves as an example of the benefit of collaborative efforts between these groups.

Technical Session 3: Terrestrial Ecosystems – Late Jurassic (Friday, June 9, 2023, 2:30 PM)

MESIC LATE JURASSIC COASTAL FLORAS FROM PACIFIC NORTH AMERICA

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Two Late Jurassic macrofloras from the Pacific region, originally described in the early 1900s, are reappraised. These floras are the Monte de Oro flora from northern California (late Oxfordian—early Kimmeridgian) and the Riddle flora from southwestern Oregon (late Tithonian). The cooccurrence of marine invertebrates in these formations, combined with the preservational conditions of floral elements, indicate parautochthonous, near-shore deposition. Considering the stratigraphic positions and paleogeographic configurations of these floras, they represent plant communities from volcanic arcs along the Pacific subduction margins (Figure 1A, B, D).

Cycadophytes are dominant in both floras: Cycadales and Nilssoniales in the Monte de Oro flora and Bennettitales and Nilssoniales in the Riddle flora (Figure 1C, E). Notable is the high specific diversity of cycadalean foliar genus *Ctenis*, along with their unusually large leaf sizes for the genus, in the Monte de Oro flora. The co-dominance of ginkgophytes together with cycadophytes in both floras is unusual. Scale- to awl-leaved conifers that were dominant in the low to mid-latitude during the Late Jurassic, are either insignificant or absent and instead, *Elatides* and broad-leaved *Podozamites* are common in the Monte de Oro flora. Ferns are not abundant; the taxonomically more temperate osmundaceous and dicksoniaceous ferns are found together with thermophilic schizaceous and dipteridaceous taxa. Pteridosperms are poorly represented with *Ptilozamites* and foliar and reproductive material of Caytoniales as rare exceptions, the often common coastal and littoral *Pachypteris* and *Cycadopteris* are absent.

The composition of both floras is different from the late Kimmeridgian to early Tithonian Morrison flora deposited further to the east. The Morrison flora has been reconstructed as semiarid, predominantly herbaceous, savannah-like vegetation (e.g., Parrish et al., 2004), although recent paleontological findings support wetland or conifer-dominated forest/woodland environments, at least at regional scales (e.g., Gee et al., 2019; Gorman et al., 2008). In contrast, the two floras studied herein are dominated by cycadophytes and ginkgophytes and represents warm and wet environments, with higher precipitation than the inland Morrison Basin. Among coeval floras, it is floristically most similar to the Tetori-type flora of East Asia. These two studied floras thus provide unexpected insights into the Pacific plant communities and phytogeography during the Late Jurassic.

References

Blakey, R. C. (2014). Paleogeography and paleotectonics of the Western Interior Seaway, Jurassic-Cretaceous of North America. *Search and Discovery*, Article # 30392, 1-72.

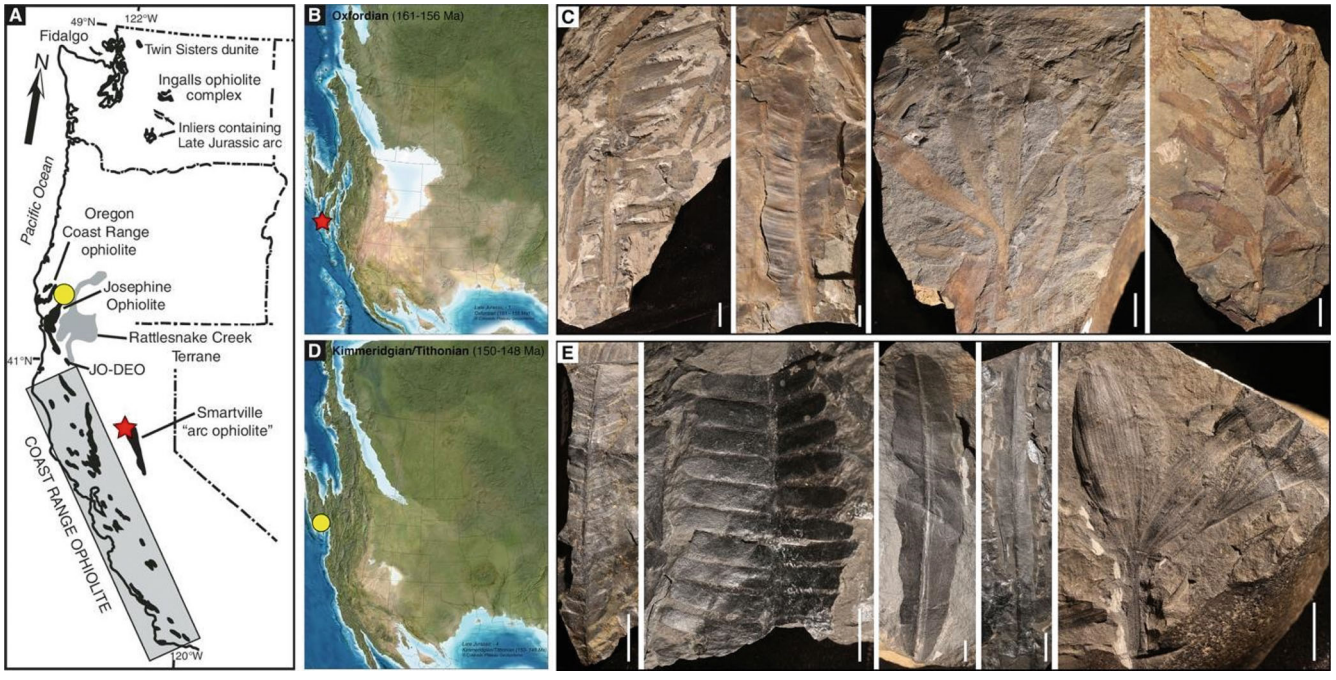


Figure 1. Location and specimens of the two Late Jurassic floras from the Pacific North America. A) Location of the floras, in relation to the Middle to Late Jurassic ophiolites in the Pacific coastal regions of the United States. Red star = Monte de Oro flora, yellow dot = Riddle flora. Map from MacDonald et al. (2008). B) Paleogeographic location of the Monte de Oro flora (late Oxfordian-early Kimmeridgian). Map from Blakey (2014). C) Common floral elements of the Monte de Oro flora; *Ctenis*, *Nilssonia*, *Ginkgoites*, and *Podozamites*. D) Paleogeographic location of the Riddle flora (late Tithonian). Map from Blakey (2014). E) Common floral elements of the Riddle flora; *Ptilophyllum*, *Pterophyllum*, *Nilssonia*, and *Ginkgoites*. Scale bars = 1cm.

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Gee, C. T., Sprinkel, D. A., Bennis, M. B., & Gray, D. E. (2019). Silicified logs of *Agathoxylon hoodia* (Tidwell et Medlyn) comb. nov. from Rainbow Draw, near Dinosaur. National Monument, Uintah County, Utah, USA, and their implications for araucariaceous conifer forests in the Upper Jurassic Morrison Formation. *Geology of the Intermountain West*, *6*, 77-92.

Gorman II, M. A., Miller, I. M., Pardo, J. D., & Small, B. J. (2008). Plants, fish, turtles, and insects from the Morrison Formation: A Late Jurassic ecosystem near Cañon City, Colorado. In R. G. Reynolds (Ed.), *Roaming the Rocky Mountains and environs: Geological field trips. Geological Society of America Field Guide 10* (pp. 295-310). Geological Society of America.

MacDonald, J. H., Harper, G. D., Miller, R. B., Miller, J. S., Mlinarevic, A. N., & Miller, B. V. (2008). Geochemistry and geology of the Iron Mountain unit, Ingalls ophiolite complex, Washington: Evidence for the polygenetic nature of the Ingalls complex. *The Geological Society of America Special Paper*, *438*, 161-173.

Parrish, J. T., Peterson, F., & Turner, C. E. (2004). Jurassic "Savannah"—plant taphonomy andclimate of the Morrison Formation (Upper Jurassic, Western USA). *Sedimentary Geology*, *167*, 137-162.

Poster Session 2 (Friday, June 9, 2023)

THE FLORA OF THE EARLY CRETACEOUS JINJU KONSERVAT-LAGERSTÄTTE (110-106 MYA, ALBIAN), SOUTH KOREA

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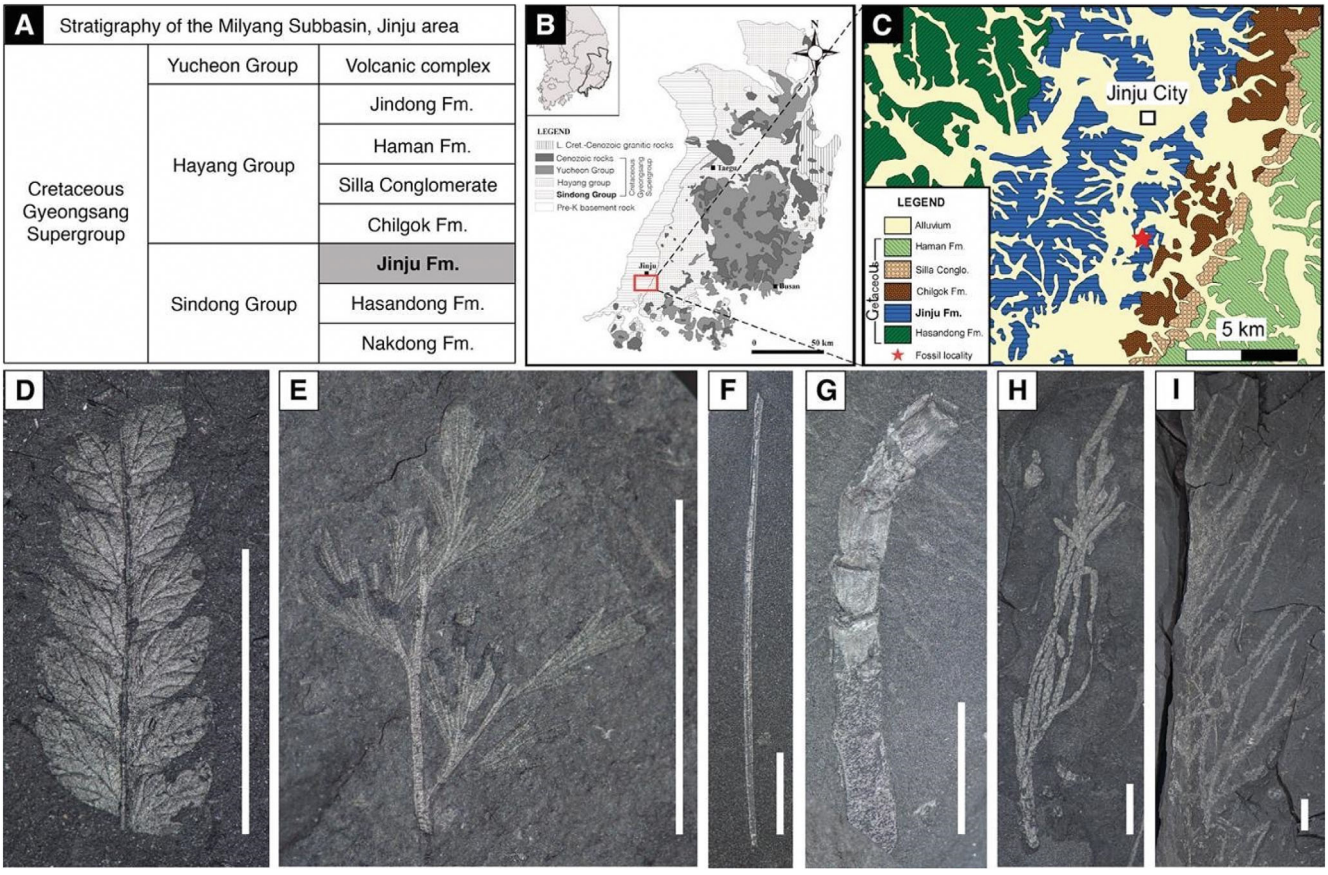


Figure 1. Geologic settings and specimens of the Jinju Formation. A) Stratigraphy of the Cretaceous Gyeongsang Basin in Jinju area, adopted from Kang and Paik (2013). B) Geologic map of the Gyeongsang Basin in the southeastern Korean Peninsula and C) near Jinju city, with the fossil locality marked as red star. D-I) Examples of the Jinju floral elements. D) *Cladophlebis* sp. E) *Sphenopteris* sp. F) *Pityophyllum* sp. G) *Pseudofrenelopsis* sp. H) *Brachyphyllum* sp. I) *Cupressinocladus* sp. Scale bars = 1cm.

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Large-bodied dinosaur assemblages are frequently associated with open vegetation, such as savannah-like shrubland and marshland. The late Early Cretaceous (110-106 mya, Albian) Jinju Konservat-Lagerstätte from South Korea preserves exceptionally preserved vertebrate trackways (e.g., nonavian and avian dinosaurs, pterosaurs, crocodylomorphs, lizards, anurans, mammals), as well as terrestrial and freshwater arthropod body fossils. The Early Cretaceous Gyeongsang basin, in which the Jinju Formation was deposited, preserves a rich ecological and taxonomic diversity of terrestrial vertebrates. Here, we report new findings for the relatively poorly understood Jinju paleoflora.

An allochthonous macroflora from the Jinju Formation, preserved as compressions and impressions was exposed during construction excavations in Jeongchon-myeon, Jinju, South Korea. Foliar taxa are represented by 10-15 fragmented pteridophyte types, abundant microphyllous conifers (e.g., *Brachyphyllum*, *Cupressinocladus*, *Pseudofrenelopsis*), *Pityophyllum*, rare *Elatocladus* and taxodioid types, and 1-2 broadleaf gymnosperm taxa of uncertain taxonomic affinity (Figure 1). Diaspores and reproductive structures are represented by a few winged diaspores, several diaspores of undetermined taxonomic affinity and dispersal mode, and one relatively large fleshy diaspore (∼1.5cm in length). Several reproductive structures are identified: a full conifer ovuliferous cone, fragmented cone scales, as well as partial structures putatively identified as *Umaltolepis* and *Umkomasia*. The latter two are produced by peat-forming gymnosperms found in coal assemblages in nearby and coeval East Asian localities, although this taxonomic assignment should be treated with caution as their epidermal features are not available to lack of cuticle preservation.

The allochthonous Jinju flora includes elements of shrubland vegetation composed of ground covering pteridophytes with conifer shrubs and trees across the landscape and plants from lacustrine environments. Considering the prevalence of microphyllous conifers, which are taxonomically assigned to or affiliated with the xeric-tolerant Mesozoic conifer family Cheirolepidiaceae, combined with previous palynological work reporting dominance of its pollen *Classopollis* and the presence of evaporites in the formation, all suggest an overall warm and arid environment. In lacustrine environments, marshland likely existed which comprised horsetails and the aforementioned peat-forming gymnosperms.

References

Kang, H.-C., & Paik, I. S. (2013). Review on the geological ages of the formation in the Gyeongsang Basin, Korea. *Journal of the Geological Society of Korea*, *41*, 17-29

Theme Session: Laramidia to Asia: Biota and Biogeography of Interconnected Iconic Late Cretaceous Ecosystems (Saturday, June 10, 2023, 5:20 PM)

NEW VERTEBRATE RECORDS FROM THE UPPER CRETACEOUS (CAMPANIAN) NESLEN FORMATION, EASTERN UTAH

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During the Late Cretaceous, North America was bisected by the Western Interior Seaway, stretching from the western Tethys to the Boreal Ocean (Roberts & Kirschbaum, 1995). The landmass to the west of that seaway, known as Laramidia (Archibald, 1996), preserves a multitude of vertebrate-bearing fossil assemblages in fluvial basins deposited during the Campanian. These penecontemporaneous assemblages have been well-sampled from Mexico to Alberta and serve as a study system for understanding paleobiogeography and evolutionary patterns during the Late Cretaceous. The observed distributions of taxa within several vertebrate clades support hypotheses of provinciality and endemism (Gates et al., 2010; Lehman, 1997). However, the nature of the boundaries of any potential biogeographic provinces is difficult to test, owing to a large gap in sampling between the Kaiparowits Basin in southern Utah and the Two Medicine and Judith River formations of Montana. One of the formations that may help fill this geographic gap is the Campanian (∼75 Ma) Neslen Formation of east-central Utah. The Neslen Formation represents deposition in fluvial to paralic settings in the Sevier foreland basin. Compared to units of similar age, the Neslen Formation has not been surveyed as much for its paleontological resources. Thus far, only two vertebrates – the hadrosaur *Rhinorex* (Gates & Scheetz, 2015) and a partial tyrannosaur hindlimb (Thompson et al., 2013) – have been published from the formation.

I present new contributions to the fossil assemblage of the Neslen Formation from outcrops in western Grand County, Utah. These new records are the result of two field seasons in the formation conducted by the Prehistoric Museum at Utah State University Eastern. These expeditions have produced over 100 new cataloged specimens, including vertebrate and invertebrate trace fossils, angiosperms, gymnosperms, freshwater molluscs, chondrichthyans, turtles, crocodilians, and dinosaurs. The lower portion of the formation, referred to as the Lower Palisades and Palisades Coal zones (e.g., Shiers et al.,

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2017), is the most fossiliferous and is easily accessible in the areas we have prospected thus far, with the Lower Palisades Zone being the most fossiliferous. The Neslen Formation overlies the marginal marine Sego Sandstone, which contains abundant oyster beds within alternating nearshore sandstones and mudstones in this area. The Lower Palisades Zone is interpreted as floodplain and mire deposits, typified by organic-rich mudstones and coal. These deposits are capped by sandstone channels interpreted as bayhead deltas (e.g., Aschoff et al., 2018) containing marine trace fossils, including abundant *Teredolites*.

Though most of the vertebrate material consists of well-preserved isolated bones and other fragmentary remains, several fossils have proven to be diagnostic. Turtles are the most common identifiable vertebrates from the formation. Taxa identified thus far include *Adocus*, *Basilemys*, *Neurankylus*, a plastomenine trionychid, and at least two other trionychid form taxa. The plastomenine is represented by a distal costal that exhibits fine ridges between pits of varying shape. Laterally, the costal possesses a groove (or splitting into dorsal and visceral lobes, sensu Joyce et al., 2009) that is apomorphic for the clade including *Helopanoplia* and *Hutchemys* based on previous phylogenetic analyses (e.g., Edgar et al., 2022; Jaskinski et al., 2022; Joyce et al., 2009).

At least two morphotypes of crocodylomorph teeth were recovered from the Neslen Formation. One of these is a large, robust form that possesses prominent, longitudinal striations on the enamel surface on the crownward half of the tooth. There is also a smaller, gracile, recurved morphotype that is strongly bicarinate with some minor fluting of the enamel on the lingual half. Other crocodylomorph specimens collected from the formation include a quadrate, partial ischium, and a small femur, all from separate localities. New dinosaurian fossils from the formation include dromaeosaur and tyrannosaur teeth, various non-diagnostic hadrosaur elements, ankylosaur osteoderms, and ceratopsian bones. One ceratopsian specimen is represented by a complete, isolated postorbital horn that preserves a portion of the dorsal orbital margin. The base of the horn originates just dorsal to the orbit, projects dorsolaterally for approximately 50% of its length, then curves dorsally and slightly anteriorly. The horn is oval in cross section basally before becoming more rounded distally.

The published tyrannosaur pes from the Neslen Formation shares a plantar ridge on metatarsal IV with taxa from Montana and Alberta, differing from the state present in tyrannosaurs from southern Utah and New Mexico (Thomson et al., 2013). This suggests the Neslen tyrannosaur belongs to one of the tyrannosaur lineages endemic to northern Laramidia. Though they are more abundant in southern Laramidia during the Campanian, records of plastomenine trionychids are known from northern basins as well. However, the clade of plastomenines that includes *Hutchemys* spp. and *Helopanoplia distincta* is known only from the Kaiparowits Basin and more southerly latitudes during the Campanian, preceding a northward dispersal by the clade during the Maastrichtian. The record from the Neslen Formation would represent the northernmost locality to date for this clade during the Campanian. The new ceratopsian postorbital horn exhibits a morphology not present in previously described taxa, and may represent a species as yet unique to the Neslen Formation drainage basin.

Based on these preliminary observations, a mix of taxa typical of the hypothesized northern and southern Campanian biogeographic provinces are found in the fossil assemblage of the Neslen Formation. In particular, species-level studies on freshwater turtles (e.g., Hutchison et al., 2013; Lively, 2016) support a pattern of northern and southern biogeographic provinces during the Campanian. The unique ceratopsian horn may support the hypothesis that some clades exhibit basin-scale endemism, as suggested by previous work on ceratopsians (e.g., Sampson et al., 2010). Ultimately, it is likely each clade exhibits its own unique biogeographic pattern, as evidenced by previous work on Late Cretaceous squamates (Nydam et al., 2013; Woolley et al., 2020). Continued exploration of the Neslen Formation will help elucidate these patterns by providing a critical data source between better-studies formations in southern Utah and Montana.

References

Archibald, J. D. (1996). *Dinosaur extinction and the end of an era: What the fossils say*. Columbia University Press.

Aschoff, J. I., Olariu, C., & Steel, R. J. (2018). Recognition and significance of bayhead delta deposits in the rock record: a comparison of modern and ancient systems. *Sedimentology, 65*, 62-95.

Edgar, S. C., Brinkman, D. B., Ryan, M. J., & Evans, D. C. (2022). A new plastomenid trionychid (Testudines: Pan-Trionychidae) from Milk River Formation of southern Alberta (Cretaceous: Santonian). *Canadian Journal of Earth Sciences, 59*(4), 205-215.

Gates, T. A., Sampson, S. D., Zanno, L. E., Roberts, E. M., Eaton, J. G., Nydam, R. L., Hutchison, J. H., Smith, J. A., Loewen, M. A., & Getty, M. A. (2010). Biogeography of terrestrial and freshwater vertebrates from the Late Cretaceous (Campanian) Western Interior of North America. *Palaeogeography, Palaeoclimatology, Palaeoecology, 291*, 371-387.

Gates, T. A., & Scheetz, R. (2015). A new saurolophine hadrosaurid (Dinosauria: Ornithopoda) from the

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Campanian of Utah, North America. *Journal of Systematic Palaeontology, 13*(8), 711-725.

Hutchison, J. H., Knell, M. J., & Brinkman, D. B. (2013). Turtles from the Kaiparowits Formation, Utah. In A. L. Titus & M. A. Loewen (Eds.), *At the top of the Grand Staircase: The Late Cretaceous of southern Utah* (pp. 295-318). Indiana University Press.

Jasinski, S. E., Heckert, A. B., Sailar, C., Lichtig, A. J., Lucas, S. G., & Dodson, P. (2022). A softshell turtle (Testudines: Trionychidae: Plastomeninae) from the uppermost Cretaceous (Maastrichtian) Hell Creek Formation, North Dakota, USA, with implications for the evolutionary relationships of plastomenines and other trionychids. *Cretaceous Research, 135*, 105172.

Joyce, W. G., Revan, A., Lyson, T. R., & Danilov, I. G. (2009). Two new plastomenine softshell turtles from the Paleocene of Montana and Wyoming. *Bulletin of the Peabody Museum of Natural History, 50*(2), 307-325.

Lehman, T. M. (1997). Late Campanian dinosaur biogeography in the western interior of North America. In D. Wolberg & E. Stump (Eds.), *Dinofest International Proceedings* (pp. 223-240). Philadelphia Academy of Sciences.

Lively, J. R. (2016). Baenid turtles of the Kaiparowits Formation (Upper Cretaceous: Campanian) of southern Utah, USA. *Journal of Systematic Palaeontology, 14*(11), 891-918.

Nydam, R. L., Rowe, T. B., & Cifelli, R. L. (2013). Lizards and snakes of the Terlingua Local Fauna (late Campanian), Aguja Formation, Texas, with comments on the distribution of paracontemporaneous squamates throughout the Western Interior of North America. *Journal of Vertebrate Paleontology, 33*(5), 1081-1099.

Roberts, L. N. R., & Kirschbaum, M. A. (1995). Paleogeography of the Late Cretaceous of the Western Interior of middle North America – coal distribution and sediment accumulation. *United States Geological Survey Professional Paper* 1561.

Sampson, S. D., Loewen, M. A., Farke, A. A., Roberts, E. M., Forster, C. A., Smith, J. A., & Titus, A. L. (2010). New horned dinosaurs from Utah provide evidence for intracontinental dinosaur endemism. *PLoS ONE, 5*(9), e12292.

Shiers, M. N., Hodgson, D. M., & Mountney, N. P. (2017). Response of a coal-bearing coastal-plain succession to marine transgression: Campanian Neslen Formation, Utah, USA. *Journal of Sedimentary Research, 87*, 168-187.

Thomson T., Irmis, R. B., & Loewen, M. A. (2013). First occurrence of a tyrannosaurid dinosaur from the Mesa Verde Group (Neslen Formation) of Utah: implications for upper Campanian Laramidian biogeography. *Cretaceous Research, 4*, 70-79.

Woolley, C. H., Smith, N. D., & Sertich, J. J. W. (2020). New fossil lizard specimens from a poorly-known squamate assemblage in the Upper Cretaceous (Campanian) San Juan Basin, New Mexico, USA. *PeerJ, 8*, e8846.

Poster Session 2 (Friday, June 9, 2023)

A LARGE, SAURISCHIAN-DOMINATED, TRACKSITE IN THE UPPER JURASSIC MORRISON FORMATION, GRAND COUNTY, UTAH: A SPECTACULAR EXAMPLE OF EXTENSIVE DINOTURBATION

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To date, ~75 dinosaur tracksites have been reported from the bone-rich Upper Jurassic Morrison Formation of the western USA (Lockley et al., 2018). With the exception of the Purgatoire site in SE Colorado which yields ~2100 tracks from an area of ~8,600 m^2 (Schumacher & Lockley, In press), most tracksites are relatively small. Herein we report a very extensive, dinoturbated tracksite, newly discovered in 2021, in the Blue Hills region south of the Spanish Trail, northwest of Moab, Grand County, Utah. Our preliminary study has established that exposures of a heavily trampled surface are intermittently visible in a polygonal area of approximately 300 m (N-S) and 700 m (E-W). Through careful measurement of the extent of exposed track-bearing surface within this area of ~282,000 m^2 we estimate that ~19% of the area (54,000m^2) is visible and available for ichnological study (Figure 1A). Using drones to obtain images of these areas it has been possible to use the resulting images to count a minimum of more than 2000 tracks from the larger exposures. Work on some of the smaller areas is ongoing.

Despite the extent of the reliably correlated track-bearing surfaces, most of these areas are best described as moderately to heavily dinoturbated, with variable post-exhumation erosion. The only unambiguously identified track morphotypes are those of theropods and sauropods (Figure 1B and a-d). In this regard, the assemblage is

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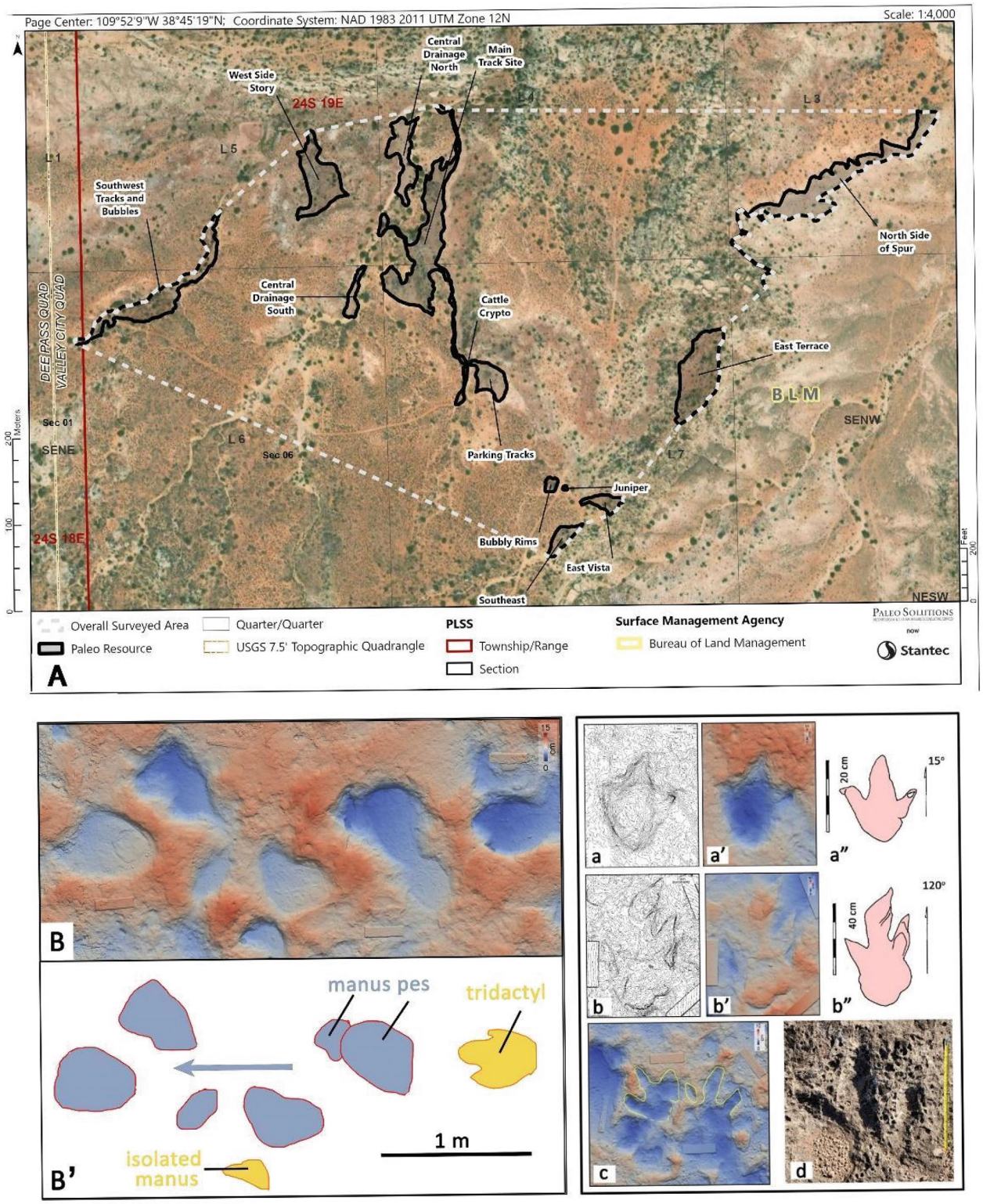


Figure 1. A. The study area marked by a polygon (white dashed line) includes 14 discrete areas of correlated track-bearing surface (black outlines). An estimated ~2000 tracks have been identified in the central area (Main Tracksite area and connected surfaces). Saurischian dinosaur tracks from BHSS. Sauropod trackway surface shown as: B, depth map; and B', schematic interpretation. The arrow shows the direction of progression. Theropod tracks (lower case a–d) shown as (a, b) contour lines; (a', b', c) depth maps; (a", b") schematic interpretations; (d) photograph (with 30 cm scale bar) registered on a surface with vesicular, 'bubbly' texture attributed to MISS effects.

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saurischian-dominated like most Morrison Formation tracksites. We have named the tracksite the Blue Hills Stomp Site (BHSS) to distinguish it from a nearby and older Moab Member (Curtis Formation) site popularly known as the "Stomping Ground" and developed as a Bureau of Land Management (BLM) interpretative site. The BHSS site is also on BLM land.

The western half of the tracksite area reveals only the track-bearing surface and overlying beds. However, the eastern half reveals the underlying stratigraphic sequence, most notably a three-meter thick channel sandstone that thins to the north and east into thinner track-bearing sequences. Current indicators suggest flow predominantly to the north and northeast.

The sedimentology indicates a high-energy sheet flood event (avulsion from a large underlying channel) leading to the deposition of a sand sheet ~ 30-50 cm in thickness as the uppermost depositional unit prior to the deposition of red floodplain muds. Thinner and less extensive channel sandstones higher in the sequence also reveal theropod and sauropod tracks mostly preserved as natural casts. In many places, tracks show steep walls and high rims. We infer that such features are inconsistent with track registration in wet sand that is not bound by microbial mat. In some areas, the track-bearing surface reveals a vesicular bubbly texture (Fig 2d) also suggestive of microbial activity.

The size of the BHSS exposure is far larger (~54,000 m^2) than any previously reported Morrison Formation tracksite: i.e., at ~8,600 m^2 track-bearing exposures at the Purgatoire tracksite measures less than one-sixth of the exposed BHSS area. However, unlike the Purgatoire site very few trackway segments are recognizable at the BHSS location. This means that it is impossible to obtain any useful quantitative census of track types as obtained for the Purgatoire site and other sites. In short, the BHSS is best described as a dinoturbated or trampled site indicative of the activity of a saurischian-dominated fauna. Post-exhumation erosion of the track-bearing surface especially in the more pronounced and narrow drainages has damaged the trampled surface enough to make individual tracks difficult to discern.

As noted elsewhere in the literature on Morrison Formation tracksites, both the individual site-based and collective censuses indicate that the ichnofaunas were saurischian dominated. The majority of sites represent siliciclastic fluvio-lacustrine paleoenvironments associated with fine-grained floodplain deposits incised by sand-filled channels. Such sites contrast with the carbonate-rich lake basin deposits described from the Purgatoire site.

Future work anticipates attempting to describe and explain variable track density across the area. We also hope to assess the role of microbial mat, how it developed in a newly deposited sand sheet and the role it played in preserving tracks.

References

Lockley, M. G., Foster, J. R., & Hunt Foster, R. (2018). The first North American *Deltapodus* trackway in a diverse Anomoepus, theropod, sauropod, and turtle track assemblage from the Upper Jurassic Salt Wash Member (Morrison Formation) of eastern Utah. *New Mexico Museum of Natural History and Science Bulletin, 79*, 407-415.

Schumacher, B. A., & Lockley, M. G. (In press). North America's largest assemblage of Late Jurassic dinosaur trackways, the Purgatoire Valley dinosaur tracksite ("Dinosaur Lake"), Morrison Formation, southeastern Colorado, United States. *Historical Biology*. DOI: 10.1080/08912963.2022.2081567

Poster Session 2 (Friday, June 9, 2023)

MULTIPLE DINOSAUR TRACKSITES DOMINATED BY DIMINUTIVE TRIDACTYL TRACKMAKERS FROM THE UPPER JURASSIC, MOAB MEMBER (CURTIS FORMATION), GRAND COUNTY, UTAH

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Ongoing studies of the tetrapod tracks from the Moab Member of the Curtis Formation on the SW flank of the Salt Valley Anticline (SVA), Grand County, Utah, have reveal a hitherto unrecognized abundance of tracksites yielding diminutive (or "tiny") dinosaur tracks (Footprint Length FL: ~3.0 cm - ~7.0 cm) and previously unrecognized invertebrate traces. Marty (2008) defined tracks <10 cm in length as "tiny" and Lockley et al. (2021) noted that ~83% of modern birds had track FLs <10.0. Thus, the Moab Member tracks are similar in size to typical modern bird tracks, although they have hitherto been attributed to small non-avian theropods and possibly small bipedal ornithischians.

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To date at least 40 tracksites have been recorded along the Moab Member strike belt exposed in the SW flank of the SVA for a distance of ~23 km. We contend that all presently-reported tracksites occur in the uppermost ~1.0 - ~2.0 meters of the Moab Member, possibly because this portion of the unit is the most extensively exposed throughout the region. Despite unpublished reports that these tracks were abundant, the small shallow tracks are not always easy to recognize, and only 16 sites had previously been reported in the literature (Lockley & Meyer 2022, and refs therein). The present study has demonstrated that in some areas a high density of tracksites, some <5.0m apart, occur on different dune set surfaces in small areas: e.g., eight sites in ~200m^2 (Figure 1). Because the sites all occur on different dune foresets, they cannot be regarded as exposures of different areas of the same surfaces. While individual tracksites are mostly small and can be mapped using traditional methods (compass, tape & tracings), the areas with multiple closely-spaced sites have been imaged using drone technology (Figure 1).

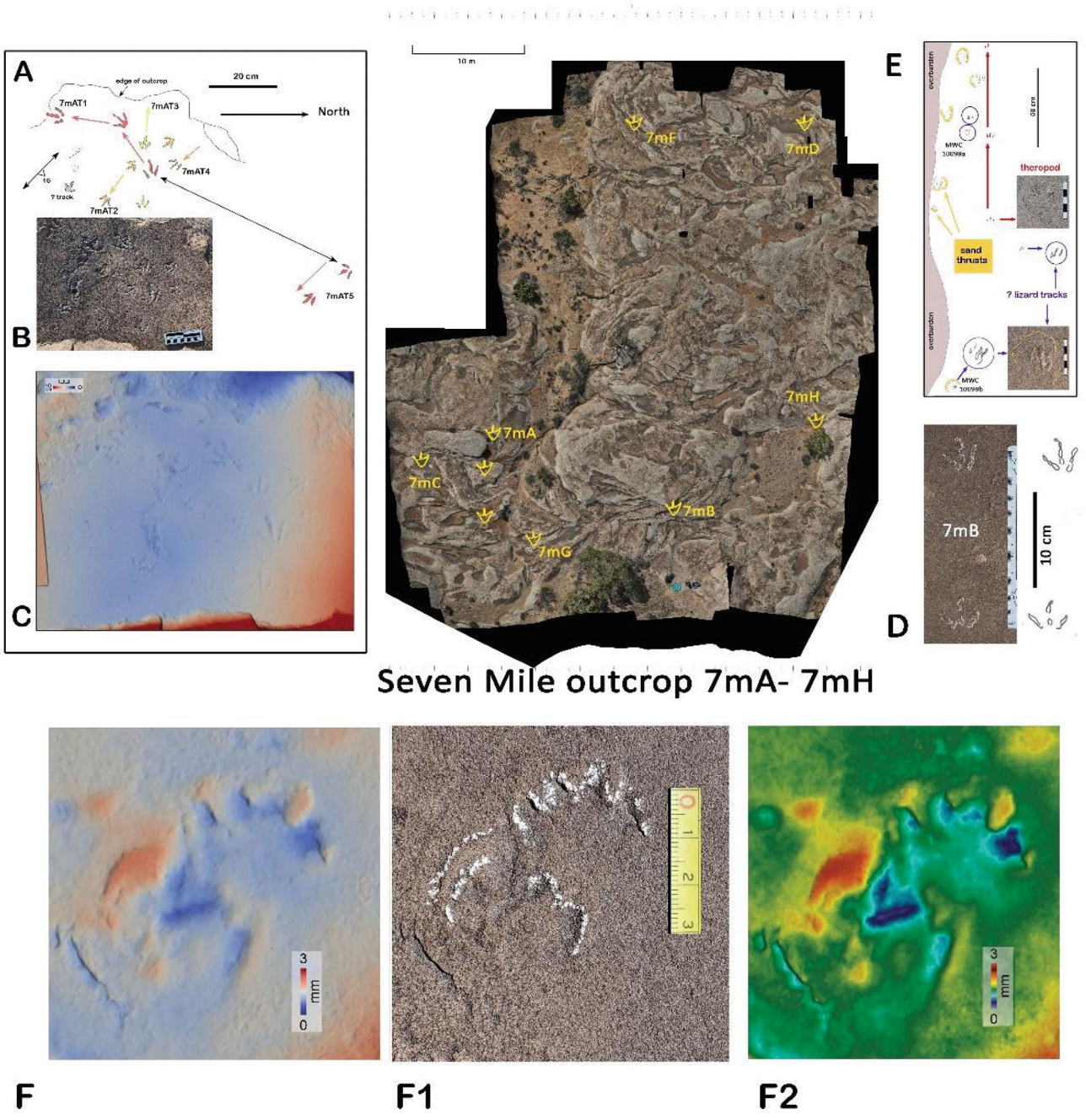


Figure 1. A-C: three images (map, photo and 3Dimage) of 12 tridacyl tracks from site 7mA; D: two consecutive small tracks from site 7mB; E: map of tracks from site 7mG. Central drone map shows location of these three sites in close proximity to five other sites (7mC-7mF, and 7mH); F, F1 and F2. Three images of the first mammal reported from the Moab Member (F and F2 are 3D images.

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The tracksites in the upper 1.0 - 2.0 m zone of the Moab Member are inferred to represent the activity of small "bird-sized" dinosaurs (non-avian theropods and ornithischians) in small coastal dunes. This zone of tracks is immediately overlain by the celebrated Moab Megatracksite (Lockley, 2021a,b) in which a thin (~ 1.0 m) unit of reworked Moab Member sand constitutes the transgressive transition into the upper tongue of the Summerville Formation, and in which only large and abundant theropod tracks (*Megalosauripus* and *Therangospodus*) have been recorded. Thus, the Moab Member 'small tracks' zone immediately underlies the Moab Megatracksite and represents an entirely different facies and ichnofauna: i.e., the onshore coastal dunes, exposed prior to the landward encroachment of overlying transgressive sand deposits. This observation raises the interesting possibly that the Moab Member track zone might represent the first example of a megatracksite (~ 23 m in lateral extent) in a dune facies.

Another significant result of the present study has been the recognition of the first unequivocal mammaloid tracks (cf. *Brasilichnium*) from the Moab Member (FL FW ~ 3.0 cm). These are morphologically similar to the *Brasilichnium* tracks reported from the dune facies of the Lower Jurassic (e.g., Navajo Sandstone). We have also identified the first reported example of spider-like trackway (cf. *Octopodichnus*). Both *Octopodichnus* and *Brasilichnium* are characteristic of the dune (or *Chelichnus*) ichnofacies. However, the dominance of small tracks of small tridactyl bipeds identified as *Grallator*, suggests what has been called the shoreline *Grallator* ichnofacies. In short, the ichnofaunas suggest the intercalation of ichnofacies, where shorelines and coastal dunes intersect.

References

Lockley, M. G. (2021a). Integration of tetrapod ichnofaunas and coastal dynamics for paleocommunity reconstruction in the Curtis and Summerville formations (Jurassic), eastern Utah. *Historical Biology, 34*, 784-801. doi.org/10/1080/08912963.2021.1946531

Lockley, M. G. (2021b). The distribution of theropod-dominated ichnofaunas in the Moab Megatracksite area, Utah: implications for Late Jurassic paleobiology along an arid coast. *Historical Biology, 34*, 1717-1751. DOI: 10.1080/08912963.2021.1975279

Lockley, M. G., Abbassi, N., & Helm, C. (2021). Large unwebbed bird and bird-like footprints
from the Mesozoic and Cenozoic: a review of ichnotaxonomy and trackmaker affinity. *Lethaia, 54*, 969-987. DOI 10.1111/let.1245

Lockley, M. G., & Meyer, C. A. (2022). The Megatracksite phenomenon: implications for tetrapod palaeobiology across terrestrial-shallow marine transitional zones. In C. Console-Gonella, S. de Valais, I. Díaz-Martínez, P. Citton, M. Verde & D. McIlroy (Eds.), *Ichnology in shallow marine and transitional environments. Geological Society of London Special Publications* 522. https://doi.org/10.1144/SP522-2021-164

Marty, D. (2008). Sedimentology, taphonomy, and ichnology of Late Jurassic dinosaur tracks from the Jura carbonate platform (Chevenez—Combe Ronde tracksite, NW Switzerland): insights into the tidal-flat palaeoenvironment and dinosaur diversity, locomotion, and palaeoecology. *GeoFocus, 21*, 1-278.

Theme Session: Laramidia to Asia: Biota and Biogeography of Interconnected Iconic Late Cretaceous Ecosystems (Saturday, June 10, 2023, 4:10 PM)

CAMPANIAN CENTROSAURINE CERATOPSID DIVERSITY AND REGIONAL ENDEMISM IN SOUTHERN LARAMIDIA

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Ceratopsian dinosaurs first appear in the Late Jurassic fossil record of Asia and diversify throughout the Early Cretaceous. Following the extinction of psittacosaurids in the middle Cretaceous, relatively advanced forms with elongated orbital horns appear ~92 Ma in Asia (*Turanoceratops*) and North America (*Zuniceratops*) and represent the likely ancestral stock for the well-known Late Cretaceous radiation of ceratopsids in North America. Isolated from eastern North America by the Western Interior Seaway at ~95 Ma, Laramidia represents the western portion of North America. Ceratopsid dinosaurs rapidly radiated on Laramidia subsequent to its isolation and include two major recognized groups, the Chasmosaurinae (with elongated narial complexes and elongate squamosals) and the Centrosaurinae (with round narial complexes and short squamosals). Over the span of 13 million years, centrosaurines diversified into over thirty currently known forms and dispersed to Asia before going extinct in the early Maastrichtian (Sampson & Loewen, 2010).

The lower three members of the Wahweap Formation of southern Utah record the best chronologic and physical

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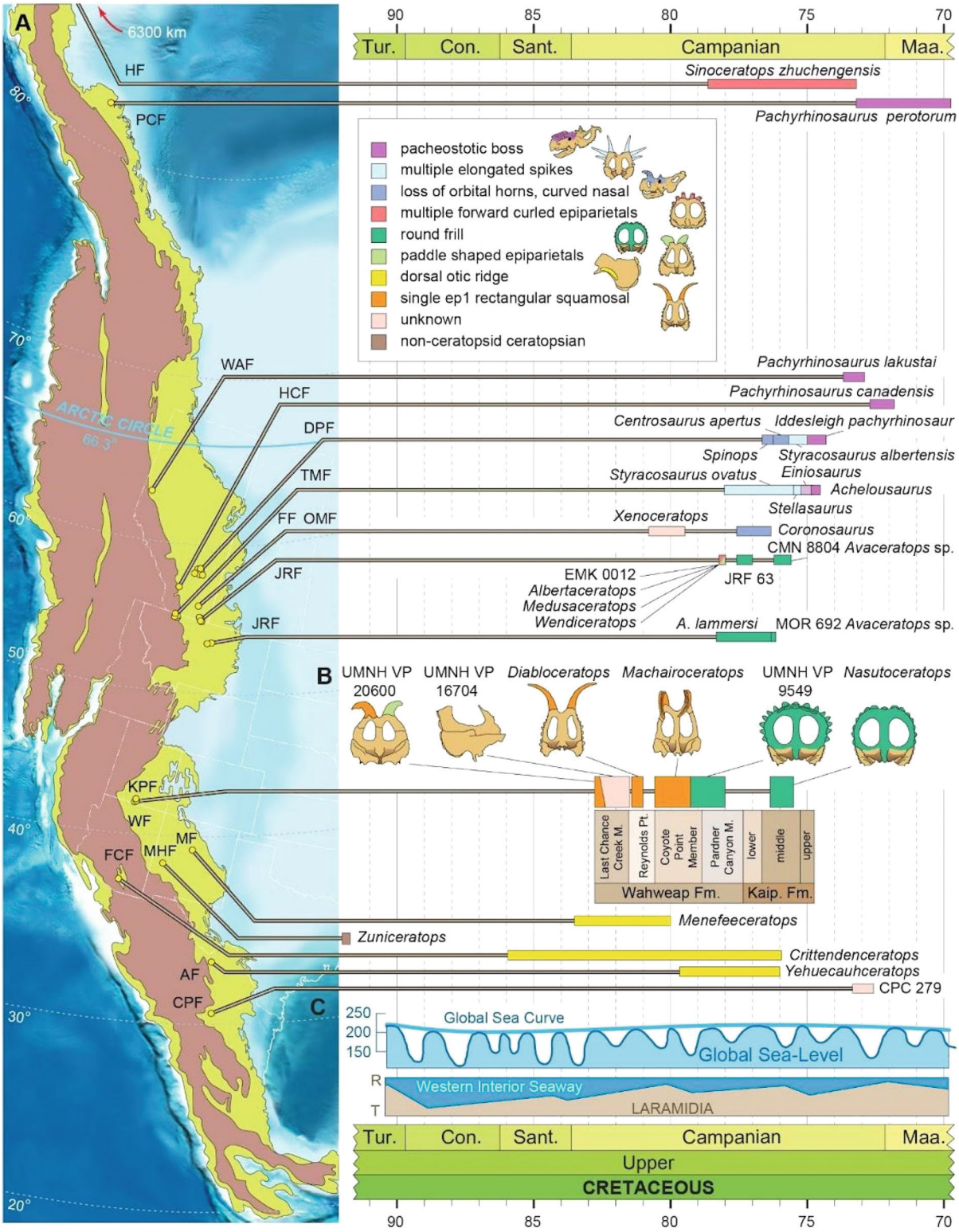


Figure 1. (A) Paleogeographic and stratigraphic distribution of centrosaruine dinosaurs. (B). Centrosaurine diversity in the Wahweap and Kaiparowits formations of Utah. (C). Global Sea-Levels from Haq et al. (2014) and Western Interior Seaway transgression and regression cycles from Li & Aschoff (2022). *Formation abbreviations*: AF, Aguja Fm.; CDP, Cerro del Pueblo Fm.; DPF, Dinosaur Park Fm.; FCF, Fort Crittenden Fm.; FF, Foremost Fm.; HCF, Horseshoe Canyon Fm.; HF, Hongtuya Fm.; JRF, Judith River Fm.; KF, Kaiparowits Fm.; MF, Menefee Fm.; MHF, Moreno Hill Fm., OMF, Oldman Fm.; PCF, Prince Creek Fm.; TMF, Two Medicine Fm.; WA, Wapiti Fm.; WF, Wahweap Fm. Paleogeographic reconstruction modified after Blakey & Rainey, 2018.

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record of centrosaurine diversity in southern Laramidia, currently preserving the remains of five distinct taxa. The oldest (UMNH VP 20600) at 81.74 +1.04 -0.25 Ma (Beveridge et al., 2022) is present near the base of the formation in the Last Chance Creek Member and differs from *Diabloceratops* and *Machiroceratops* in the shape if its elongated of epiparietals (Loewen et al., 2013). Fifty meters above the base of the formation, a partial skull (UMNH VP 16704) preserves a fan-shaped squamosal that differs from those of *Diabloceratops* and *Machiroceratops* and is precisely dated to 81.69 +0.94 -0.20 Ma (Beveridge et al., 2022). *Diabloceratops* (UMNH VP 16699) is 105 meters above the base of the formation in the Reynolds Point Member, an interval dated to 81.27 +0.15 -0.26 Ma (Beveridge et al., 2023), and is unequivocally the most basally branching centrosaurine, retaining an accessory antorbital fenestra between the premaxilla, maxilla and nasal. The relatively rectangular squamosal outline; and an unrestricted otic notch in Diabloceratops are similar to the conditions present in protoceratoapsids (Kirkland & DeBlieux, 2010). *Machiroceratops* (UMNH VP 20550) is 246 meters above the base of the formation in the Coyote Point Member, dated to 80.06 +0.62 -0.50 Ma (Beveridge et al., 2022) and also has a relatively rectangular squamosal outline and an unrestricted otic notch similar to the condition in protoceratoapsids and *Diabloceratops*, but differs in the form (curved and grooved) and number (only one per side) of its epiparietals (Lund et al., 2016a; Sampson et al., 2013). The youngest centrosaurine specimen (UMNH VP 9549) is from an interval dated to 79.00 +0.98 -0.99 Ma (Beveridge et al., 2022) is 313 meters above the base of the formation in the Last Chance Creek. It differs from all the other centrosaurines from the Wahweap Formation in the round overall shape of its frill, the positions of its epiparietals, and ridges on the dorsal surface of the frill (Loewen et al., 2013).

Diabloceratops and *Machiroceratops* are the only ceratopsids that retain the primitive rectangular morphology of the squamosal, similar to protoceratopsids and *Zuniceratops*. UMNH VP 20600 and *Machiroceratops* share the presence of a single epiparietal on each side of a midline parietal embayment. Both specimens lack evidence of other epiparietals. UMNH VP 9549 shares a round frill with *Nasutoceratops* but is unique in the ornamentation of the dorsal surface of the frill.

Other specimens from southern Laramidia remain poorly known and their ages poorly constrained. *Crittendenceratops* from the Fort Crittenden Formation of Arizona can currently be constrained to a 10 million year interval, ranging from 86-76 Ma, and is represented by extremely fragmentary material that includes a unique squamosal that exhibits a dorsal otic ridge and a parietal frill with curled epiparietals (Dalman et al., 2018). *Menefeeceratops* from the Menefee Formation of New Mexico is from an interval dated between 83.5-80 Ma and is represented by a unique squamosal that exhibits a distinct dorsal otic ridge (Dalman et al., 2021). *Yehuecauhceratops* from the Aguja Formation of Coahuila Mexico is constrained to a wide interval of 80.0-76.28 ± 0.06 Ma (Leslie et al., 2018) and is also represented by a unique squamosal that exhibits a distinct dorsal otic ridge (Rivera-Sylva et al., 2016, 2017). The presence of a distinct ridge dorsal to the otic notch is present only in southern Laramidia in specimens recovered from Coahuila, Arizona, New Mexico, and Utah. The dorsal otic ridge differs from the lateral squamosal ridge in *Nasutoceratops* (Lund et al., 2016b; Sampson et al., 2013) from the Kaiparowits Formation of southern Utah (76.394 ± 0 .040 -75.609 ± 0.015 Ma [Ramezani et al., 2022]).

Interestingly, following the appearance of eucentrosaurans in the north of Laramidia ~78 Ma (*Coronosaurus*), there is no evidence for any members of this clade (much less Pachyrhinosaurini) in the south of Laramidia. The youngest centrosaurine specimen in the south of Laramidia, CPC 279, is a fan-shaped but otherwise nondiagnostic squamosal that lacks a dorsal otic ridge (Loewen et al., 2010) from the Cerro del Pueblo Formation (73.63-72.74 Ma [Fowler, 2017]). This data supports an emerging pattern of regionally constrained radiations of centrosaurines in northern and southern Laramidia that is more extreme than those documented in any other macroherbivorous dinosaurs during Campanian.

References

Blakey, R. C., & Ranney, W. D. (2018). The Continental Arc, Sevier Orogeny, Western Interior Seaway and Flat-Slab Subduction: Cretaceous Period: Ca. 145-65 Ma. In R. C. Blakey & W. D. Ranney (Eds.), *Ancient landscapes of western North America, a geologic history with paleogeographic maps* (1st ed.) (pp. 103-130). Springer.

Dalman, S. G., Hodnett, J.-P. M., Lichtig, A. J., & Lucas, S. G. (2018). A new ceratopsid dinosaur (Centrosaurinae: Nasutoceratopsini) from the Fort Crittenden Formation, Upper Cretaceous (Campanian) of Arizona. *New Mexico Museum of Natural History and Science Bulletin, 79*, 141-164.

Dalman, S. G., Lucas, S. G., Jasinski, S. E., Lichtig, A. J., & Dodson, P. (2021). The oldest centrosaurine: A new ceratopsid dinosaur (Dinosauria: Ceratopsidae) from the Allison Member of the Menefee Formation (Upper Cretaceous, early Campanian), northwestern New Mexico, USA. *Paläontologische Zeitschrift, 95*, 291-335.

Fowler, D. W. (2017). Revised geochronology, correlation, and dinosaur stratigraphic ranges of the Santonian-Maastrichtian (Late Cretaceous) formations of the

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Western Interior of North America. *PLoS ONE, 12*(11), e0188426.

Haq, B. U., Hardenbol, J., & Vail, P. R. (1987). Chronology of fluctuating sea levels since the Triassic. *Science, 235*, 1156-1167.

Kirkland, J. I., & DeBlieux, D. D. (2010). New basal centrosaurine ceratopsian skulls from the Wahweap Formation (Middle Campanian), Grand Staircase– Escalante National Monument, southern Utah. In M. J. Ryan, B. Chinnery-Allgeier, & D. A. Eberth (Eds.), *New perspectives on horned dinosaurs: The Royal Tyrrell Museum Ceratopsian Symposium* (pp. 117-140). Indiana University Press.

Li, Z., & Aschoff, J. (2022). Shoreline evolution in the Late Cretaceous North American Cordilleran foreland basin: An exemplar of the combined influence of tectonics, sea level, and sediment supply through time. *Earth-Science Reviews, 226*, 103947.

Leslie, C. E., Peppe, D. J., Williamson, T. E., Heizler, M., Jackson, M., Atchley, S. C., Nordt, L., & Standhardt, B. (2018). Revised age constraints for Late Cretaceous to early Paleocene terrestrial strata from the Dawson Creek section, Big Bend National Park, west Texas. *Geological Society of America Bulletin, 130*(7-8), 1143-1163.

Loewen, M. A., Farke, A. A., Sampson, S. D., Getty, M. A., Lund, E. D., & O'Connor, P. M. (2013). Ceratopsid dinosaurs from the Grand Staircase of southern Utah. In A. L. Titus & M. A. Loewen (Eds.), *At the top of the Grand Staircase: The Late Cretaceous of southern Utah* (pp. 488-503). Indiana University Press.

Loewen, M. A., Sampson, S. D., Lund, E. K., Farke, A. A., de Leon, C., Aguillón Martínez, M. C., Rodríguez de la Rosa, R. A., Getty, M. A., & Eberth, D. A. (2010). Horned dinosaurs (Ornithischia: Ceratopsidae) from the Upper Cretaceous (Campanian) Cerro del Pueblo Formation, Coahuila, Mexico. In M. J. Ryan, B. Chinnery-Allgeier, & D. A. Eberth (Eds.), *New perspectives on horned dinosaurs: The Royal Tyrrell Museum Ceratopsian Symposium* (pp. 99-116). Indiana University Press.

Lund, E. K., O'Connor, P. M., Loewen, M. A., & Jinnah, Z. A. (2016a). A new centrosaurine ceratopsid, *Machairoceratops cronusi* gen et sp. nov., from the upper Sand Member of the Wahweap Formation (Middle Campanian), Southern Utah. *PLoS ONE, 11*(5), e0154403.

Lund, E. K., Sampson, S. D., & Loewen, M. A. (2016b). *Nasutoceratops titusi* (Ornithischia, Ceratopsidae), a basal centrosaurine ceratopsid from the Kaiparowits Formation, southern Utah. *Journal of Vertebrate Paleontology, 36*(2), e1054936-2.

Ramezani, J., Beveridge, T. L., Rogers, R. R., Eberth, D. A., & Roberts, E. M. (2022). Calibrating the zenith of dinosaur diversity in the Campanian of the Western Interior Basin by CA-ID-TIMS U-Pb geochronology. *Scientific Reports, 12*(1), 16026.

Rivera-Sylva, H. E., Hendrick, B., & Dodson, P. (2016). A centrosaurine (Dinosauria: Ceratopsia) from the Aguja Formation (Late Campanian) of Northern Coahuila, Mexico. *PLoS ONE, 11*(4), e0150529

Rivera-Sylva, H. E., Frey, E., Stinnesbeck, W., Guzman-Gutierrez, J. R., & Gonzalez-Gonzalez, A. H. (2017). Mexican ceratopsids: Considerations on their diversity and evolution. *Journal of South American Earth Sciences, 75*, 66-73. doi:10.1016/j.jsames.2017.01.008.

Sampson, S. D., & Loewen, M. A. (2010). Unraveling a radiation: a review of the diversity, stratigraphic distribution, biogeography, and evolution of horned dinosaurs (Ornithischia: Ceratopsidae). In M. J. Ryan, B. Chinnery-Allgeier, & D. A. Eberth (Eds.), *New perspectives on horned dinosaurs: The Royal Tyrrell Museum Ceratopsian Symposium* (pp. 405-427). Indiana University Press.

Sampson, S. D., Lund, E. K., Loewen, M. A., Farke, A. A., & Clayton, K. E. (2013). A remarkable short-snouted horned dinosaur from the Late Cretaceous (late Campanian) of southern Laramidia. *Proceedings of the Royal Society of London B, 280*(1766), 20131186.

Technical Session 3: Terrestrial Ecosystems – Late Cretaceous (Saturday, June 10, 2023, 2:45 PM)

HATCHLINGS OF *TYRANNOSAURUS REX* AND THE EVOLUTION OF DINOSAUR REPRODUCTIVE STRATEGIES

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Tyrannosaurs were giant predatory dinosaurs occupying the apex of Late Cretaceous food chains. Little is known about their early life due to the extreme rarity of juveniles. We describe hatchling remains (< 1 yr) of Tyrannosauridae, weighing ~2.5 kg respectively, <0.1% adult mass. From hatchling mass it is possible to estimate egg size; adult mass is tightly correlated with clutch mass. From egg size and clutch mass it becomes possible to estimate clutch size; clutches were likely large (est. 25-60 eggs) suggesting an r-selected reproductive strategy. Synchrotron scans reveal remodeling and intensive loading of pedal elements, showing tyrannosaurs moved soon after hatching. Hatchling tyrannosaurs' small size and precociality suggest limited parental care. Tyrannosaurs had proportionately larger offspring than ancestral Archosauria, but relatively smaller hatchlings than Maniraptora, suggesting a reproductive strategy intermediate between basal archosaurs and birds. Multiple dinosaur lineages evolved large eggs and hatchlings, suggesting an evolutionary trend towards increased parental investment in the Mesozoic.

Technical Session 3: Terrestrial Ecosystems – Late Cretaceous (Saturday, June 10, 2023, 2:15 PM)

CENTROSAURINE CERATOPSID MATERIAL FROM THE LATE CRETACEOUS (CAMPANIAN) MENEFEE FORMATION OF NORTHWEST NEW MEXICO

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Recent paleontological survey work undertaken by the North Carolina Museum of Natural Sciences (NCMNS) in the Late Cretaceous (Campanian) Allison Member of the Menefee Formation of northwest New Mexico is yielding new information on the diversity of ceratopsians from the Western Interior Basin (WIB). Newly recovered specimens include the associated skeletons of two ceratopsian individuals. One skeleton pertains to a large individual similar in size to some chasmosaurine species (e.g., *Triceratops*); however, referral to a particular subfamily (i.e., chasmosaurine or centrosaurine) is difficult due to the state of preservation of this material. Recovered elements to date include a scapula, several dorsal vertebrae, a partial sacrum, several caudal vertebrae, and several partial dorsal ribs.

The smaller individual is well-preserved and is represented by a combination of articulated and disarticulated elements. Thus far, these include elements of the axial skeleton (i.e., cervical, dorsal, sacral, caudal vertebrae, and ribs), forelimb (humerus), partially articulated pelvic girdle (ilium, pubis, ischium), and most of the hind limb (femur, tibia, fibula, and astragalus). The recovered skeletal elements appear to derive from a single skeletally immature individual based on overall skeletal size and degree of sutural closure noted in the recovered elements of the axial column. The specimen is preserved in a moderately calcareous, silty mudstone containing numerous calcareous nodules and abundant carbonized and broken plant materials (i.e., plant hash). Considered together, the disarticulated nature of the skeleton and abundant plant hash layers suggests the specimen was deposited in a low to moderate energy flooding event within a fluvial floodplain or were transported into a fluvial associated catchment basin (e.g., pond).

Despite a long history of geological and paleontological exploration, the ceratopsian fossil record from the Menefee Formation has remained relatively enigmatic as compared to other contemporaneous to penecontemporaneous southern WIB fossiliferous formations (e.g., Wahweap Formation, Grand Staircase Escalante National Monument, southern Utah), with only one named taxon (i.e., *Menefeeceratops sealeyi*). The recently recovered ceratopsian materials preliminarily appear to be referable to Centrosaurinae based on observed synapomorphies of the postcranial skeleton including humeral characters (i.e., humerus generally long and slender, smaller mid humeral shaft diameter, deltopectoral crest occupying nearly half the total length of the humerus, and the distal end modestly expanded and rugose) and ischial characters (i.e., relatively straight ischial shaft, ischial shaft terminates in an acute apex, ischial pubic peduncle more broadly expanded, and ischial shaft mediolaterally compressed). However, comparison with *Menefeeceratops* is limited due to the dearth of diagnostic elements, cranial or postcranial, shared between these two specimens. Given that the cervical ribs and vertebrae are near the back wall, further field collection of this specimen may ameliorate this issue by providing overlapping skull elements. Regardless, these new specimens increase the known ceratopsian material from the southern WIB generally and the Menefee Formation specifically and may either increase the known material referable to *Menefeeceratops* and add unknown skeletal element descriptions to that taxon (e.g., pubis and ischium) or increase the known diversity of Late Cretaceous (Campanian) ceratopsids from southern Laramidia. If the latter is true, this specimen will add key information for testing current paleobiogeographical hypotheses

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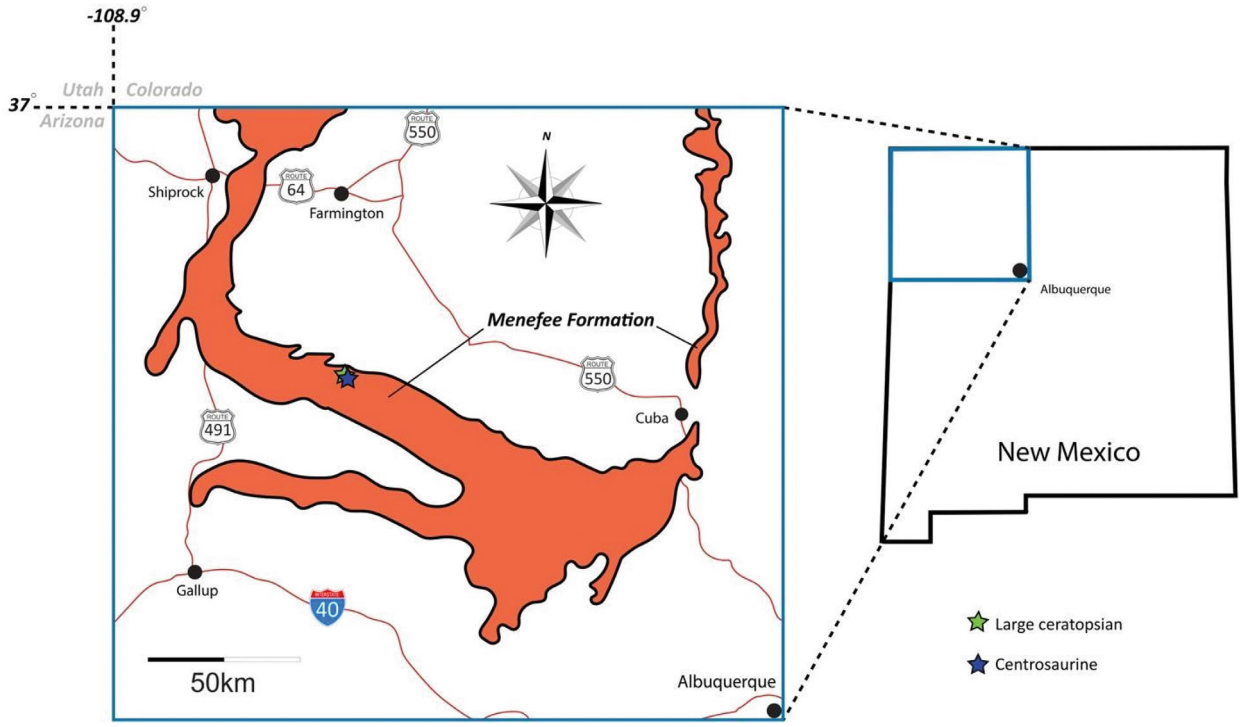


Figure 1. Approximate location of NCSM ceratopsid localities (colored stars) within surface exposure of the early Campanian Menefee Formation (orange) in northwestern New Mexico, United States. Modified from Dalman et al., 2021.

regarding the possibility of distinct northern and southern centers of endemism in the WIB and expounds the paleoecological, paleobiological, and paleogeographical understanding of an important Late Cretaceous geologic basin in southern Laramidia.

Reference

Dalman, S. G., Lucas, S. G., Jasinski, S. E., Lichtig, A. J., & Dodson, P. (2021). The oldest centrosaurine: A new ceratopsid dinosaur (Dinosauria: Ceratopsidae) from the Allison Member of the Menefee Formation (Upper Cretaceous, early Campanian), northwestern New Mexico, USA. *Paläontologische Zeitschrift, 95*(2), 291-335.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 1:45 PM)

AN INTERCONTINENTAL ASSOCIATION OF DRAGONFLY OVIPOSITION ON A FLOATING AQUATIC PLANT FROM THE LATE CRETACEOUS OF NORTH AMERICA AND ASIA

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Odonate (dragonfly & damselfly) oviposition on the floating aquatic angiosperm *Quereuxia* spp. from the Campanian of western North America and northeastern Asia represent a rare intercontinental plant–insect association in deep time. Fossil plant material from the Kaiparowits Formation (Utah, USA) (Maccracken, 2020; Miller et al., 2013) and Kundar Formation (Amur Oblast, Russia) (Enushchenko & Frolov, 2020; Vasilenko, 2008) provide abundant evidence for this highly specialized plant–insect association spanning two continents during the Late Cretaceous.

Quereuxia is a morphogenus of extinct aquatic angiosperm with heterophyllus leaves, sometimes preserved as a rosette of small, circular leaves or as detached leaves (Hickey, 2001). The taxonomic affinities of *Quereuxia* are unknown at present, although recent work has indicated that the previous placement within Lythraceae (formerly Trapaceae) may not be valid (Liang et al., 2021). Regardless of affinity, *Quereuxia* spp. are an important floating aquatic angiosperm in a range of Late Cretaceous to Paleocene deposits in the Northern Hemisphere

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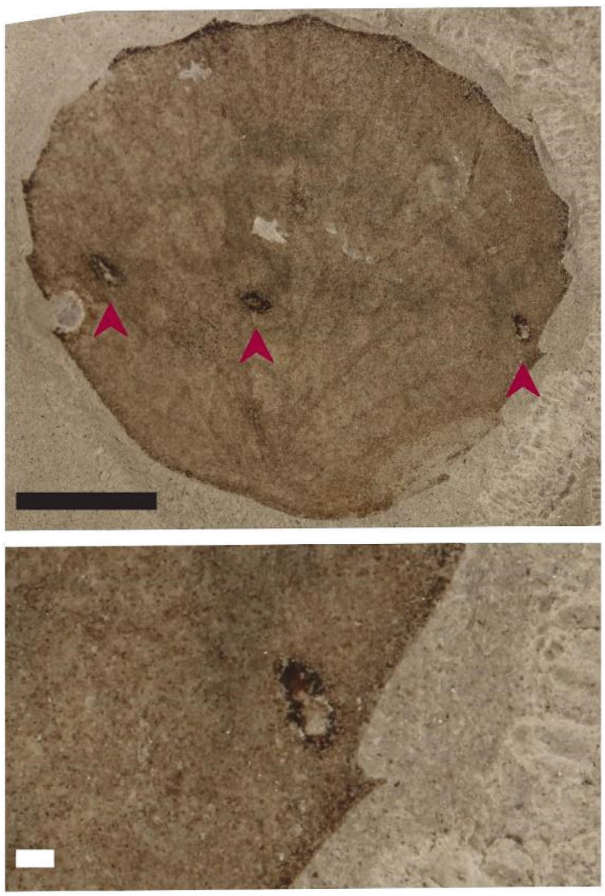


Figure 1. Oviposition scars on c.f. *Quereuxia angulata* (DMNH EPI.45447) denoted by red arrows. Black scale = 5 mm; White scale = 1 mm.

(Golovneva, 2000). Specimens of this morphogenus are frequently collected from Laramidian deposits (Crabtree, 1987; Miller et al., 2013; Spicer and Parrish, 1987), as well as from Asian and European floras of the same age (Golovneva et al., 2008; Kodrul et al., 2009; Kvaček & Herman, 2004).

Quereuxia of Campanian Age are especially common in the Amur region of Russia, and oviposition was extensively described on *Q. angulata* (Lesq.) Krysht. leaves from the Udurchukan locality of the Upper Kundar Formation (Vasilenko, 2008). Vasilenko (2008) identified multiple ichnospecies of *Paleoovoidus*, now recognized as *Paleoexoovoida* (Enushchenko & Frolov, 2020), which is hypothesized to have been produced by damselfly and dragonfly oviposition. Oviposition scars described by Vasilenko (2008) include lines of eggs or egg scars produced by the arcuate (fan-shaped) movement of an odonate ovipositor while the abdomen was stationary on the leaf. Similar and abundant oviposition scars are also found on *Quereuxia* c.f. *Q. angulata* leaves from the Kaiparowits Fm., with ∼28–50% of leaf specimens from multiple localities exhibiting oviposition damage (Figure 1). These damage types (DT100, DT101) (Labandeira et al., 2007), although not arcuate, do include linear arrangements of eggs and are hypothesized to be dragonfly (Anisoptera) in origin.

While the individual odonate species may have differed between the Kaiparowits Formation and Upper Kundar Formation, the broad plant–insect ecological associations of *Q. angulata* and Odonata extend broadly over at least two continents. This intercontinental niche conservatism of deep time plant–insect associations provides important clues into paleobiogeography of plants and their insect herbivores. During the Campanian, North American and Asia were connected across Cretaceous Beringia (LePage et al., 2005). With hospitable environments extending into the polar regions at this time, biotic interchange across the Beringian Corridor was likely established by the Albian (ca. 100 Ma) (LePage et al., 2005), although Late Cretaceous interchange is less well known (Fiorillo, 2008; Vavrek et al., 2014; Wolfe, 1975). The discovery of the intercontinental *Quereuxia*–Odonata association is among first evidence of widespread ecological niche conservatism between North American and Asia during the Campanian.

References

Crabtree, D. R. (1987). Angiosperms of the northern Rocky Mountains: Albian to Campanian (Cretaceous) megafossil floras. *Annals of the Missouri Botanical Garden, 74*, 707-747.

Enushchenko, I. V., & Frolov, A. O. (2020). Revision of existing classification of fossil insect feeding traces and description of new ichnotaxa from Middle Jurassic sediments of Eastern Siberia (Russia). *Zootaxa, 4758*, 347-359.

Fiorillo, A. R. (2008). Dinosaurs of Alaska: Implications for the Cretaceous origin of Beringia. *Geological Society of America Special Papers, 442*, 313-326.

Golovneva, L., Sun, G., & Bugdaeva, E. (2008). Campanian flora of the Bureya River basin (Late Cretaceous of the Amur region). *Paleontological Journal, 42*, 554-567.

Golovneva, L. B. (2000). Aquatic plant communities at the Cretaceous-Palaeogene boundary in north-eastern Russia. *Acta Palaeobotanica, 40*, 139-151.

Hickey, L. J. (2001). On the nomenclatural status of the morphogenera, *Quereuxia* and *Trapago*. *Taxon, 50*, 1119-1124.

Kodrul, T., Krassilov, V., & Vasilenko, D. (2009). Campanian aquatic and wetland biota from Kundur, Amur Region, Russian far east. *Palaeobiology*, *Tenth International Symposium on Mesozoic Terrestrial Ecosystems and Biota*, 119-120.

Kvaček, J., & Herman, A. (2004). The Campanian Grünbach flora of Lower Austria: palaeoecological interpretations. *Annalen des Naturhistorischen Museums in Wien*

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Serie A für Mineralogie und Petrographie, Geologie und Paläontologie, Anthropologie und Prähistorie, 91-101.
Labandeira, C. C., Wilf, P., Johnson, K. R., & Marsh, F. (2007). Guide to insect (and other) damage types on compressed plant fossils (version 3.01). Smithsonian Institution, National Museum of Natural History, Department of Paleobiology, Washington, DC:25.
LePage, B. A., Yang, H., & Matsumoto, M. (2005). The evolution and biogeographic history of Metasequoia. In B. A. LePage, J. C. Williams, & H. Yang (Eds.), *The geobiology and ecology of Metasequoia* (pp. 3-114). Springer.
Liang, F., Tian, N., Sun, W., Wu, Q., Liu, B., & Wang, H. (2021). Epidermal features of the floating leaves of Quereuxia angulata (Newberry) Krištofovič, an aquatic angiosperm from the Upper Cretaceous of Northeast China. *Cretaceous Research, 125*, 104835.
Maccracken, S. A. (2020). *Plant–arthropod associations from the Western Interior of North America during the Late Cretaceous* [Doctoral dissertation, University of Maryland].
Miller, I. M., Johnson, K. R., Kline, D. E., Nichols, D. J., & Barclay, R. S. (2013). A Late Campanian flora from the Kaiparowits. In A. L. Titus & M. A. Loewen (Eds.), *At the top of the Grand Staircase: The Late Cretaceous of southern Utah* (pp. 107-131). Indiana University Press.
Spicer, R. A., & Parrish, J. (1987). Plant megafossils, vertebrate remains, and paleoclimate of the Kogosukruk tongue (Late Cretaceous), North Slope, Alaska. *US Geological Survey Circular, 998*, 47-48.
Vasilenko, D. V. (2008). Insect ovipositions on aquatic plant leaves *Quereuxia* from the Upper Cretaceous of the Amur region. *Paleontological Journal, 42*, 514-521.
Vavrek, M. J., Hills, L. V., & Currie, P. J. (2014). A hadrosaurid (Dinosauria: Ornithischia) from the Late Cretaceous (Campanian) Kanguk Formation of Axel Heiberg Island, Nunavut, Canada, and its ecological and geographical implications. *Arctic, 67*, 1-9.
Wolfe, J. A. (1975). Some aspects of plant geography of the Northern Hemisphere during the late Cretaceous and Tertiary. *Annals of the Missouri Botanical Garden, 62*, 264-279.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 9:45 AM)

THE MID-CRETACEOUS FOSSIL RECORD OF CAENAGNATHIDS IN NORTH AMERICA AND ITS IMPLICATIONS FOR THE TIMING OF FAUNAL INTERCHANGE WITH ASIA

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Caenagnathids are toothless pennaraptoran theropods that are becoming increasingly common in Campano-Maastricthian of the Western Interior Basin. The last couple of decades have witnessed a surge in their known diversity with the naming of more than half a dozen new taxa (Funston, 2020), although the validity of some of these remains debated. The clade also has a growing fossil record in Asia including remarkably large-bodied taxa such as *Beibeilong sinensis* (Pu et al., 2017) and *Gigantoraptor erlianensis* (Xu et al., 2007). In contrast to their Campano-Maastrichtian record, the published pre-Campanian record of caenagnathids in North America is poorly known and restricted to the enigmatic small, and juvenile, holotype specimen of *Microvenator celer* from the Early Cretaceous Cloverly Formation. *Microvenator* was originally proposed to be an oviraptorosaur by Currie and Russell (1988), a point later confirmed through numerous phylogenetic analyses starting with Makovicky and Sues (1998).
The stratigraphic gap in the North American record between *Microvenator* and Campano-Maastrichtian taxa was until recently only punctuated by eggs and eggshell referred to the ootaxon *Macroelongatoolithus carlylei*, which is referred to caenagnathids based on embryonic remains (Simon et al., 2019). *M. carelylei* eggshell was first reported from the Cenomanian Mussentuchit member of the Cedar Mountain Formation by Jensen (1970) and named *Boletuoolithus carlylei* by Bray (1998), but later synonymized with the oogenus *Macroelongatoolithus* by Zelenitsky et al. (2000). *Macroelongatoolithus* eggs and eggshells are now known to occur in in the penecontemporaneous Wayan Fm. of Idaho, as well as more broadly in Asia (Simon et al., 2019; Zelenitsky et al., 2000). Near complete pairs of eggs have been collected from the Wayan Formation (Simon et al., 2019) and also the Mussentuchit Member (Zanno et al., 2019), exhibiting sizes consistent with being laid by a *Gigantoraptor*-sized animal.
Fieldwork by the Field Museum in the Mussentuchit Member (MM) of the Cedar Mountain Formation led to the discovery of body fossils that complement the earlier oological discoveries. Field Museum crews excavated the

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partial skeleton of a large caenagnathid in 2012, including a pubis, femur, tibia, and caudal vertebrae forming a pygostyle-like structure. With a tibial length of 95 cm, this specimen is second only to the holotype of *Gigantoraptor* in size among oviraptorosaurs. The discovery of this specimen allowed for the reinterpretation of a small partial theropod skeleton collected by OMNH crews from the MM as a juvenile specimen of the same species based on several derived features of the distal femur. These include opposing longitudinal grooves on the tibiofibular crest and medial condyle that face each other across the popliteal fossa, and a conical process on the lateral distal condyle. The juvenile specimen was originally interpreted as the earliest occurrence of an ornithomimosaur in North America by Cifelli et al. (1996) (J. Kirkland, pers. comm.), a record we correct here. The new specimen provides new anatomical information on the pectoral girdle and forelimb of the species.

Femoral synapomorphies observed in the Mussentuchit material are also evident in an isolated femur collected from the Antlers Fm. of north Texas by a Field Museum party led by Rainer Zangerl. This nearly complete femur measures 34 cm in length and exhibits caenagnathid synapomorphies such as a reduced femoral neck, reduction of the 4th trochanter, well-developed muscle scar for the *m. caudifemoralis longus* on the posterior face of the distal shaft, and medially grooved tibiofibular crest. It represents the first verifiable caenagnathid specimen from the Antlers Formation, and thus both a major geographic range extension, as well as a possible stratigraphic one, for this clade in North America. It also adds to the already significant taxonomic overlap between the Antlers and Cloverly Formations, which share a majority of their named dinosaurian genera including *Tenontosaurus, Deinonychus, Acrocanthosaurus* and *Sauroposeidon*, in addition to caenagnathids.

Mid-Cretaceous terrestrial faunas of the WIB are best known from intensive microvertebrate sampling, a method that is biased against edentulous clades such as caenagnathids. As increased sampling and description of body fossils is reconciled with the microvertebrate record, a more informed picture of the pace and timing of faunal interchange between North America and Asia in the Cretaceous is coming together, indicating both an earlier onset of interchange that previously suggested, as well as more gradual turnover among North American lineages (Zanno & Makovicky, 2011).

References

Bray, E. S. (1998). Dinosaur eggshell *Boletuoolithus carlylensis*, oogenus nov. from the Lower
Cretaceous Cedar Mountain Formation of Utah. In S. G. Lucas, J. I. Kirkland, & J. W. Estep (Eds.), *Lower and Middle Cretaceous terrestrial ecosystems. New Mexico Museum of Natural History and Science Bulletin, 14*, 221-224.

Cifelli, R. L., Kirkland, J. I., Weil, A., Deino, A. L., & Kowallis, B. J. (1996). High-precision 40Ar/39Ar geochronology and the advent of North America's Late Cretaceous terrestrial fauna. *Proceedings of the National Academy of Sciences, 94*, 11163-11167.

Currie, P. J., & Russell, D. A. (1988). Osteology and relationships of *Chirostenotes pergracilis*
(Saurischia, Theropoda) from the Judith River (Oldman) Formation of Alberta, Canada. *Canadian Journal of Earth Sciences, 25*, 972-86.

Funston, G. (2020). Caenagnathids of the Dinosaur Park Formation (Campanian) of Alberta,
Canada: anatomy, osteohistology, taxonomy, and evolution. *Vertebrate Anatomy Morphology Palaeontology, 8*, 105-153.

Jensen, J. (1970). Fossil eggs in the Lower Cretaceous of Utah. *Brigham Young University Geology Studies, 17*, 51-65.

Makovicky, P. J., & Sues, H. D. (1998). Anatomy and phylogenetic relationships of the theropod
dinosaur *Microvenator celer* from the Lower Cretaceous of Montana. *American Museum Novitates, 3240*, 1-28.

Pu, H., Zelenitsky, D. K., Lu, J., Currie, P. J., Carpenter, K., Xu, L., Koppelhus, E. B., Jia, S., Le, X., Chuang, H., & Li, T. (2017). Perinate and eggs of a giant caenagnathid dinosaur from the Late Cretaceous of Central China. *Nature Communications, 8*, 14952.

Simon, D. J., Varricchio, D. J., Jin, X., & Robison, S. F. (2018). Microstructural overlap of *Macroelongatoolithus* eggs from Asia and North America expands the occurrence of colossal oviraptorosaurs. *Journal of Vertebrate Paleontology, 38*, 6 DOI:
10.1080/02724634.2018.1553046

Xu, X., Tan, Q., Wang, J., Zhao, X., & Tan, L. (2007). A gigantic bird-like dinosaur from the Late Cretaceous of China. *Nature, 447*, 844-847.

Zanno, L. E., & Makovicky, P. J. (2011). On the earliest record of Cretaceous tyrannosauroids in western North America: implications for an Early Cretaceous Laurasian interchange event. *Historical Biology, 23*, 317-325.

Zanno, L. E., Avrahami, H. M., Gates, T. A., Tucker, R., & Makovicky, P. J. (2019). Preliminary Data on Elongatoolithid clutches and associated fauna from the Cenomanian Mussentuchit Member, Cedar Mountain Formation of Utah. *VII International Symposium on Dinosaur Eggs and Babies, Shiyan, China*.

Zelenitsky, D. K., Carpenter, K., & Currie, P. J. (2000). First record of elongatoolithid theropod eggshell from North America: The Asian oogenus *Macroelongatoolithus* from the Lower Cretaceous of Utah. *Journal of Vertebrate Paleontology, 20*(1), 130-138.

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Poster Session 3 (Saturday, June 10, 2023)

LATE MAASTRICHTIAN CHASMOSAURINE CERATOPSIDS OF CANADA AND HORNED DINOSAUR EVOLUTION PRECEDING THE TERMINAL CRETACEOUS

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The terrestrial fossil assemblage of the upper Maastrichtian of Montana has greatly influenced our understanding of dinosaur evolution leading up to the end-Cretaceous mass extinction. Ongoing study of these deposits, particularly in the last two decades, has led to novel insights about the taxonomy and systematics of pachycephalosaurids (Horner & Goodwin, 2009), hadrosaurids (Campione & Evans, 2012), and tyrannosaurids (Woodward et al., 2020), among others. Regarding the horned ceratopsids, a wealth of new fossil and biostratigraphic data have motivated new hypotheses about the synonymy of *Torosaurus* with *Triceratops* (Scannella & Horner, 2010), and anagenetic evolution in the latter genus (Scannella et al., 2014).

Popperian falsifiability demands that we continually test our scientific models with new data. Upper Cretaceous terrestrial fossil deposits in western Canada have long yielded the data necessary to test the above hypotheses about taxonomy and evolutionary mode in *Triceratops*, but these data have not featured prominently in developing those hypotheses until very recently.

The ontogenetic trajectory hypothesis (OTH) of Scannella and Horner (2010) maintains that *Torosaurus* is a late-stage growth form of *Triceratops*, and is thus a junior synonym of the latter genus. Evidence marshalled in favour of the OTH includes purported transitional forms (Scannella & Horner, 2010, 2011) and osteohistology showing both the continued development of the elongate parietal and the senescence of the postorbital horncores in *Torosaurus* (Horner & Lamm, 2011; Scannella & Horner, 2011). Crucially, an unambiguous example of an immature *Torosaurus*, which would conclusively discount the OTH, has been missing before now.

Recently, one of us (JCM) helped redescribe a partial skeleton of *Torosaurus* cf. *T. latus*, collected from the uppermost Maastrichtian Frenchman Formation of southern Saskatchewan in 1947 (Mallon et al., 2022). Osteohistology of the left femur revealed a heavily remodeled inner cortex with increasing primary bone tissue occurring externally. Four lines of arrested growth were counted within the primary cortex, and no external fundamental system was observed near the periosteum. These findings are consistent with the specimen representing a late subadult or early adult stage, still in the process of growing, rather than a somatically mature individual as posited by the OTH. We thus maintain that *Torosaurus* is a valid genus that ranged northward into Canada, and is not the senescent form of *Triceratops*.

The anagenetic model of *Triceratops* evolution maintains that the chronologically older *Triceratops horridus* directly gave rise to the younger *Triceratops prorsus*, evidenced in part by a stratigraphically intermediate morph sharing features of both species (Scannella et al., 2014). This evolutionary model has been developed with specific reference to the fossil record of the Hell Creek Formation in Montana. However, penecontemporaneous deposits in Canada (Scollard and Frenchman formations), equivalent to the upper third of the Hell Creek Formation (Eberth & Kamo, 2019), offer a crucial test of the anagenesis hypothesis; if the hypothesis is true, all specifically diagnostic instances of *Triceratops* in Canada should be referrable to *T. prorsus*. Despite a cursory review by Tokaryk (1986), a systematic survey of the Canadian *Triceratops* material has not occurred before now.

Our exhaustive survey of the Canadian material reveals that all specimens preserving diagnostic cranial elements ($n = 9$) are attributable to *T. prorsus*. Where preserved, all skulls exhibit a hypertrophied, anteriorly inclined nasal horncore, a vertical nasal process of the premaxilla, and relatively short postorbital horncores and parietosquamosal frills—all features considered diagnostic of the species. There is no evidence for the existence of either *T. horridus* or the unnamed intermediate morph within the Frenchman Formation. We thus confirm the anagenetic evolutionary model for *Triceratops*. Stratigraphically calibrated morphospace analysis yields no evidence for the directional evolution of *Triceratops* within the formation, suggesting that, whatever external forces had driven the evolution of *T. prorsus* from *T. horridus*, they were subsequently inoperable.

The Canadian fossil record has thus played an important role in advancing arguments about the diversity and evolution of end-Cretaceous ceratopsids, but it has also raised several questions. For example, what is the nature of *Triceratops albertensis*? Originally erected based on a massive, partial skull by Sternberg (1949), it has since

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been regarded as a nomen dubium. on account of its incompleteness and supposed distorted nature (Forster, 1996; Ostrom & Wellnhofer, 1986). However, the posterior sweep of the postorbital horncores and the large size of the antorbital fenestrae are distinctive and not attributable to taphonomic deformation, lending some credence to the hypothesis that *T. albertensis* might be a valid taxon. Similarly, what of *Eotriceratops xerinsularis*? This species was likewise erected based on a large, partial skull (Wu et al., 2007); however, although it appears to be chronologically older than the traditional Lancian *Triceratops*, the anatomical features that set it apart from *Triceratops* are not especially distinctive or unambiguously disconnected from ontogeny. Work on these questions is ongoing.

References

Campione, N. E., & Evans, D. C. (2011). Cranial growth and variation in edmontosaurs (Dinosauria: Hadrosauridae): implications for latest Cretaceous megaherbivore diversity in North America. *PLoS ONE, 6*, e25186.

Eberth, D. A., & Kamo, S. L. (2019). First high-precision U–Pb CA–ID–TIMS age for the Battle Formation (Upper Cretaceous), Red Deer River valley, Alberta, Canada: implications for ages, correlations, and dinosaur biostratigraphy of the Scollard, Frenchman, and Hell Creek formations. *Canadian Journal of Earth Sciences, 56*, 1041-1051.

Horner, J. R., & Lamm, E.-T. (2011). Ontogeny of the parietal frill of *Triceratops*: a preliminary histological analysis. *Comptes Rendus Palevol, 10*, 439-452.

Horner, J. R., & Goodwin, M. B. (2009). Extreme cranial ontogeny in the Upper Cretaceous dinosaur *Pachycephalosaurus*. *PLoS ONE, 4*, e7626.

Forster, C. A. (1996). Species resolution in *Triceratops*: cladistic and morphometric approaches. *Journal of Vertebrate Paleontology, 16*, 259-270.

Ostrom, J. H., & Wellnhofer, P. (1986). The Munich specimen of *Triceratops* with a revision of the genus. *Zitteliana, 14*, 111-158.

Scannella, J. B., & Horner, J. R. (2010). *Torosaurus* Marsh, 1891, is *Triceratops* Marsh, 1889 (Ceratopsidae: Chasmosaurinae): synonymy through ontogeny. *Journal of Vertebrate Paleontology, 30*, 1157-1168.

Scannella, J. B., & Horner, J. R. (2011). '*Nedoceratops*': an example of a transitional morphology. *PLoS ONE, 6*, e28705.

Scannella, J. B., Fowler, D. W., Goodwin, M. B., & Horner, J. R. (2014). Evolutionary trends in *Triceratops* from the Hell Creek Formation, Montana. *Proceedings of the National Academy of Sciences USA, 111*, 10245-10250.

Sternberg, C. M. (1949). The Edmonton fauna and description of a new *Triceratops* from the Upper Edmonton member; phylogeny of the Ceratopsidae. *National Museum of Canada Bulletin, 113*, 33-46.

Woodward, H. N., Tremaine, K., Williams, S. A., Zanno, L. E., Horner, J. R., & Myhrvold, N. (2020). Growing up *Tyrannosaurus rex*: Osteohistology refutes the pygmy "*Nanotyrannus*" and supports ontogenetic niche partitioning in juvenile *Tyrannosaurus*. *Science Advances, 6*, eaax6250.

Wu, X.-C., Brinkman, D. B., Eberth, D. A., & Braman, D. R. (2007). A new ceratopsid dinosaur (Ornithischia) from the uppermost Horseshoe Canyon Formation (upper Maastrichtian), Alberta, Canada. *Canadian Journal of Earth Sciences, 44*, 1243-1265.

Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 4:40 PM)

NEWLY RECOGNIZED GYMNOSPERM DIVERSITY IN THE UPPER JURASSIC BRUSHY BASIN MEMBER OF THE MORRISON FORMATION BASED ON 3-DIMENSIONALLY PRESERVED REPRODUCTIVE STRUCTURES FROM THE HENRY MOUNTAINS OF UTAH, USA

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Newly investigated casts of cones and seeds supplement data from leaf and dispersed pollen assemblages to give an improved picture of gymnosperm diversity in the late Jurassic. These specimens, gathered by dedicated paleobotanical collectors over many decades (Bass, 1964; Dayvault & Hatch, 2003) and now housed at the US National Museum, and at the Florida Museum of Natural History, and the Denver Museum of Nature and Science, were difficult to study and document in detail prior to the availability of micro-CT scanning technology. Specimens were hand-picked and/or washed from lag deposits along with woody twigs and short shoots in the Brushy Basin Member of the Morrison Formation in the Henry Mountains, south of Hanksville, Utah. Most are three-

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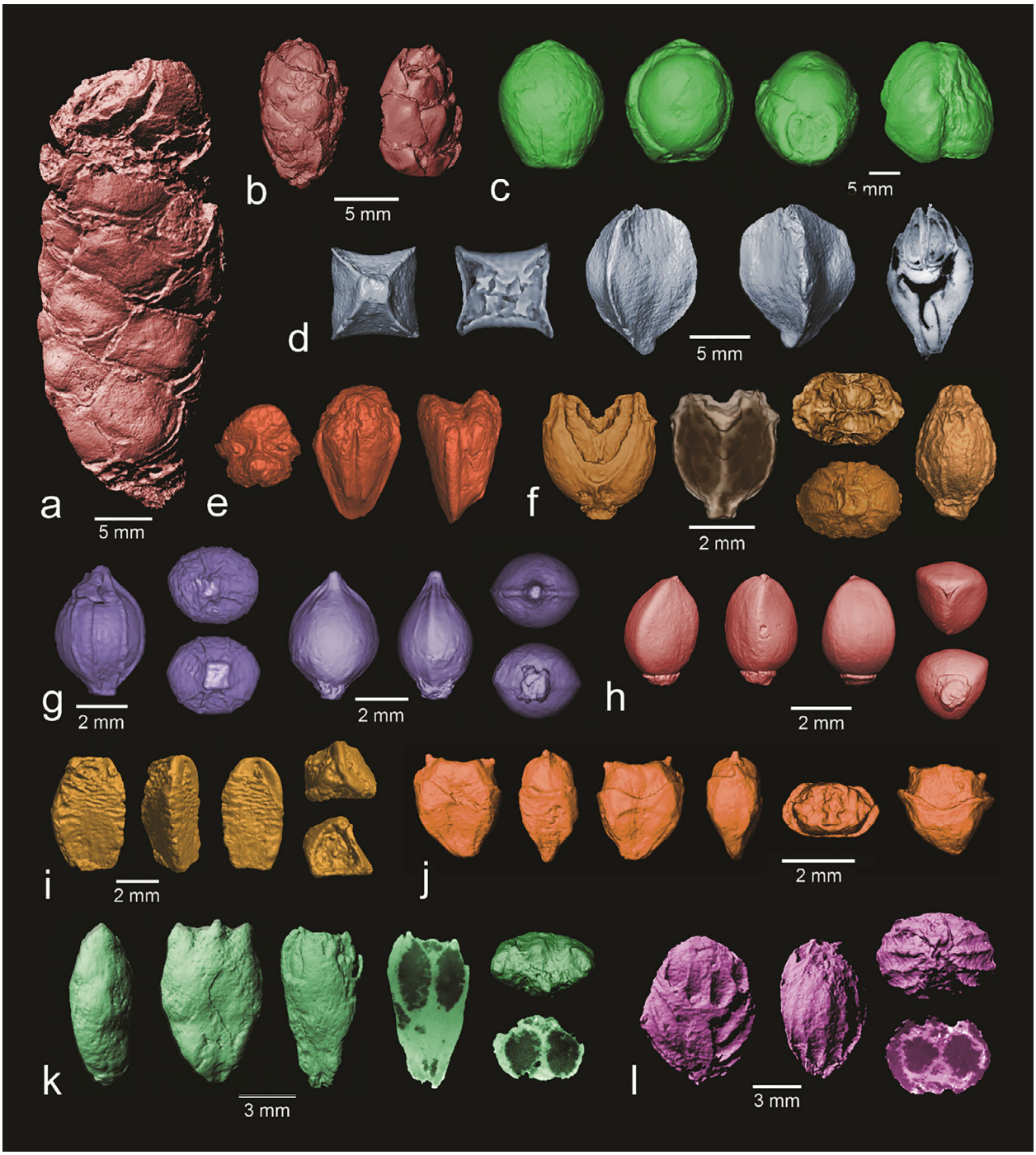


Figure 1. Cones and seeds from Mt. Ellen, Utah. USNM collection of Charles Bass, Glen and Donna Hood. (A) Coniferous cone cf. morphotype 4 of Gee et al. (2014). USNM 785463. (B) Cones resembling *Hillistrobus* (Chandler, 1966). USNM,785464, 785464. (C) Seeds of Jensenispermum redmondii showing lateral aril or cupule (Chandler, 1966). DMNH EPI47804. (D) Cones of *Dayvaultia tetragona* showing the tetragonal transverse section and the apices of several four-lobed seeds (Manchester et al. 2021). USNM 770200 and UF 19572-82578. (E) Coniferous bract-scale complex. (F) Cone of *Bassitheca hoodiorum* showing elliptical transverse section, two seed cavities and an opposite, decussate arrangement of bracts (Manchester et al., 2022), USNM 770219. (G) Seed with longitudinal surface ribs, smooth inner surface, lensoidal transverse section, basal protuberance and a probable micropyle at the apex. USNM 785406, 785407. (H) Seed with smooth surface, trigonal transverse section, prominent basal protrusion and probable micropyle at the seed apex USNM 785387. (I) Seed with sinuous transverse ridges, trigonal cross section and prominent hilar scar. UF18537-84214. (J) Bisymmetrical two-seeded cones with an opposite, decussate arrangement of bracts, USNM 771557, 771549+ region 19. (K) Two-seeded cone with opposite, decussate arrangement of surrounding bracts, USNM771476, 771477. (L) Cone with at least three pairs of opposite and decussate vertically stacked seeds, USNM 785399.

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dimensional calcitic casts preserving only external morphology, but some specimens are partially permineralized with traces of internal structure and vasculature visible in micro-CT scans. From the Mount Ellen flora, introduced by Bass (1964), we recognize at least a dozen kinds of gymnosperm reproductive structures. These include at least two kinds of conifer cones including *Hillistrobus* Chandler 1966 (Figure 1B) and morphotype 4 of Gee et al., 2014; Figure 1A), dispersed bract-scale complexes (Figure 1E), a mystery cupulate seed known as *Jensenispermum redmondii* Chandler 1966 (Figure 1C), and a variety of cones and seeds that are probably related to extant *Ephedra* or the other two genera of extant Gnetales (Figure 1D, F-L).

Probable Gnetales include the two recently described genera, *Dayvaultia* (Manchester et al. 2021; Figure 1D) and *Bassitheca* (Manchester et al., 2022; Figure 1F), as well as various taxa that remain to be described and named (Figure 1G–L). Some are probably single seeds with prominent hilar protuberances or scars and a probable micropyle at the apex (Figure 1G, H, I), but while some have a single plane of symmetry and a lensoidal transverse section (Figure 1G), others are trigonal in transverse view (Figure 1H, I). Undescribed cones include two new morphotypes that are two-seeded with an opposite, decussate arrangement of surrounding scales (Figure 1J, K), and another that bears three vertically stacked opposite and decussate pairs of seeds (Figure 1L). With the exception of conifer cones that range from 1.5 to 4.0 cm in length, the other reproductive structures are all relatively small, with a maximum dimension of 2.0 to 12.0 mm. By analogy with extant *Ephedra*, to which some of these fossils are probably closely related, we speculate that the small cones and seeds were derived from shrubby plants that were probably important in relatively open, possibly semi-arid, vegetation.

The newly investigated fossils augment our understanding of regional vegetation during deposition of the Brushy Basin Member of the Morrison Formation, which has otherwise been inferred mainly from dispersed pollen and spores and leaf impressions of ferns and seed plants recovered from other localities. The likely systematic affinities of the cones and seeds in Mount Ellen flora also suggest that extinct Gnetales were more prominent on the Morrison landscape than has been recognized previously.

References

Bass, C. (1964). Significant new fossil plant locality in Utah. *Contributions to Geology*
University of Wyoming, *3*, 94-95.

Chandler, M. E. J. (1966). Fruiting organs from the Morrison Formation of Utah, USA.
Bulletin British Museum (*Natural History*), *Geology*, *12*(4), 137-171.

Dayvault, R. D., & Hatch, H. S. (2003). Short shoots from the Late Jurassic Morrison Formation
of southeastern Utah. *Rocks & Minerals*, *78*, 232-247.

Gee, C. T., Dayvault, R. D., Stockey, R. A., & Tidwell, W. D. (2014). Greater palaeobiodiversity
in conifer seed cones in the Upper Jurassic Morrison Formation of Utah, USA. *Palaeobiodiversity and Palaeoenvironments*, *94*, 363-375.

Manchester, S. R., Zhang, X., Hotton, C. L., Wing, S. L., & Crane, P. R. (2021). Distinctive
quadrangular seed-bearing structures of gnetalean affinity from the Late Jurassic Morrison Formation of Utah, USA. *Journal of Systematic Palaeontology*, *19*, 743-760.

Manchester, S. R., Zhang, X. Q., Hotton, C. L., Wing, S. L., & Crane, P. R. (2022). Two-seeded cones of probable gnetalean affinity from the Morrison Formation (Late Jurassic) of Utah and Colorado, USA. *Acta Palaeobotanica*, *62*, 77-92.

Withdrawn

THE LIMNOGEOLOGICAL APPROACH: A TRIASSIC STUDY CASE FROM ARGENTINA

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Lake basins are very dynamic systems that respond to both environmental interactions and tectonic changes recorded in the basin sediments (e.g., Renault & Gierlowski-Kordesch, 2010). Limnogeology is a relatively young geoscience that integrates several earth science disciplines to provide a holistic approach; thus, limnogeology combines multiproxy datasets to answer tectonic, climatic, and biotic questions.

After determining the hypothesis to be tested (or research question to be answered), the first step in a limnogeology study is understanding the basin type and paleogeographic context. Based on previous studies and outcrop distribution, the dimension and the type of the basin can be defined. Next, to obtain a basin-wide view, different basin locations must be selected, where high-resolution stratigraphic sections are to be measured and sedimentological data gathered. Based on the facies analysis of the stratigraphic sections measured, the paleoenvironment and sub-environment characterizing the sedimentologic

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conditions can be inferred in detail. Subsequently, the sub-environment distribution throughout the basin and stacking pattern and cyclicity can be defined (Mancuso & Caselli, 2012). Rock and fossil samples must be collected with detailed stratigraphic control during the measurement of the log sections. Siliciclastic rock samples, mainly siltstone and mudstone, are collected to analyze clay mineralogy and major- and trace-element composition based on SEM, XRF, and XRD. Carbonate rock samples are collected to examine macroscopic and microscopic fabric through the combined use of optical petrography, cathodoluminescence, microprobe, and SEM; this work also can identify unaltered primary carbonate for geochemical analysis (Mancuso et al., 2020). The fossil record, including both ichnofossils and body fossils, must be examined to identify taxa present and place them in a stratigraphic context, identify co-occurring assemblages, and elucidate taphonomic modes and pathways. These data allow one to explore the relationship of temporal, spatial, and facies variability to observed biotic assemblages (Mancuso & Marsicano, 2008). Finally, datable rock samples are essential for determining independent biostratigraphically geologic ages that allow for intra-basinal correlation and comparison of the succession with other lake basins.

Hydrography and hydrology interpretation can be characterized based on stratigraphy, sedimentology, mineralogy, geochemistry (e.g., C-O stable isotope co-variance), and ichnologic and taphonomic models. Robust paleoclimate reconstructions must integrate different climate proxies to supply numerical ranges or general trends (e.g., primary clay-mineral assemblages, mineralogical index, chemical index of alteration (CIA), K/Al, Ba/Sr, δ18O, $\delta^{13}C$, major- and trace-element geochemical indices, biotic record, and taphonomic models). Subsequently, the trends and numerical ranges must be compared with global climate models and climate proxy data from coeval units from the same general vicinity to differentiate regional/global climate effects from local hydrology (Mancuso et al., 2020). Sequence stratigraphy can be analyzed using the sedimentological features, ichnological preservation model, and taphonomic model to identify non-depositional surfaces, flooding surfaces, and sequence boundaries. Thus, the identified non-depositional surfaces allow estimation of the duration of the hiatuses represented and distinguishing depositional sequence boundaries (allogenic) from surfaces that record 'normal' subaerial exposure of short duration (autogenic). Throughout the basin, datable levels can be used as a datum to correlate across the log sections and, therefore, allow recognition of the system-tract and depositional-sequence evolution. Integrating all the datasets, the tectonic and climate influence can be interpreted and contrasted with regional tectonic context, global paleoclimate data, and biotic evolution to characterize the paleolake (Benavente et al., 2022).

An excellent example of this approach comes from the Triassic Argentine Ischigualasto-Villa Unión Basin (IVUB), which includes as part of its infilling the Chañares-Los Rastros formations (Ch-LR) that represent an extensive lacustrine system (Mancuso & Caselli, 2012). Multiple studies have been performed on the Chañares-Los Rastros succession in the last 20 years (Benavente et al., 2022; Mancuso, 2005, 2012; Mancuso & Caselli, 2012; Mancuso & Marsicano, 2008; Mancuso et al., 2014, 2020; Marsicano et al., 2010). These studies provide an excellent framework to illustrate interdisciplinary limnogeological research integrating multiproxy datasets.

The IVUB has a half-graben geometry and covers an area of ∼3400 km^2. The Ch–LR paleolake is interpreted as an overfilled lake basin based on its sedimentology, stratigraphy, and geochemistry, which suggests short water residence time. Moreover, the lack of lateral and vertical change in the distribution of trace and body fossils––based on abundance, diversity, and taphonomic features––suggests continuous high soil moisture levels and groundwater table levels. Multiproxy analysis (sedimentologic, clay mineral, C and O stable isotopes, paleontological data) strongly supports a warm and humid climate during the Ch–LR sequence deposition. Multiple CA-TIMS U-Pb zircon ages from the Ch–LR sequence allowed correlation throughout the IVUB and indicated a Carnian age. These dates also suggest that a portion of these lacustrine strata was deposited during a global climate event, the Carnian Pluvial Episode. Integration of these sedimentological, geochemical, and ichnological data allows the recognition of a tectonic half-graben tilting during the active syn-rift phase. This second half-graben is controlled independently by a secondary fault, at least during the transgressive-highstand system tract of the Los Rastros sequence, isolating a separate small paleolake. Biotic and abiotic data are interpreted to indicate that the Ch–LR paleolake was a deep freshwater lake, meromictic with an anoxic bottom, which changed from moderately eutrophic conditions with low oxygen content to relatively oxygenated oligotrophic conditions. Therefore, without the appropriate integration of several evidence lines (limnogeological approach), the single-proxy reconstruction of the continental-interior lake basin can misrepresent the actual evolution of the system.

References

Benavente, C. A., Mancuso, A. C., Irmis, R. B., Bohacs, K. M., & Matheos, S. (2022). Tectonically conditioned record of continental interior paleoclimate during the Carnian pluvial event: The Upper Triassic Los Rastros

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Formation, Argentina. *Geological Society of America Bulletin*, *134*(1-2), 60-80.

Mancuso, A. C. (2005). *Tafonomía en ambientes lacustres: estudio paleobiológico, sedimentológico y tafonómico de las secuencias lacustres triásicas de la Cuenca de Ischigualasto-Villa Unión (formaciones Chañares, Ischichuca y Los Rastros)* [Doctoral dissertation, Universidad de Buenos Aires].

Mancuso, A. C. (2012). Taphonomic analysis of fish in rift lacustrine systems: Environmental indicators and implications for fish speciation. *Palaeoecology, Palaeogeography, Palaeoclimatology*, *339-341*, 121-131.

Mancuso, A. C., & Caselli, A. T. (2012). Paleolimnology evolution in rift basins: The Ischigualasto–Villa Unión Basin (central-western Argentina) during the Triassic. *Sedimentary Geology, 275*, 38-54.

Mancuso, A. C., & Marsicano, C. A. (2008). Paleoenvironments and taphonomy of a Triassic lacustrine system (Los Rastros Formation, central-western Argentina). *Palaios, 23*, 535-547.

Mancuso, A. C., Benavente, C. A., Irmis, R. B., & Mundil, R. (2020). Evidence for the Carnian Pluvial Episode in Gondwana: new multiproxy climate records and their bearing on early dinosaur diversification. *Gondwana Research, 86*, 104-125.

Mancuso, A. C., Gaetano, L. C., Leardi, J. M., Abdala, F., & Arcucci, A. B. (2014). The Chañares Formation: a window to the palaeobiology of a Middle Triassic vertebrate fauna. *Lethaia*, *47*, 244-265.

Marsicano, C. A., Mancuso, A. C., Palma, R. M., & Krapovickas, V. (2010). Tetrapod tracks in a marginal lacustrine setting (Middle Triassic, Argentina): taphonomy and significance. *Palaeoecology, Palaeogeography, Palaeoclimatology*, *291*, 388-399.

Renaut, R. W., & Gierlowski-Kordesch, E. H. (2010). Lakes. In R. Dalrymple & N. James (Eds.), *Facies models* (4th ed.) (pp. 541-575). Geological Association of Canada.

Technical Session 3: Terrestrial Ecosystems – Late Cretaceous (Saturday, June 10, 2023, 2:30 PM)

SAMPLING BIAS IN CERATOPSID PHYLOGENIES

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The ceratopsids represent a Late Cretaceous radiation of quadrupedal ornithischian dinosaurs remarkable for their elaborate craniofacial ornamentation (Dodson et al., 2004). All known ceratopsid taxa are referred to one of two subclades: (1) the 'short-frilled' centrosaurines, and (2) the 'long-frilled' chasmosaurines. This observable dichotomy represents the foundation of a long established and untested pre-cladistic hypothesis which currently recognizes centrosaurines and chasmosaurines as two independent ceratopsid lineages (Dodson et al., 2004; Lehman, 1990). Here, parsimony analyses were undertaken to investigate the phylogenetic relationships of all ceratopsid species. These analyses had two primary aims: (1) to test the monophyly of the centrosaurine and chasmosaurine clades as currently defined; and (2) identify and evaluate those characters which are parsimony-uninformative or those characters which are 'hidden' duplicates describing the same morphology with differing or overlapping definitions for existing characters or character states.

Two phylogenetic datasets were assembled: (1) the ceratopsid (CA) dataset, and (2) the epiossification excluded (EA) dataset. These datasets were assembled from the phylogenetic dataset of Mallon et al. (2016) with an additional 16 non-overlapping characters from the phylogenetic dataset of Chiba et al., (2018). In both matrices, characters 1-157 represent those characters that describe cranial and postcranial skeletal elements or score discrete variations associated with these characters. In the CA dataset, characters 158-188 represent those characters that describe the accessory epiparietal and episquamosal ossifications. Both the CA and EA matrices utilize an identical list of operational taxonomic units. Each dataset was analyzed using maximum parsimony (MP) implemented in TNT v. 1.5 with and without the use of extended implied weighting (EIW) analysis. *Leptoceratops gracilis* was selected as the outgroup taxon following Mallon et al. (2016). Each dataset was analyzed using the 'New Technology Search' option with sectorial searches, ratchet, drifting and tree-fusing algorithms enabled on their default settings (Goloboff et al., 2008b); parsimonious trees were generated using 10 random addition sequences. The optimal trees recovered by the 'New Technology Search' were used as starting trees for a 'Traditional Search' with the tree bisection–reconnection (TBR) algorithm following Mannion et al. (2013). For extended implied weighting, analyses were implemented with two different *k*-values; the default *k*-value of 3 and the recommended *k*-value of 12 following Goloboff et al. (2017). The higher *k*-values do not down-weight putative homoplastic characters as strongly as lower *k*-values and recover more accurate trees in a modelled environment (Goloboff et al., 2008a, 2017). In addition to the unconstrained CA and EA analyses, an unweighted MP analysis of the ceratopsid and epiparietal

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datasets was implemented using a topological constraint. This topological constraint reflects the current accepted consensus of recent published analyses for categorizing centrosaurine ceratopsids (e.g., Chiba et al., 2018; Ryan et al., 2017).

The resulting strict consensus trees from the MP analyses of the CA and EA datasets are grouped into two categories: (1) topologies where the centrosaurine and chasmosaurine clades are recovered; and (2) topologies where the centrosaurine clade as currently defined is not recovered and characterized by numerous polytomies. The centrosaurine clade as currently defined is not recovered by the unweighted analysis of the CA and EA datasets or the weighted analysis of the EA dataset with a *k*-value of 12. Furthermore, the centrosaurines *Diabloceratops eatoni* and *Machairoceratops cronusi* are recovered as successive sister taxa of the ceratopsids proper by the unweighted analysis of the CA dataset. In all analyses of the CA and EA datasets, the chasmosaurines are recovered as two early-branching subclades (i.e., '*Triceratops*-like' ceratopsids and '*Chasmosaurus*-like' ceratopsids). The unweighted analysis and a weighted analysis with a *k*-value of 12 of the EA dataset recovers six centrosaurines including *Avaceratops lammersi* and *Nasutoceratops titusi* as sister taxa to the chasmosaurine clade. However, the relationships between these centrosaurine taxa and the chasmosaurine clade are poorly resolved.

Chiba *et al*., (2018) identified 11 characters supporting centrosaurine monophyly, however, the unweighted analysis of the CA dataset optimizes these characters as either synapomorphies of the ceratopsid clade, synapomorphies of chasmosaurines with the character state in centrosaurines being plesiomorphic or as phylogenetically uninformative characters. This is likely a consequence of inadequate sampling of early ceratopsian taxa and the significant undersampling of centrosaurine characters in the source data. The source data includes 85 characters that are shared (i.e., characters utilized in both Mallon et al., 2016 and Chiba et al., 2018), however, less than 10% of these sharded characters are centrosaurine specific. This weighting of the parsimony analysis towards chasmosaurine taxa appears to result in increased resolution within the chasmosaurine clade relative to the distribution of centrosaurine taxa. Additionally, several centrosaurine taxa characterised by a high proportion of missing data were recovered as sister taxa to the chasmosaurine clade by the unweighted analysis and a weighted analysis with a *k*-value of 12 of the EA dataset. This suggests that a significant portion of what holds together the centrosaurine clade is the inclusion of intraspecifically variable epiossification characters. These analyses have identified numerous problematic characters and provide a new foundation for future studies of the ceratopsid phylogeny.

References

Chiba, K., Ryan, M. J., Fanti, F., Loewen, M. A., & Evans, D. C. (2018), New material and systematic re-evaluation of *Medusaceratops lokii* (Dinosauria, Ceratopsidae) from the Judith River Formation (Campanian, Montana). *Journal of Paleontology, 92*, 272-288.

Dodson, P., Foster, C. A., & Sampson, S. D. (2004). Ceratopsidae. In D. B. Weishampel, P. Dodson, & H. Osmólska (Eds.), *The Dinosauria* (2nd ed.) (pp. 494-513). University of California Press.

Goloboff, P., Carpenter, J., Arias, J., & Miranda-Esquivel, D. (2008a). Weighting against homoplasy improves phylogenetic analysis of morphological data sets. *Cladistics, 24*, 1-16.

Goloboff, P. A., Farris, J. S., & Nixon, K. C. (2008b). TNT, a free program for phylogenetic analysis. *Cladistics, 24*, 774-786.

Goloboff, P. A., Torres, A., & Arias, J. S. (2017). Weighted parsimony outperforms other
methods of phylogenetic inference under models appropriate for morphology. *Cladistics, 34*, 407-437.

Lehman, T. M. (1990). The ceratopsian subfamily Chasmosaurinae: sexual dimorphism and
systematics. In K. Carpenter & P. J. Currie (Eds.), *Dinosaur systematics: Approaches and
perspectives* (pp. 211-230). Cambridge University Press.

Mallon, J. C., Ott, C. J., Larson, P. L., Iuliano, E. M., & Evans, D. C. (2016). *Spiclypeus shipporum* gen. et sp. nov., a boldly audacious new chasmosaurine ceratopsid (Dinosauria: Ornithischia) from the Judith River Formation (Upper Cretaceous: Campanian) of Montana, USA. *PloS One, 11*(5), e0154218.

Mannion, P. D., Upchurch, P., Barnes, R. N., & Mateus, O. (2013). Osteology of the Late Jurassic Portuguese sauropod dinosaur *Lusotitan atalaiensis* (Macronaria) and the evolutionary history of basal titanosauriforms. *Zoological Journal of the Linnean Society, 168*, 98-206.

Ryan, M. J., Holmes, R., Mallon, J., Loewen, M., & Evans, D. C. (2017). A basal ceratopsid (Centrosaurinae: Nasutoceratopsini) from the Oldman Formation (Campanian) of Alberta, Canada. *Canadian Journal of Earth Sciences, 54*, 1-14.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 8:30 AM)

LATE JURASSIC AND EARLY CRETACEOUS MAMMALS FROM GERMANY

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One key period for the evolution of terrestrial vertebrates is the Late Jurassic to Early Cretaceous transition, which also marks the emergence of angiosperm plants. The Jurassic mammal faunas were dominated by stem mammals such as docodontans and morganucodontans, as well as typical Mesozoic crown mammals such as eutriconodontans, multituberculates, and dryolestidans. Except for the multituberculates, most Jurassic groups started to decline with the beginning of the Cretaceous era and were successively replaced by "symmetrodontans" and tribosphenic stem therians (predecessors of modern mammals) in the Northern Hemisphere. European localities yielding Late Jurassic and Early Cretaceous terrestrial vertebrates and especially mammals are rare, and were until recently restricted to the western and southwestern part of that continent. The recently discovered mammalian teeth and mandibular remains from the Late Jurassic of the Langenberg Quarry and the Early Cretaceous of the Balve-Beckum locality in Germany made new information on mammalian evolution during this important time interval in Central Europe available.

The Süntel Formation exposed in the Langenberg Quarry near the town of Goslar (Lower Saxony) with fossil bearing marls and limestones is well-dated to be of late Kimmeridgian age by the presence of marine invertebrates (Fischer, 1991). The sediments of the Süntel Formation were accumulated in a near shore area of the Lower Saxony Basin with influx of terrestrial sediments. The diverse vertebrate assemblage of the Langenberg Quarry includes chondrichthyan and osteichthyan fishes, marine turtles, a paramacellodid lizard, the small atoposaurid crocodylomorph *Knoetschkesuchus* and marine crocodyliforms, pterosaurs, the dwarfed sauropod *Europasaurus*, several theropod dinosaurs, mammaliaforms, and mammals (Marpmann et al., 2015; Richter et al., 2013; Schwarz et al., 2017; Wings, 2015; Wings & Knüppe, 2020). Morganucodontans are represented by large upper and lower molars of *Storchodon cingulatus* (Martin et al., 2019a), being less than 10% smaller than the largest known morganucodontan specimen (lower molar of *Paceyodon davidi*, Early Jurassic, Wales). Docodontans are represented by two lower molars of a yet undetermined taxon (Docodontidae indet.) and upper and lower molar fragments. Multituberculates are most abundant with more than two dozen isolated teeth. Three taxa have been identified, the pinheirodontid *Teutonodon langenbergensis* (I3, M1, M2), *Cimbriodon multituberculatus* (P3,?4, P5, p3, and p4) of the paulchoffatiid lineage, and an undetermined paulchoffatiid (p4) (Martin et al., 2021b). Cladotherians are represented by upper and lower molars of the small (*Amblotherium*-sized) dryolestid *Hercynodon germanicus* (Martin et al., 2021c). The large size of the new morganucodontan taxon likely is a phenomenon of island gigantism caused by isolation within the Late Jurassic European archipelago. Pinheirodontid and paulchoffatiid multituberculates represent endemic European clades that probably evolved on the Rhenish-Bohemian Massif and reached the Iberian Plate only in the Early Cretaceous.

The sediments of the Balve-Beckum locality in the Sauerland area (North Rhine-Westphalia) provide insight into a former Early Cretaceous upland environment. The fossiliferous sediments exposed in the Busche Quarry near Balve-Beckum are unconsolidated clay-rich silts to sands that were deposited within a deep paleo karst system in Devonian limestones (Massenkalk). They are well-dated as Barremian-Aptian age by pollen and sporomorphs (Lanser & Heimhofer, 2013). The fauna recorded comprises chondrichthyan and osteichthyan fishes, lissamphibians, several taxa of turtles, squamates, crocodyliforms, pterosaurs, dinosaurs, and mammals (Hornung et al., submitted; Schwermann et al., 2018, Skutschas et al., 2020). Remains of three major mammalian clades have been reported so far (Martin et al., 2021, 2022): pinheirodontid and eobaatarid multituberculates (*Bructerodo*n and *Cheruscodon*), "symmetrodontans" (*Cifellitherium*), and dryolestids (*Beckumia* and *Minutolestes*). The discoveries of two mammalian mandibles and articulated postcranial bones of dinosaurs underline the potential of the Balve-Beckum locality for more complete fossils. The dryolestids from Balve-Beckum are among the youngest in the Northern Hemisphere and demonstrate that they were more diverse in Europe in the Early Cretaceous than anticipated so far. According to the current hypothesis, the predominant pretribosphenic dryolestidans delayed the emergence of tribosphenidans (stem lineage representatives of modern mammals with crushing tooth function) in Europe. In summer 2022, a tribosphenic mammalian lower molar with a fully developed and deep talonid basin was discovered in Balve-Beckum, demonstrating that tribosphenidans co-existed with non-tribosphenic cladotherians in Central Europe in the Early Cretaceous. The Balve-Beckum mammal assemblage is remarkably diverse, with nearly all major Cretaceous mammalian groups present. Like the Langenberg Quarry for the Late Jurassic, Balve-Beckum forms a bridge between the Western European and the Central and Eastern Asian terrestrial Early Cretaceous vertebrate assemblages. During the Late Jurassic and Early Cretaceous most of Europe was covered by a shallow epicontinental

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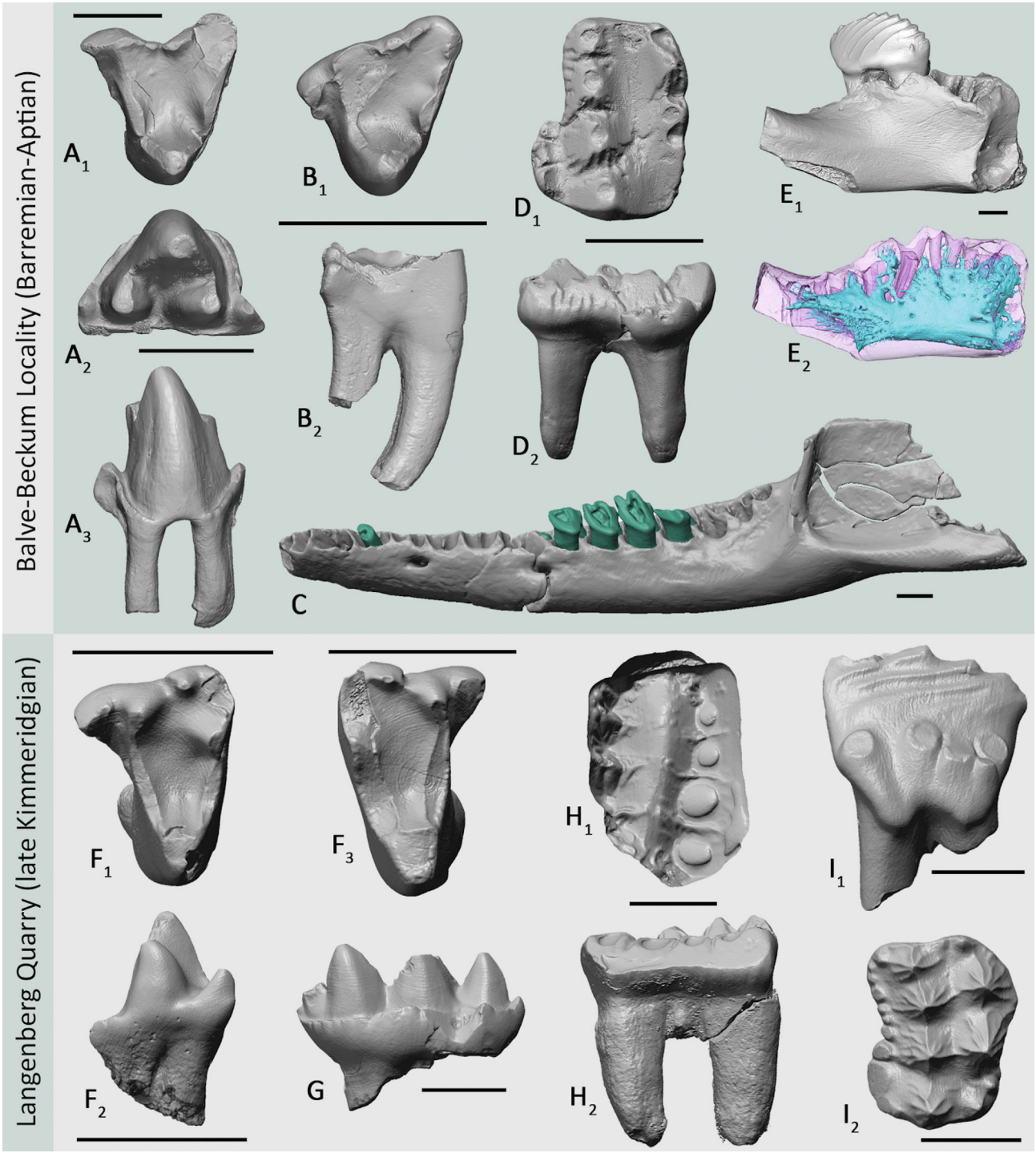


Figure 1. Mammalian teeth and gnathic remains from the Langenberg Quarry and the Balve-Beckum Locality. A, spalacotheriid *Cifellitherium suderlandicum*; A_1 right upper M1 in occlusal view (WMNM P82308); A_2 and A_3 right lower molar in occlusal (A_2) and labial (A_3) views (WMNM P82305). B, dryolestid *Minutolestes submersus*, left upper molars in occlusal view (B_1, WMNM P82306; B_2, WMNM P82304). C, dryolestid *Beckumia sinemeckelia*, left mandible in lateral view (WMNM P82301). D, pinheirodontid multituberculate *Bructerodon alatus*, left M1 (WMNM P79402) in occlusal (D_1) and lingual views (D_2). E, eobaatarid multituberculate *Cheruscodon balvensis*, right dentary fragment in lingual view (WMNM P79404); E_1, surface image with p4; E_2, transparent image with the mandibular canal and connecting tissue in blue (p4 removed). F, dryolestid *Hercynodon germanicus*; left (F_1, NLMH 105668) and right (F_3, NLMH 105669) upper molars in occlusal view; F_2, left lower molar in lingual view (NLMH 105671). G, morganucodontid *Storchodon cingulatus*, right upper molar (NLMH 105654) in lingual view. H, pinheirodontid multituberculate *Teutonodon langenbergensis*, right upper M1 (NLMH 105650) in occlusal (H_1) and lingual (H_2) views. I, pinheirodontid multituberculate *Cimbriodon multituberculatus*, left lower p3 (I_1, NLMH 105657) in labial view and left upper P4 (I_2, NLMH 105660) in occlusal view. Scale bars equal 1 mm. Images from Martin et al. (2019, 2021a-c, 2022).

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ocean due to higher sea levels, resulting in a number of scattered islands instead of one large continental area. Thus, the late survival of dryolestids in Balve-Beckum is possibly another phenomenon of insular isolation on the mid to late Mesozoic European archipelago.

For the first time, the mammalian fossils discovered in the Langenberg Quarry in the Harz Mountains (Lower Saxony) and the Balve-Beckum locality in the Sauerland (North Rhine-Westphalia) provide insight into the Late Jurassic–Early Cretaceous turnover of mammal faunas in Central Europe. These localities are remarkable by their northeastern position compared to other terrestrial or nearshore Mesozoic sites in Europe. Additionally, the fossil content of the Balve-Beckum locality represents an upland environment that is otherwise rarely documented. This is reflected by the wider taxonomic range of vertebrates at this site, including for example various amphibians. Furthermore, as karstic fissure infill, this locality has a higher potential for better preserved microvertebrates than fluvial or marginal marine deposits.

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References

Hornung, J. J., Sachs, S., & Schwermann, A. H. (submitted). The first record of sauropod dinosaurs from a palaeotopographical upland environment and its implications for megaherbivorous dinosaur faunal turnover in the Early Cretaceous of northwestern Europe. *Geologie und Palaeontologie in Westfalen*.

Lanser, K.-P., & Heimhofer, U. (2013). Evidence of theropod dinosaurs from a Lower Cretaceous karst filling in the northern Sauerland (Rhenish Massif, Germany). *Paläontologische Zeitschrift, 89*, 79e94.

Marpmann, J. S., Carballido, J. L., Sander, P. M., & Knötschke, N. (2015). Cranial anatomy of the Late Jurassic dwarf sauropod *Europasaurus holgeri* (Dinosauria, Camarasauromorpha): Ontogenetic changes and size dimorphism. *Journal of Systematic Palaeontology, 13*, 221-263. https://doi.org/10.1080/14772019.2013.875074

Martin, T., Averianov, A. O., Jäger, K. R. K., Schwermann, A. H., & Wings, O. (2019). A large morganucodontan mammaliaform from the Late Jurassic of Germany. *Fossil Imprint, 75*, 504-509.

Martin, T., Averianov, A. O., Schultz, J. A., Schwermann, A. H., & Wings, O. (2021a). Late Jurassic multituberculate mammals from Langenberg Quarry (Lower Saxony, Germany) and palaeobiogeography of European Jurassic multituberculates. *Historical Biology, 33*, 616-629. https://doi.org/10.1080/08912963.2019.1650274

Martin, T., Averianov, A. O., Schultz, J. A., & Schwermann, A. H. (2021b). First multituberculate mammals from the Lower Cretaceous of Germany. *Cretaceous Research, 119*, 104699.

Martin, T., Averianov, A. O., Schultz, J. A., Schwermann, A. H., & Wings, O. (2021c). A derived dryolestid mammal indicates possible insular endemism in the Late Jurassic of Germany. *Naturwissenschaften, 108*, 23.

Martin, T., Averianov, A. O., Schultz, J. A., Schellhorn, R., Schwermann, A. H. (2022). First spalacotheriid and dryolestid mammals from the Cretaceous of Germany. *Acta Palaeontologica Polonica*, *67*, 55-175.

Richter, A., Knötschke, N., Kosma, R., Sobral, G., & Wings, O. (2013). The first Mesozoic lizard from northern Germany (Paramacellodidae, Late Jurassic, Langenberg Quarry) and its taphonomy. *Journal of Vertebrate Paleontology*, *S2013*, 198

Schwarz, D., Raddatz, M., & Wings, O. (2017). *Knoetschkesuchus langenbergensis* gen. nov. sp. nov., a new atoposaurid crocodyliform from the Upper Jurassic Langenberg Quarry (Lower Saxony, northwestern Germany), and its relationships to *Theriosuchus*. *PLoS One, 12*, e0160617. https://doi.org/10.1371/journal.pone.0160617

Schwermann, A. H., Schöllmann, L., & Pott, C. (2018). Vertebrate fauna of a fissure filling from the Lower Cretaceous (Barremiane Aptian) of Balve, Westphalia, Germany. *Terra Nostra, 2018*(1), 111e112.

Skutschas, P. P., Kolchanov, V. V., & Schwermann, A. H. (2020). First salamander from the Lower Cretaceous of Germany. *Cretaceous Research, 116*, 104606.

Wings, O. (2015). The Langenberg Quarry near Goslar: unique window into a terrestrial Late Jurassic ecosystem in Northern Germany. In *Abstracts of the 12th Symposium on Mesozoic Terrestrial Ecosystems* (p. 99-100). Shenyang Normal University.

Wings, O., & Knüppe, J. (2020). *Europasaurus - Life on Jurassic islands*. Dr. Friedrich Pfeil.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 9:30 AM)

COLORADO'S OLDEST DINOSAURS: THEROPODS FROM THE RED SILTSTONE MEMBER OF THE CHINLE FORMATION IN THE EAGLE BASIN OF COLORADO AND A SUMMARY OF LATE TRIASSIC ORNITHODIRAN BIOCHRONOLOGY IN WESTERN NORTH AMERICA

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The red siltstone member in the Eagle Basin of Colorado is the northernmost stratigraphic unit of the Chinle Formation to produce a rich record of Late Triassic terrestrial vertebrates. The red siltstone member was deposited by rivers draining the remnants of the "Ancestral Rocky Mountains" (Uncomphagria and Frontrangia). Vertebrate fossils are usually recovered as isolated elements in conglomeratic sandstones deposited by small bedload-dominated channels, although well-articulated specimens occur in finer-grained sandstones and siltstones representing overbank deposits. In addition to fish, metoposaurs, the stem caecilian *Chinlestegophis jenkinsi*, a leptopleurine procolophonid, shuvosaurids, rauisuchids, crocodylomorphs, the aetosaur *Stenomyti huangae* and another form similar to *Rioarribasuchus*, the Eagle Basin localities have also produced the lagerpetid *Dromomeron romeri*, the silesaurid *Kwanasaurus williamparkeri*, the basal theropod *Chindesaurus bryansmalli* and a new coelophysoid neotheropod. *Chindesaurus bryansmalli* is represented only by a proximal femur. The new coelophysoid, known from cervical vertebrae, femora, ilia, and an astragalocalcaneum, is diagnosed by two autapomorphies (the absence of a raised dorsolateral trochanter on the femur and a tapering postacetabular process of the ilium) and a unique combination of ancestral and derived character states among coelophysoids (a weakly developed brevis shelf on the ilium, a pubic peduncle on the ilium that is ventral to the ischial peduncle, a short tibiofibular crest on the distal femur, and the lack of a medial fossa on the astragalus). The Eagle Basin fauna is probably Revueltian (Middle Norian-Rhaetian) based on the occurrence of *Dromomeron romeri* and an aetosaur with similarities to *Rioarribasuchus*, as well as the circumstantial absence of characteristic Otischalkian-Adamanian vertebrates such as *Poposaurus*, trilophosaurids, malerisaurines, and doswellids. An overview of the known record of Late Triassic dinosauromorphs in western North America reveals some interesting patterns. Lagerpetids are currently known from the Otischalkian, Adamanian, and Revueltian but silesaurids have been reported only from the upper Adamanian and Revueltian. Neither group is currently known from the Apachean, suggesting that theropods and pterosaurs may have been the only ornithodirans in North America by the end of the Triassic. Basal theropods and coelophysoids are known from all four biochrons. Known ornithodiran diversity was highest in the Revueltian, when these groups were joined by large basal neotheropods (*Gojirasaurus quayi*) on the line leading to Averostra. This fits into the general emerging picture of significant faunal reorganizations after the Adamanian-Revueltian turnover.

Poster Session 2 (Friday, June 9, 2023)

VERTEBRATE ICHNOFOSSILS FROM JURASSIC NATIONAL MONUMENT, UPPER MORRISON FORMATION, UTAH - A PRELIMINARY CENSUS

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Among the plethora of fossilized skeletal remains of dinosaurs and other Jurassic fauna uncovered from the Cleveland-Lloyd Dinosaur Quarry at Jurassic National Monument throughout the past century also lie a significant abundance of vertebrate ichnofossils that have been painfully overlooked in this area of the Brushy Basin member, following the same trend observed elsewhere in the Morrison Formation throughout much of its exploration history (Lockley & Hunt, 1995). However, stratigraphic and lithological data of known vertebrate traces can yield potential trends in preservational or biological biases in the track record of this area. Here we report data on eight vertebrate ichnofossil localities in Jurassic National Monument as part of a small preliminary sample of ongoing work in the vicinity of the Cleveland-Lloyd Dinosaur Quarry.

Ichnofossil localities were recorded with a GARMIN™ GPSmap 76CSx handheld GPS unit and stratigraphic positioning was measured from the contact of the Brushy Basin member of the Morrison Formation and the overlying Buckhorn Conglomerate (Figure 1).

The most common tracks are those made by sauropod dinosaurs, following the same ichnological trend observed throughout the Morrison Formation as a whole (Lockley et al., 1998). Interestingly, most of the sauropod traces from Jurassic National Monument were either sandstone casts or sandstone underprints, indicating a very strong bias towards mud facies in the sauropod ichnofossil record. Perhaps this is a result of a preservational bias as sauropod prints made in muddy sediment are more likely to preserve as they remain more intact for longer time periods before migrating river channels

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Ichnofossil Locality	Elevation (m)	Track Type	Meters below the Buckhorn Conglomerate	Facies	Ichnotaxa
1	1794	Natural Cast	5	Find Sand	*Grallator isp.*
2	1789	Underprint	10	Mud	*Dinehichnus isp.*
3	1789	Underprint	10	Mud	*Brontopodus isp.*
4	1786	Natural Cast	13	Mud	*Parabrontopodus isp.*
5	1777	Natural Cast	22	Mud	*Parabrontopodus isp.*
6	1776	Underprint	23	Mud	*Brontopodus isp.*
7	1774	Underprint	25	Mud	*Parabrontopodus isp.*
8	1749	Natural Mold	50	Sand	*Brontopodus isp.*

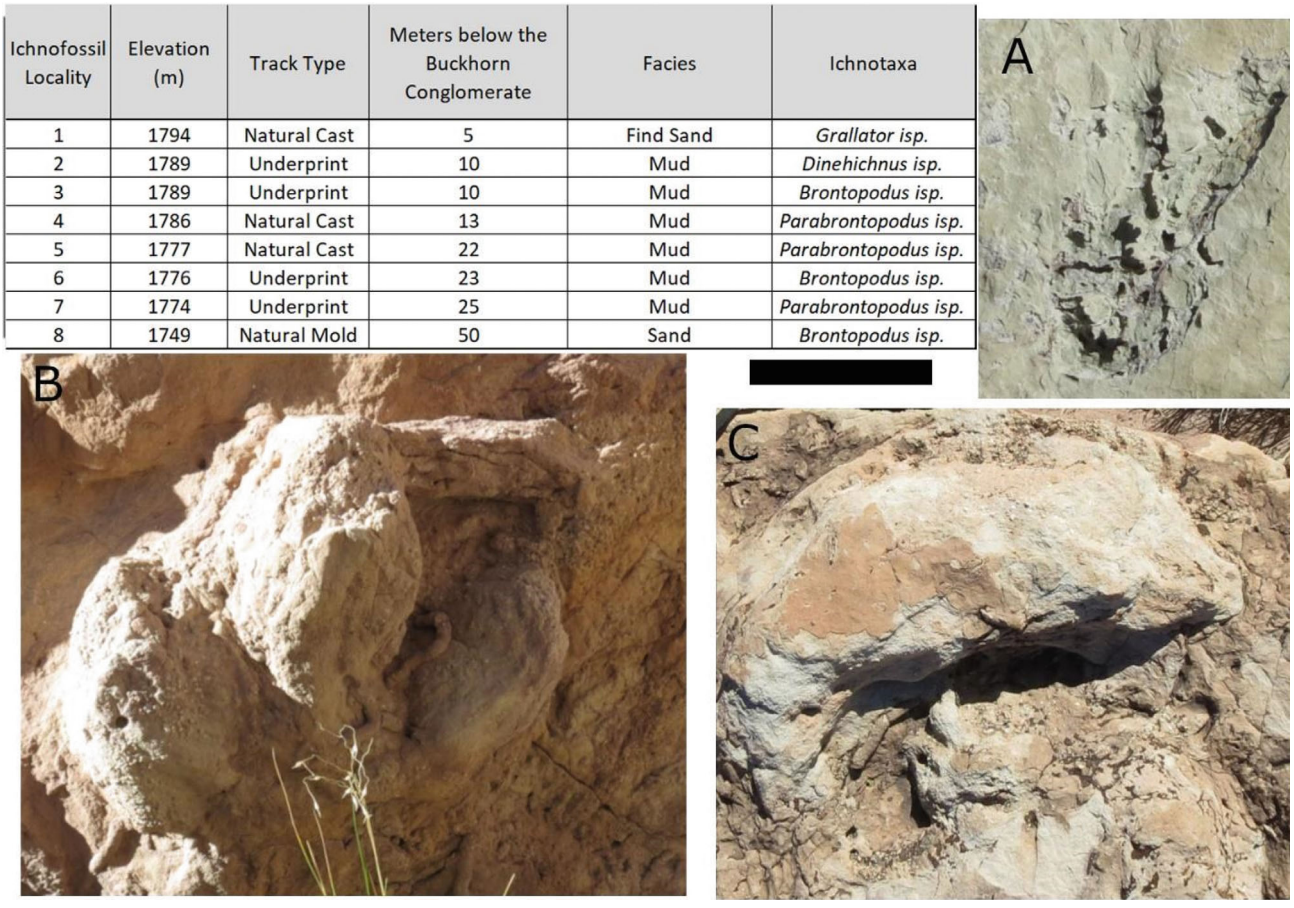


Figure 1. Data table displaying the ichnogenus, facies, trace type, and stratigraphic position of vertebrate tracks in Jurassic National Monument. A) Partial *Grallator isp*. track in sand facies; B) Underprint of ornithopod-like *Dinehichnus isp*.; C) Underprint of a sauropod-like *Brontopodus isp*. Scale bar equals 10 cm.

deposited sand overtop of the prints (Lockley et al., 1995). Alternatively, there may be a biological bias towards mud facies as sauropods may have spent much of their time walking over muddy riverside sediments supporting much of the vegetation they fed on.

While most identified traces are attributed to sauropod-like *Brontopodus isp*. and *Parabrontopodus isp*., non-sauropod traces such as *Grallator isp*. and *Dinehichnus isp*. occur at a higher stratigraphic position; no more than ten meters below the base of the Buckhorn conglomerate wedge. In contrast, nearly all the sauropod traces were more than ten meters below the contact, most occurring between 13 and 25 meters beneath this point. While preliminary and based on a small dataset, this has led to further questions regarding population dynamics approaching the end of the Jurassic as well as preservational biases.

Continued exploration into potential trends within the ichnofossil record of the Cleveland-Lloyd Dinosaur Quarry at Jurassic National Monument and the Morrison Formation in general has strong potential to provide insight into the overall understanding of the late Jurassic ecosystem of the western United States. In the vicinity of Jurassic National Monument in Utah, the stratigraphic and lithological biases associated with the known ichnogenera creates a significant amount of room for interpretation of the potential geological and paleobiological factors.

References

Lockley, M. G., Foster, J. R., & Hunt, A. P. (1998). A short summary of dinosaur tracks and other fossil footprints from the Morrison Formation. *Modern Geology, 23*, 277-290.

Lockley, M. G., & Hunt, A. P. (1995). *Dinosaur tracks and other fossil footprints of thewestern United States*. Columbia University Press.

Poster Session 3 (Saturday, June 10, 2023)

REASSESSMENT OF VERTEBRATE MICROFOSSILS FROM THE STRAIGHT CLIFFS FORMATION (TURONIAN-EARLY CAMPANIAN) OF SOUTHERN UTAH

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Vertebrate microfossils, particularly teeth, can provide key information on biodiversity, and, for taphonomic reasons, often provide information on extinct ecosystems for which no other fossil data is available. The Straight Cliffs Formation of southern Utah represents a paralic/coastal plain environment from the mid-Cretaceous period, a time of important, yet poorly understood faunal turnover. Quality skeletal material is rare in the formation, and most fossil data comes in the form of isolated teeth (Eaton et al., 1999). With the exception of a well-studied mammal fauna, most of these teeth have never been figured in the literature, nor reconsidered in the light of taxonomic advances over the last two decades.

With this in mind, we critically reexamined historic collections of microvertebrate fossils from the Straight Cliffs formation, specifically the large sample housed by the Oklahoma Museum of Natural History. These fossils were originally sourced from the Smoky Hollow Member (Turonian) and John Henry Member (Coniacian-Campanian), with no fossils stemming from the lowest or highest parts of the formation (Primm et al., 2018).

We employed, qualitative and quantitative morphological analysis in an attempt to reproduce, falsify, or refine previous classifications of this material including, morphometric multivariate analysis (Larson & Currie, 2013). Notably, teeth from the Smoky Hollow Member previously classified as "protoceratopsian" and "ceratopsid" are reidentified as a relatively basal ceratopsomorph, likely *Zuniceratops*-grade. Dental material previously described as "hadrosaurid" compares well to the hadrosauromorphs *Jeyawati and Bactrosaurus*, and the early diverging hadrosaurid *Eotrachodon*. Theropod teeth include indeterminate dromaeosaurs and tyrannosaurs as well as an unusual paravian crown remarkably similar to remains from the Campanian of Spain (Isasmendi et al., 2022). Teeth from both members attributable to the enigmatic paravian morphotaxon "*Richardoestesia*" are exceptionally numerous in the collection. They can be discretized into the relatively slender, straight-crowned morphotype "*R. isosceles*" and the shorter, thicker, and more recurved- crowned morphotype "*R. gilmorei*" consistent with the morphology preserved in younger Campano-Maastrichtian formations (Larson & Currie 2013).

The taxonomic diversity of the Straight Cliffs Formation is similar to other Turonian faunas of the Western Interior Basin, notably the Moreno Hill formation, particularly the ceratopsian material. The assemblages also compare well at coarse taxonomic levels with the more intensely studied Campanian and Maastrichtian ecosystems in the region, lending support to the early (pre-Cretaceous Thermal Maximum) assembly of Late Cretaceous faunas. This and other previously unreported information on this poorly understood paleofauna continues to enhance our picture of a scantily understood part of vertebrate history.

References

Eaton, J. G., Cifelli, R. L., Hutchison, J. H., Kirkland, J. I., & Parrish, M. (1999). Cretaceous Vertebrate Faunas from the Kaiparowits Plateau, South-Central Utah. In D. D. Gilette (Ed.), *Vertebrate Paleontology in Utah* (pp. 345-353). *Utah Geological Survey Miscellaneous Paper, 99-1*.

Isasmendi, E., Torices, A., Canudo, J. I., Currie, P. J., & Pereda-Suberbiola, X. (2022). Upper Cretaceous European theropod palaeobiodiversity, palaeobiogeography and the intra-Maastrichtian faunal turnover: new contributions from the Iberian fossil site of Lano. *Papers in Paleontology, 8*(1), e1419. https://doi.org/10.1002/spp2.1419

Larson, D. W., & Currie, P. J. (2013). Multivariate analyses of small theropod dinosaur teeth and implications for paleoecological turnover through time. *PLoS ONE, 8* (1), e54329. https://doi.org/10.1371/journal.pone.0054329

Primm, J. W., Johnson, C. L., & Stearns, M. (2018). Basin-axial progradation of a sediment supply driven distributive fluvial system in the Late Cretaceous southern Utah foreland. *Basin Research, 30*, 249-278.

Theme Session: Global Perspectives on Mesozoic Lacustrine Ecosystems (Thursday, June 8, 2023, 4:30 PM)

ECOSYSTEMS OF THE MOENAVE FORMATION ACROSS THE TRIASSIC–JURASSIC TRANSITION

Milner, Andrew R. C.[1], Harris, Jerald D.[1,2], Kirkland, James I.[3], Lockley, Martin G.[4], Suarez, Celina[5], Sharman, Glenn R.[5], Olsen, Paul E.[6], Buchwitz, Jaleesa C.[1]

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The Moenave Formation of southwestern Utah was long under-studied paleontologically until the discovery of the

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localities at and around the St. George Dinosaur Discovery Site (SGDS) beginning in 2000 that revealed a diverse paleoecosystem. In this area, the Moenave is divided into fluvial deposits of the Dinosaur Canyon Member (DC) and overlying lacustrine beds of the Whitmore Point Member (WP). The DC contains the "End-Triassic Extinction" (ETE) and the Triassic–Jurassic transition (Suarez et al., 2017). The DC in southwestern Utah has thus far produced fossils primarily of both endemic and widespread plants (Tidwell & Ash, 2006) and locally abundant vertebrate tracks from the upper part of the member, including *Grallator, Batrachopus*, rare *Eubrontes*, and *Anomoepus*-like footprints.

In contrast, the WP produces both trace and body fossils of organisms from marginal lacustrine to fully lacustrine settings. The lowermost WP at the SGDS is dominated by vertebrate tracks, especially those of theropods, on multiple track-bearing horizons in a marginal lacustrine setting. Thousands of vertebrate footprints pertaining to the ichnotaxa *Eubrontes*, *Grallator*, *Anomoepus*, *Batrachopus*, and cf. *Brasilichnium* are present, as are fish swim traces (*Undichna* ispp.) and a variety of invertebrate burrows (*Skolithos* isp., *Palaeophycus tubularis*, *Scoyenia* isp.), grazing trails (*Helminthoidichnites tenuis*), and arthropod trackways (*Diplichnites triassicus, Lunulipes* isp., *Siskemia eurypyge*, cf. *Kouphichnium* isp.). Many tracks display exceptional preservation (i.e., skin impressions and traces; Hendrickx et al., 2022). Tracks and trackways at the SGDS sites represent a wide variety of theropod and crocodylomorph behaviors, such as crouching (Milner et al., 2009) and swimming (Milner & Lockley, 2016; Milner et al., 2006), as well as walking, running, limping, and slipping.

Prior to the SGDS discoveries, North American Triassic–Jurassic transition terrestrial fossils were known almost exclusively from the Newark Supergroup of the North American east coast (e.g., Hitchcock, 1858; Olsen, 1980; Olsen et al., 2002, 2004, 2009). The overall similarity of the WP ichnofauna and fauna to those of equivalent Newark

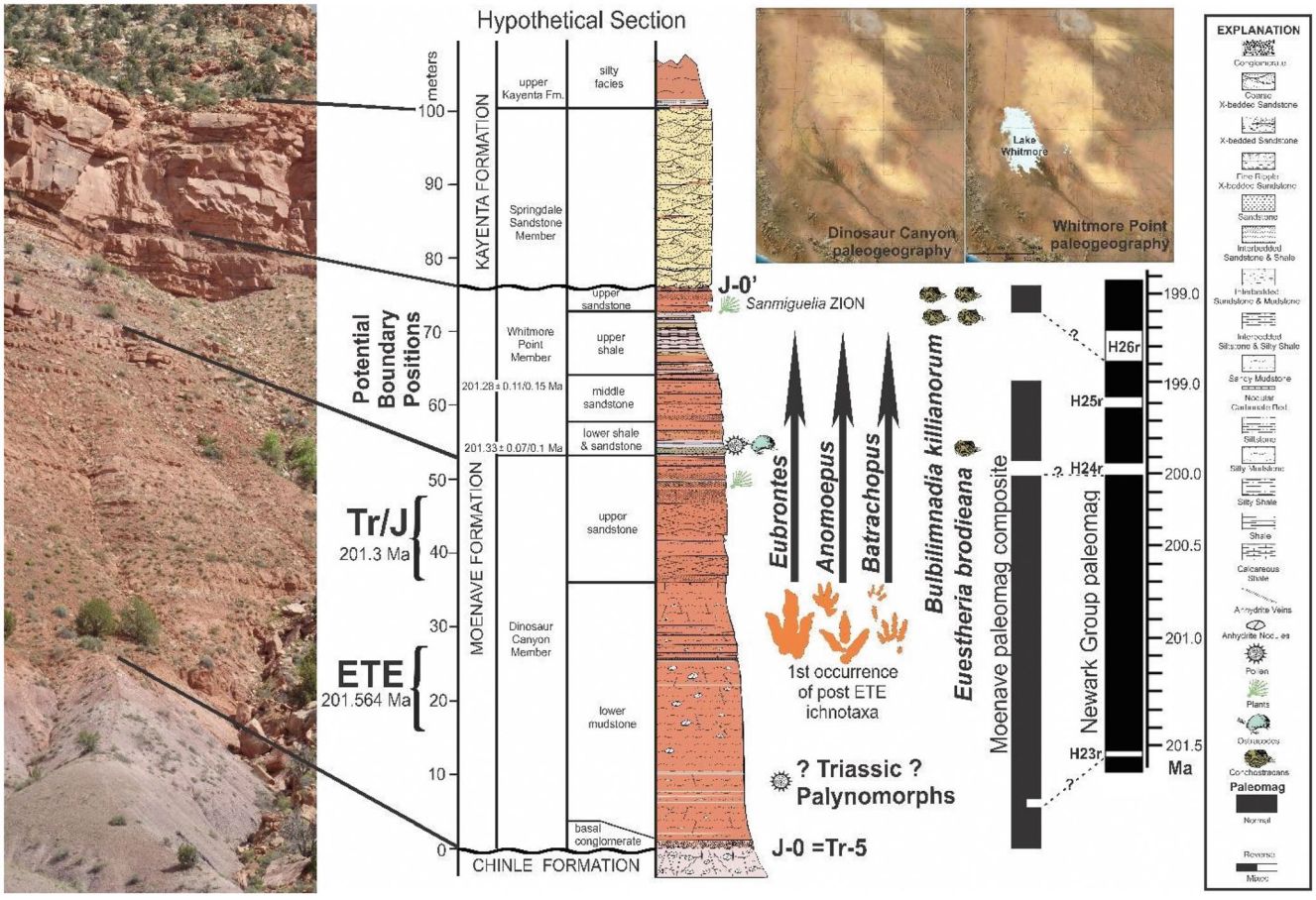


Figure 1. Hypothetical stratigraphic section of the Moenave Formation showing the estimated positions of the ETE and TR-J boundary, first occurrences of post-ETE ichnotaxa and conchostracans in comparison with outcrops at Black Canyon in Zion National Park. Magnetostratigraphic correlation of a Moenave composite section from Donohoo-Hurley et al. (2010) compared with a Newark Supergroup core (Kent & Olsen, 2007) along with modified ages based on Blackburn et al. (2013). Inset paleogeographic maps of the American Southwest during Dinosaur Canyon and Whitmore Point times showing river systems flowing from the southeast toward the northwest, and the estimated extent of Lake Whitmore. Maps courtesy of Ron Blakey (Blakey & Ranney, 2008). Figure modified from Suarez et al. (2017) and Kirkland et al. (2014).

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Supergroup strata strongly suggest a broad-level homogeneity of North American faunas in the earliest Jurassic, as well as roughly synchronous faunal turnover from the latest Triassic. For example, both the Moenave Formation and Newark Supergroup record the absence of characteristic Late Triassic taxa (e.g., phytosaurs, aetosaurs, "rauisuchians") and the appearance of new taxa (e.g., ornithischian and larger theropod dinosaurs), demonstrating that faunal turnover happened geologically more or less simultaneously across the continent. The WP track-making fauna bears much greater similarity to the fauna of the overlying Kayenta Formation in Arizona than it does the underlying, Upper Triassic Chinle Formation.

References

Blackburn, T., Olsen, P. E., Bowring, S. A., McLean, N. M., Kent, D. V., Puffer, J., McHone, G., Rasbury, E. T., & Et-Touhami, M. (2013). Zircon U-Pb geochronology links the end-Triassic extinction with Central Atlantic Magmatic Province. *Science, 340*, 941-945.

Blakey, R., & Ranney, W. (2008). *Ancient landscapes of the Colorado Plateau. Grand Canyon, Arizona*. Grand Canyon Association.

Donohoo-Hurley, L. L., Geissman, J. W., & Lucas, S. G. (2010). Magnetostratigraphy of the uppermost Triassic and lowermost Jurassic Moenave Formation, western United States: correlation with strata in the United Kingdom, Morocco, Turkey, Italy, and eastern United States. *Geological Society of America Bulletin, 122*, 2005-2019.

Hendrickx, C., Bell, P. R., Pittman, M., Milner, A. R. C., Cuesta, E., O'Connor, J., Loewen, M., Currie, P. J., Mateus, O., Kaye, T. G., & Delcourt, R. (2021). Morphology and distribution of scales and other non-feather epidermal structures in non-avialan theropod dinosaurs. *Biological Reviews, 97*, 960-1004.

Hitchcock, E. (1858). *Ichnology of New England – A report on the sandstone of the Connecticut Valley, especially its fossil footmarks*. W. White, Printer of the State.

Kent, D. V., & Olsen, P. E. (2008). Early Jurassic magnetostratigraphy and paleolatitudes from the Hartford continental rift basin (eastern North America): testing for polarity bias and abrupt polar wander in association with the central Atlantic magmatic province. *Journal of Geophysical Research, 113*, 1-24.

Kirkland, J. I., Milner, A. R. C., Olsen, P. E., & Hargrave, J. E. (2014). The Whitmore Point Member of the Moenave Formation in its type area in northern Arizona and its age and correlation with the section in St. George, Utah: evidence for two major lacustrine sequences. *Utah Geological Association, 43*, 321-356.

Milner, A. R. C., & Lockley, M. G. (2016). Dinosaur swimtrack assemblages: Characteristics, contexts and ichnofacies implications. In P. L. Falkingham, D. Marty, & A. Richter (Eds.), *Dinosaur tracks—Next steps* (pp. 152-180). Indiana University Press.

Milner, A. R. C., Lockley, M. G., & Kirkland, J. I. (2006). A large collection of well-preserved theropod dinosaur swim tracks from the Lower Jurassic Moenave Formation, St. George, Utah. *New Mexico Museum of Natural History and Science Bulletin, 37*, 315-328.

Milner, A. R. C., Harris, J. D., Lockley, M. G., Kirkland, J. I., & Matthews, N. A. (2009). Bird-like anatomy and behavior revealed by an Early Jurassic theropod resting trace. *PLoS ONE, 4*, e4591.

Olsen, P. E. (1980). Fossil great lakes of the Newark Supergroup in New Jersey. In W. Manspeizer (Ed.), *New Jersey geology and guide to field trips, 52nd Annual Meeting of the New York Geological Association* (pp. 2-39). Rutgers University.

Olsen, P. E., Kent, D. V., & Whiteside, J. H. (2004). *The Newark Basin, the Central Atlantic Magmatic Province, and the Triassic–Jurassic boundary. 8th Annual DOSECC Workshop on Continental Scientific Drilling Field Trip Guide*. Rutgers University.

Olsen, P. E., Kent, D. V., Sues, H.-D., Koeberl, C., Huber, H., Montanari, A., Rainforth, E. C., Fowell, S. J., Szajna, M. J., & Hartline, B. W. (2009). Ascent of dinosaurs linked to an iridium anomaly at the Triassic–Jurassic boundary. *Science, 296*, 1305-1307.

Olsen, P. E., Koeberl, C., Huber, H., Montanari, A., Fowell, S. J., Et-Touhami, M., & Kent, D. V. (2002). Continental Triassic-Jurassic boundary in central Pangea: Recent progress and discussion of an Ir anomaly. *Geological Society of America Special Paper, 356*, 505-522.

Suarez, C. A., Knobbe, T. K., Crowley, J. L., Kirkland, J. I., & Milner, A. R. C. (2017). A chronostratigraphic assessment of the Moenave Formation, USA using C-isotope chemostratigraphy and detrital zircon geochronology: Implications for the terrestrial end Triassic extinction. *Earth and Planetary Science Letters, 475*, 83-93.

Tidwell, W. D., & Ash, S. R. (2006). Preliminary report on the Early Jurassic flora from the St. George Dinosaur Discovery Site, Utah. *New Mexico Museum of Natural History and Science Bulletin, 37*, 414-420.

Theme Session: Global Perspectives on Mesozoic Lacustrine Ecosystems (Thursday, June 8, 2023, 3:15 PM)

THE MIDDLE–LATE TRIASSIC FLORA FROM THE MADYGEN LAGERSTÄTTE, SW KYRGYZSTAN

Moisan, Philippe[1], Voigt, Sebastian[2], Bomfleur, Benjamin[3], Kerp, Hans[3], Schneider, Jörg W.[4], Fischer, Jan[2], Kogan, Ilja[4]

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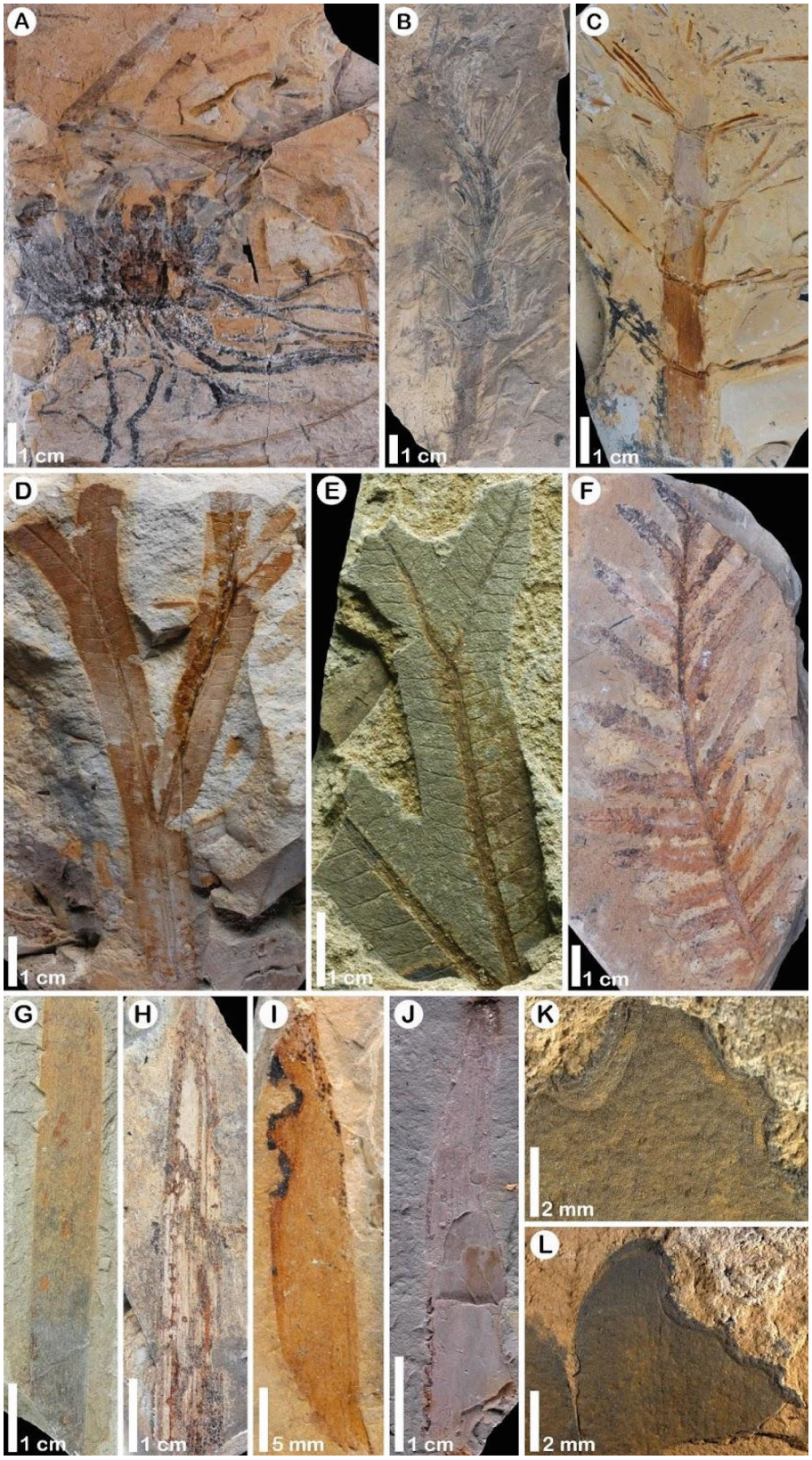


Figure 1. A–C: *Neocalamites* specimens showing the arrangement of the root system and stems with foliar whorls. D–E: Bifurcate fronds of the seed fern *Vittaephyllum*. F: frond of the seed fern *Lepidopteris*. G: Oviposition marks on a *Podozamites* leaf. H: Piercing/sucking on a *Podozamites* leaf. I: Circular marginal feeding excisions on *Podozamites*. J: Cuspate margin excisions on a putative *Desmiophyllum* leaf. K–L: *Ptilozamites* pinnules showing margin feeding excisions.

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The non-marine Middle to Late Triassic (Ladinian–Carnian) Madygen Formation of Kyrgyzstan represents a unique fossil *Lagerstätte* for early Mesozoic insects and small reptiles with exquisite soft-tissue preservation (Voigt et al., 2017). It is one of the few occurrences of continental Triassic deposits in Central Asia and represents one of the world's most famous non-marine Triassic fossil sites.

The Madygen Formation is exposed in several areas between the northern foothills of the Turkestan Mountains and the southern part of the Fergana Valley in southwestern Kyrgyzstan and neighboring areas of Tajikistan and Uzbekistan. The formation consists of a thick succession an up to 560 meters of complexly interbedded conglomerates, sandstones, and siltstones that represent alluvial, fluvial and lacustrine deposits. Biostratigraphic and U-Pb zircon geochronological data indicate a Ladinian–Carnian age (237 $\pm$ 2 Ma). The environmental conditions of the ancient Madygen ecosystem, centered around a large perennial lake, were favorable as indicated by a rich fossil record of water plants, aquatic and non-aquatic invertebrates, freshwater sharks, bony fishes, amphibians, and reptiles (Voigt et al., 2017)

Plant fossils from these deposits are known since the 1930's and constitute one of the richest and most diverse Triassic floras of Eurasia (e.g., Dobruskina, 1995; Moisan et al., 2021). The fossil flora from Madygen is of special interest because it thrived at mid-northern latitudes (35°–40°N) in an intramontane basin, situated within the warm temperate zone. The flora is characterized by its abundance and diversity of vascular plants (sphenopsids, lycopsids, ferns, cycadophytes, ginkgoaleans and conifers) (Figure 1A–F) and non-vascular plants (bryophytes). Of great interest is that the Madygen biota contains several characteristic taxa with a restricted geographic distribution, some of which rare or unknown from coeval paleoecosystems elsewhere, and therefore they appear to be endemic. Another important aspect of the Madygen flora is that many gymnosperm and pteridophyte fossils show evidence for plant-insect interactions, such as traces of margin-feeding, galling, or oviposition (Figure 1G–L). While this phenomenon has been recognized in the Middle and Upper Triassic of the USA, Western Europe, and South Africa, few data have so far become known from coeval Asian sequences.

Although the Madygen biota has been studied for almost a century, new discoveries are still being made. They complement our understanding of the composition and complexity of this exceptional Triassic ecosystem and underscore the importance of further collecting expeditions in order to accurately document the fossil diversity in this famous *Lagerstätte*.

References

Dobruskina, I. A. (1995). Keuper (Triassic) flora from Middle Asia (Madygen, South Fergana). *New Mexico Museum of Natural History and Science Bulletin*, *5*, 1-49.

Moisan, P., Krings, M., Voigt, S., & Kerp, H. (2021). Fossil roots with root nodules from the Madygen Formation (Ladinian–Carnian; Triassic) of Kyrgyzstan. *Geobios*, *64*, 65-75.

Voigt, S., Buchwitz, M., Fischer, J., Kogan, I., Moisan, P., Schneider, J. W., Spindler, F., Brosig, A., Preuße, M., & Scholze, F. (2017). Triassic life in an inland lake basin of the warm temperate biome – the Madygen Lagerstätte (Southwest Kyrgyzstan, Central Asia). In N. C. Fraser & H.-D. Sues (Eds.), *Terrestrial conservation lagerstätten: Windows into the evolution of life on land* (pp. 65-104). Dunedin Academic Press.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 11:15 AM)

EVIDENCE FOR POTENTIAL PISCIVORY IN JURASSIC MEGALOSAUROID THEROPODS

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Most non-coelurosaurian averostran theropods, excluding spinosaurs, have long been thought to retain the plesiomorphic dinosaurian condition of carnivory. However, recent discoveries, such as *Berthasaura* and *Limusaurus*, have shown that different diets – such as herbivory – evolved outside Coelurosauria. Although members of Spinosauridae are known for their piscivory and possess several adaptations for subaqueous feeding and locomotion, their sister clade, Megalosauridae, has generally been considered to include only terrestrial predators. However, increasing evidence suggests that megalosaurids, especially European taxa, had a preference for feeding in mesic and aquatic environments. In addition to reviewing current evidence for a semiaquatic lifestyle in megalosaurids, we present new preliminary data in support of the hypothesis that they had different lifestyles and environmental preferences from other terrestrial theropods (Allain, 2005; Fabbri et al., 2022; Rauhut et al., 2004).

Spinosauridae is a widely distributed clade found at low palaeolatitudes, and its members are best known from mesic continental ecosystems in Europe and Africa during the late Early–Late Cretaceous. The discovery of corroded fish scales within the stomach cavity of *Baryonyx* provided the first widely accepted evidence of semiaquatic behaviour and piscivory among dinosaurs (Charig & Milner, 1986). Subsequent studies on oxygen isotopes from spinosaurid teeth (Amiot et al., 2010), the association of teeth with fish remains, and postcranial bone density and morphology, provided further evidence of sub-aqueous behaviour (Fabbri et al., 2022). By contrast, megalosaurids were most diverse in Europe during the Middle–Late Jurassic, living among insular archipelagos in shallow continental seas. Their remains are often preserved in coastal or marine sediments, where the remains of herbivorous taxa are scarce.

As early as 1838, the megalosaurid *Poekilopleuron* was discovered with fish remains in its stomach, as also noted more recently for *Dubrellisaurus*, with these two discoveries suggesting that piscivory was potentially plesiomorphic for Megalosauroidea, rather than an autapomorphy of Spinosauridae (Allain, 2005). Several other earlier-branching megalosaurids have been discovered in coastal habitats, with little evidence of post-mortem transportation. Coupled with evidence from stomach contents, this suggests that these taxa lived in these environments, similar to how *Spinosaurus* and the titanosaurian sauropod *Paralititan* dwelt in the mangrove swamps of north Africa. A Middle Jurassic site in Portugal shows palaeoethological evidence for megalosaurids crossing a tidal flat and feeding on aquatic fauna, as the unique pattern of footprints present are inconsistent with migrating or milling animals (Razzolini et al., 2016). Also, unlike spinosaurids, the bone density of megalosaurids falls within the range of taxa that could be terrestrial or aquatic (Fabbri et al., 2022). Finally, the megalosaurid *Eustreptospondylus* has been suggested to be piscivorous based on skull morphology (Sadlier et al., 2008).

Megalosaurids and spinosaurids co-existed with other large carnivorous dinosaurs, a phenomenon known as 'Stromer's riddle', as exemplified by localities in the Kem Kem Group and Bahariya Formation of Morocco and Egypt, respectively, where *Spinosaurus* lived alongside carcharodontosaurids and abelisaurids. Several studies have proposed ecological niche partitioning between spinosaurids and these other taxa. Similarly, the Late Jurassic theropods *Allosaurus* and *Torvosaurus* co-existed at several localities, spanning at least two continents, suggesting ecological partitioning, with it being theorised that the former preferred hunting around waterways, and the latter in more open environments (Bakker & Gir, 2004). Rauhut et al. (2004) also proposed niche partitioning, with Allosauroidea preferring more inland habits and megalosaurids more coastal ones.

The dentary and premaxilla of several theropods were scanned using microCT, including taxa with uncontroversial diets, *Majungasaurus* and *Neovenator*, and the megalosauroids, *Spinosaurus, Baryonyx*, and *Megalosaurus*. Using Avizo, we reconstructed the neurovascular canals and compared the extent and complexity of these structures with those published for *Tyrannosaurus* and crocodylians (Bouabdellah et al., 2022). Preliminary reconstructions of the mandibular canals of megalosaurids show that they have more similarities with those of spinosaurids than other terrestrial theropods, suggesting that their senses were more suited to aquatic habitats than other terrestrial theropods. Furthermore, megalosauroids show greater similarities in mandibular canal structures to crocodylians than other terrestrial theropods, suggesting potential ecological adaptations in the sensory use of the lower jaw. There are different complexities and patterns in the premaxillary canals seen among theropod taxa, suggesting different sensory capabilities, with potential implications for hunting and feeding strategies. Quantitative analyses will show if these differences are significant and may provide evidence for the presence or absence of lips within different theropod clades (Bouabdellah et al., 2022). The teeth of *Megalosaurus*, an unnamed spinosaurid from the Kem Kem Group, and *Neovenator* were observed under a Scanning Electron Microscope. Significant microwear differences were noted between the spinosaurid and *Neovenator*, with their different microwear textures supporting diets of piscivory and carnivory, respectively (Bestwick et al., 2019). Preliminary data suggests that megalosaurids were

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plesiomorphically piscivorous due to their morphology, habitats and stomach contents. The diversification of Megalosauridae within the Jurassic European archipelagos might have been driven by their adaptations for piscivory within these marine-influenced environments.

References

Allain, R. (2005). The postcranial anatomy of the megalosaur *Dubreuillosaurus valesdunensis*
(Dinosauria Theropoda) from the Middle Jurassic of Normandy, France. *Journal of Vertebrate Paleontology, 25*(4), 850-858.

Amiot, R., Buffetaut, E., Lécuyer, C., Wang, X., Boudad, L., Ding, Z., Fourel, F., Hutt, S., Martineau, F., Medeiros, M. A., & Mo, J. (2010). Oxygen isotope evidence for semi-aquatic habits among spinosaurid theropods. *Geology, 38*, 139-142.

Bakker, R. T., & Bir, G. (2004). Dinosaur crime scene investigations: theropod behavior at Como Bluff, Wyoming, and the evolution of birdness. In P. J. Currie, E. B. Koppelhus, M. A. Shugar, & J. L. Wright (Eds.), *Feathered dragons: Studies on the transition from dinosaurs to birds* (pp. 301-342). Indiana University Press.

Bestwick, J., Unwin, D. M., & Purnell, M. A. (2019). Dietary differences in archosaur and lepidosaur reptiles revealed by dental microwear textural analysis. *Scientific Reports, 9*(1), 11691.

Bouabdellah, F., Lessner, E., & Benoit, J. (2022). The rostral neurovascular system of *Tyrannosaurus rex*. *Palaeontologia Electronica, 25*(1), 25.1.a3.

Charig, A., & Milner, A. (1986). *Baryonyx*, a remarkable new theropod dinosaur. *Nature, 324*, 359-361.

Fabbri, M., Navalón, G., Benson, R. B., Pol, D., O'Connor, J., Bhullar, B. A., Erickson, G. M., Norell, M., Orkney, A., Lamanna, M. C., Zouhri, S., Becker, J., Emke, A., Sasso, C. D., Bindellini, G., Maganuco, S., Auditore, M., & Ibrahim, I. (2022). Subaqueous foraging among carnivorous dinosaurs. *Nature, 603*(7903), 852-857.

Razzolini, N. L., Oms, O., Castanera, D., Vila, B., Santos, V. F. D., & Galobart, À. (2016). Ichnological evidence of megalosaurid dinosaurs crossing Middle Jurassic tidal flats. *Scientific Reports*, *6*(1), 31494.

Rauhut, O. W., Hübner, T., & Lanser, K. P. (2016). A new megalosaurid theropod dinosaur from the late Middle Jurassic (Callovian) of north-western Germany: Implications for theropod evolution and faunal turnover in the Jurassic. *Palaeontologia Electronica, 19*(2), 19.2.29A.

Sadleir, R., Barrett, P. M., & Powell, H. P. (2006). The anatomy and systematics of *Eustreptospondylus oxoniensis*, a theropod dinosaur from the Middle Jurassic of Oxfordshire, England. *Monographs of the Palaeontographical Society, 160:627*, 1-82.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 8:30 AM)

THE VAST MISSING DIVERSITY OF THE DINOSAUR FOSSIL RECORD

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To make robust inferences about the structure, composition, and dynamics of Mesozoic ecosystems, it is critical to accurately estimate and bound the uncertainty imposed by the incompleteness of the fossil record. Non-avian dinosaurs (hereafter "dinosaurs") are the best-studied and apparently ecologically dominant Mesozoic terrestrial vertebrates, making estimation of their missing diversity of particular importance. Approximately ~1,200 valid dinosaur species are currently described. Prior estimates of total (known and unknown) dinosaur diversity generally have indicated a richness of <4000 total species (Russell, 1995; Starrfelt & Liow, 2016; Wang & Dodson, 2006), with outlier studies implying a total richness of between 10,000 and 20,000 species (Benson, 2018; Le Loeuff, 2012). Without a reliable estimate of the total diversity of any clade in deep time, these values have little context for evaluation of their relative accuracy or reasonability. In place of total diversity, we explore this question in terms of standing diversity, expressed in the units of species per million years, allowing use of the Recent (past 1 million year) diversity of modern amniote clades as an explicit comparator. Expressed in terms of standing diversity, all but one prior estimate of dinosaur diversity equates to a lower standing diversity than that of recent crocodylians – a taxonomically depauperate and ecomorphologically canalized extant clade. For non-avian dinosaurs to have been as diverse as modern clades of equivalent ecomorphological disparity, all prior estimates of their diversity must be one to two orders of magnitude too low. To test that, we simulate total dinosaur diversity based on the observed diversity of Recent amniote clades, recovering a wide envelope of possible diversities, centered on a tight 99% confidence interval that indicates ~2,200 species of dinosaurs lived on Earth at any one time during their heyday in the Jurassic-Cretaceous – and that over 300,000 species existed in total during the Mesozoic. The 1,200 recognized species of dinosaurs therefore equate to less than 0.4% of the species that ever existed. This diversity is asymmetrically distributed in

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time and space, with 20% of the Mesozoic Era containing over 50% of known dinosaur species, and each time interval represented by regional localities rather than a global sample. Even the most productive strata and localities present clear taphonomic bias (Brown et al., 2016, 2021), usually (but not exclusively) favoring the preservation of large taxa. Regression and rarefaction analyses further indicate that the observed diversity of any geological interval is almost purely a function of how many fossil occurrences have been reported, with the unusually rich Campanian stage showing the only vestiges of a slowdown in fossil discovery. The implication of this work is that we remain in the initial phase of dinosaur discovery, with no indication of a deceleration of new species discovery that would be expected if we were beginning to fully sample any geological interval. With few exceptions, the dinosaur fossil record presents a biased and mostly incomplete picture of diversity on local, regional, and global scales. The incompleteness and non-random bias in the fossil record presents clear challenges to most areas of vertebrate paleontology. In short, the axiom 'absence of evidence is not evidence of absence' applies strongly, necessitating a clear emphasis on the use of positive evidence to exclude competing hypotheses. Negative evidence (the absence of a species, clade, or morphotype) should generally be treated as circumstantial unless it is thoroughly vetted, correlated with other apparent patterns, and corrected for potential impacts of taphonomic bias and geographic/temporal gaps in the fossil record. Finally, our results reaffirm the importance of field exploration, collection and preparation of new fossil material, and alpha taxonomic work as essential cornerstones of vertebrate paleontology. Almost 300,000 dinosaur species await discovery, each of which may provide critical new information on dinosaur evolution and systematics, and play a critical role in testing hypotheses regarding the structure and dynamics of Mesozoic terrestrial ecosystems.

References

Benson, R. B. J. (2018). Dinosaur macroevolution and macroecology. *Annual Review of Ecology Evolution and Systematics, 49*, 379-408.

Brown, C. M., Evans, D. C., Campione, N. E., O'Brien, L. J., & Eberth, D. A. (2013). Evidence for taphonomic size bias in the Dinosaur Park Formation (Campanian, Alberta), a model Mesozoic terrestrial alluvial-paralic system. *Palaeogeography, Palaeoclimatology, Palaeoecology, 372*, 108-122.

Brown, C. M., Campione, N. E., Wilson Mantilla, G. P., & Evans, D. C. (2021). Size-driven preservational and macroecological biases in the latest Maastrichtian terrestrial vertebrate assemblages of North America. *Paleobiology, 48*, 210-238.

Le Loeuff, J. (2012). Paleobiogeography and biodiversity of Late Maastrichtian dinosaurs: How
many dinosaur species went extinct at the Cretaceous-Tertiary boundary? *Bulletin de la Société Géologique de France*, *183*, 547-559.

Russell, D. A. (1995). China and the lost worlds of the dinosaur era. *Historical Biology, 10*, 3-12.

Starrfelt, J., & Liow, L. H. (2016). How many dinosaur species were there? Fossil bias and true richness estimated using a Poisson sampling model. *Philosophical Transactions of the Royal Society B, 371*, 20150219

Wang, S. C., & Dodson, P. (2006). Estimating the diversity of dinosaurs. *Proceedings of the National Academy of Sciences, 103*, 13601-13605.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 1:15 PM)

FAUNAL COMPOSITION, DISTRIBUTION, AND PALEOBIOGEOGRAPHY OF FOSSIL VERTEBRATES FROM THE LEWISVILLE FORMATION (WOODBINE GROUP, CENOMANIAN)

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Major temporal and spatial biases characterize the known terrestrial fossil record of North America. The greatest concentrations of documented fossil deposits occur in the Lower Cretaceous Aptian and Albian stages and the Upper Cretaceous Campanian and Maastrichtian stages, separated by a 20-million-year gap from the Cenomanian through Santonian stages (83-100 Ma), an interval that remains largely

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undocumented, though existing collections from strata in this interval provide evidence of major faunal turnover (Jacobs & Winkler, 1998; Zanno & Makovicky, 2013). Until recently, the details of the faunal transition were sparse, with most documented fossils known from sites along the western landmass of Laramidia. In contrast, the faunal assemblage from sites along the eastern landmass of Appalachia remains poorly documented and poorly understood.

The fossil biota recovered from Lewisville Formation exposures in the Dallas-Ft. Worth metroplex (Figure 1) has added substantially to our understanding of a rare Cenomanian Appalachian paleoecosystem. The Lewisville Formation is part of the larger Woodbine Group, which is composed of a series of fluvio-deltaic depositional systems deposited over 1.5 m.y. (Ambrose et al., 2009; Denne et al., 2016). To date at least 40 unique vertebrates have been

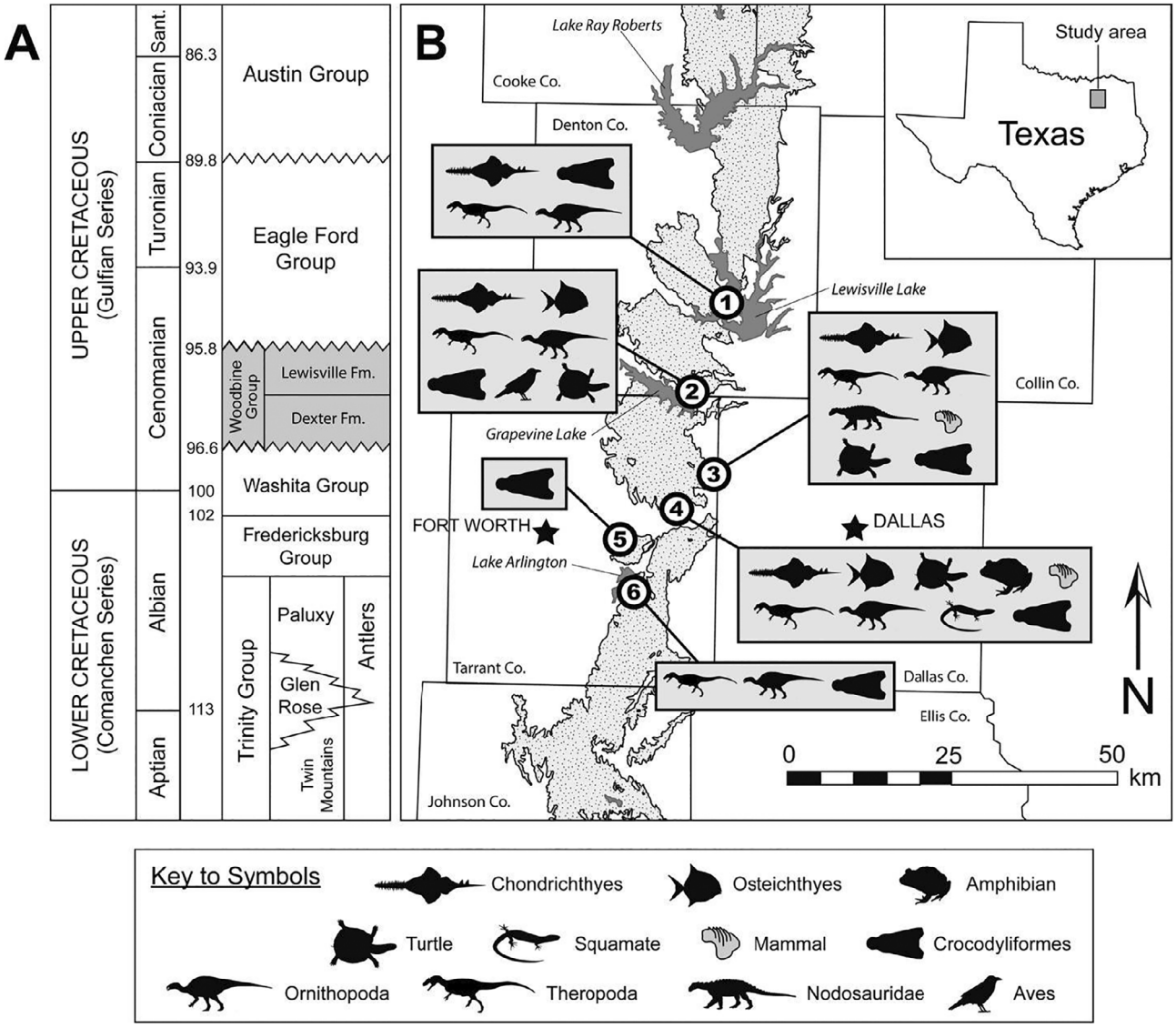


Figure 1. Location and geologic position of the Woodbine Group. A) General stratigraphic sequence and timescale for the Cretaceous strata of central and north central Texas with the Woodbine Group highlighted in gray. Time scale based on Denne et al. (2016). B) Map of Woodbine Group surface exposures in the study area showing position of major fossil localities and distribution of vertebrate groups currently known. Exposures are stippled, water bodies are dark gray. 1= Lewisville Lake localities (including SMU 495), 2= Lake Grapevine localities and Flower Mound locality (SMU 303), 3= Bear Creek (SMU 245), 4= Arlington Archosaur Site, 5= Rush Creek locality (SMU 234), 6= Veteran's Park. Silhouettes courtesy of Phylopic Ornithopoda is "Equijubus" by Pete Buchholz under a CC BY-SA 3.0 license (https://creativecommons.org/licenses/by-sa/3.0/). Chondrichthyes is "Onchopristis" by Tyler Greenfield under a CC BY 3.0 license (https://creativecommons.org/licenses/by/3.0/). Theropoda is "Allosaurus" by Scott Hartman under a CC BY-NC-SA 3.0 license (https://creativecommons.org/licenses/by-nc-sa/3.0/). Crocodyliformes is "Crocodylus falconensis" by Armin Reindl under a CC BY 4.0 license (https://creativecommons.org/licenses/by/4.0/). All other phylopic images are available under CCO 1.0 Universal Public Domain Dedication license. Permalink: phylopic.org/permalinks/194b35d4cfdd8b0afe5bb01359f931c603992bfd4885431462390368778 0b626 [Corrections added after online publication, May 23, 2023: Figure 1 caption has been updated.].

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described from surface collection, quarry excavation, and screenwashing. While there are nine primary localities recognized for producing significant vertebrate material, a majority of these taxa come from a single locality called the Arlington Archosaur Site (AAS). The microvertebrate assemblage includes osteichthyans and chondrichthyans, amphibians, squamates, and multituberculate and metatherian mammals. A diverse turtle fauna has been identified, including new species of baenid and bothremydid, *Naomichelys*, and a medium-sized trionychid. These taxa range from fully aquatic to semi-terrestrial forms and include relict, and novel immigrant and endemic species. The Lewisville baenid represents the latest known member of its family in Appalachia, while *Naomichelys* represents the earliest Late Cretaceous occurrence of Helochelydridae on the subcontinent. The basal bothremydid *Pleurochayah appalachius* is the earliest known crown pleurodiran turtle from North America and Laurasia. The recent identification of the protostegid *Desmatochelys* adds a fully marine component to the Lewisville turtle fauna. Crocodyliforms are both taxonomically and ecologically diverse, including large semi-aquatic generalists like *Deltasuchus*, long-snouted marine-tolerant forms such as *Woodbinesuchus* and *Terminonaris*, and the small durophagous/omnivorous species *Scolomastax*. Dinosaurs, while fragmentary, are well represented. Ornithischians include a nodosaur and the basal hadrosauroid *Protohadros* (Head, 1998; Lee, 1997). *Protohadros* material from the AAS represent an MNI of at least five individuals and includes previously unknown postcrania. Theropods are represented by teeth and scant postcrania including a large carcharodontosaur, a medium-sized tyrannosauroid, an ornithomimosaur, a large dromaeosaurine, a small dromaeosaurid, a small troodontid, and a medium-sized maniraptoran. The enantiornithine *Flexomornis* remains the sole avian currently known (Tykoski & Fiorillo, 2010).

Reconstructing the larger Lewisville paleoecosystem has proved challenging without clearly defined criteria for correlating the many isolated exposures that contain fossil material. Nevertheless, the following relationships and patterns are noted. First, large-bodied taxa appear more widespread across different depositional environments, while smaller taxa are typically confined to single localities. This may represent different habitat preferences and/or taphonomic factors. Second, taxonomic richness is dominated by carnivores (28 taxa), followed by omnivores (9 taxa). Herbivores are currently represented by only two taxa: *Protohadros* and a nodosaurid. *Protohadros* is found across multiple localities with individuals ranging ontogenetically from small juveniles (~1m), to subadults (~3 m), and large adults (~5-6 m). Juveniles and subadults compose the bulk of known material, particularly at the AAS, where they were consumed by *Deltasuchus*. *Protohadros* may have been a common, wide-ranging herbivore, with younger ontogenetic stages filling the smaller herbivore niches and providing abundant fodder for the carnivores. Third, the high carnivore diversity was likely supported by niche partitioning, as seen in the crocodyliforms, who exhibit large disparities in snout shape and body size. Recent work has demonstrated shifts in head shape and tooth morphology throughout ontogeny in *Deltasuchus*, which would have differentiated members of this group from other crocodyliforms in its immediate vicinity throughout life. The body size range in theropods and inferred habitat preferences in the turtles may be a result of similar niche partitioning among these groups.

Though less complete, taxonomic and ecological diversity in the Lewisville Member of the Woodbine Group is comparable to that of the penecontemporaneous Mussentuchit Member of the Cedar Mountain Formation, with multiple taxa shared between the deposits, or with a close sister-taxon relationship. The Lewisville Formation contains the single-most fossiliferous and diverse assemblage to represent the Late Cretaceous of Appalachia. Far from being a depauperate transitional fauna, the Lewisville assemblage demonstrates that the evolution of North American terrestrial communities in the "middle" Cretaceous was a gradual and complex process involving the integration of an older, cosmopolitan fauna with recent immigrants. Multiple taxa, including crocodyliforms, turtles, fish, and dinosaurs, represent clades with origins in Europe, Asia, and Gondwana, although the biogeographic patterns differ between groups, implying complex, clade-specific responses. This complexity is due, at least in part, to two separate large-scale marine transgressions of the epeiric seaway in the late Albian and middle Cenomanian that ultimately separated Laramidia and Appalachia. The Lewisville assemblage therefore represents a distinctive local fauna on the southwestern coast of Appalachia, composed of a mixture of formerly cosmopolitan groups and recent immigrants, with high diversity likely supported by the paleoenvironmental heterogeneity of the vastly complex paralic coastal-to delta plain and shallow shelf ecosystems.

References

Denne, R. A., Breyer, J. A., Kosanke, T. H., Spaw, J. M., Callender, A. D., Hinote, R. E., Kariminia, M., Tur, N., Kita, Z., Lees, J. A., & Rowe, H. (2016). Part 1: Biostratigraphic and geochemical constraints on the stratigraphy and depositional environments of the Eagle Ford and Woodbine Groups of Texas. In J. A. Breyer (Ed.), *The Eagle Ford Shale: A renaissance in U.S. oil production* (pp. 1-86). *American Association of Petroleum Geologists Memoir 110*.

Head, J. J. (1998). A new species of basal hadrosaurid (Dinosauria, Ornithischia) from the Cenomanian of Texas. *Journal of Vertebrate Paleontology, 18*, 718-738.

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Jacobs, L. L., & Winkler, D. A. (1998). Mammals, archosaurs, and the Early to Late Cretaceous transition in north-central Texas. In Y. Tomida, L. J. Flynn, & L. L. Jacobs (Eds.), *Advances in vertebrate paleontology and geochronology* (pp. 253-280). National Science Museum Monographs 14.

Lee, Y.-N. (1997). The Archosauria from the Woodbine Formation (Cenomanian) in Texas. *Journal of Paleontology, 71*, 1147-1156.

Tykoski, R. S., & Fiorillo, A. R. (2010). An enantiornithine bird from the lower middle Cenomanian of Texas. *Journal of Vertebrate Paleontology, 30*, 288-292.

Zanno, L. E., & Makovicky, P. J. (2013). Neovenatorid theropods are apex predators in the Late Cretaceous of North America. *Nature Communications, 4*, 2827.

Technical Session 3: Terrestrial Ecosystems – Late Cretaceous (Saturday, June 10, 2023, 1:30 PM)

DECIPHERING THE WOODBINE GROUP (LATE CRETACEOUS; CENOMANIAN) OUTCROPS OF THE DALLAS–FT. WORTH METROPLEX: NEW DATA AND NEW HORIZONS

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The Woodbine Group of north-central Texas is an important, yet poorly understood sedimentary succession deposited within the elusive "middle" Cretaceous (Cenomanian) interval during a period of major faunal turnover (Zanno & Makovicky, 2013). Until recently the vertebrate fossils recovered from the Woodbine have been frustratingly fragmentary, isolated, and poorly-preserved. This changed with the discovery of the Arlington Archosaur Site (AAS), Lake Grapevine Spillway (LGS), and nearby localities that resulted in the identification of several new taxa. Analyses of these discoveries paint a complex picture of an isolated, endemic ecosystem related to the opening of the Western Interior Seaway (WIS). However, the local stratigraphic framework of the Woodbine, critical for placing these fossil discoveries in context, remains woefully incomplete. This project combines a broad suite of sedimentologic, stratigraphic, palynological, paleobotanical, and geochemical data collected from the AAS, LGS, and nearby localities to systematically document the range of depositional environments represented in Woodbine outcrops of the Dallas area, characterize the paleoenvironmental evolution, and develop a sequence stratigraphic framework.

As proven hydrocarbon producers, Woodbine subsurface deposits in the East Texas field east of the Mexia-Talco fault zone in the East Texas Basin are well documented in abundant drill core and wireline logs (Ambrose et al., 2009; Denne et al., 2016; Hentz et al., 2014). Ambrose et al. (2009) classified the Woodbine as a 3rd order regressive sequence (deposited over 1.5 m.y.) containing numerous embedded 4th order sequences defined by sequence boundaries and flooding surfaces (up to 14 sequences each deposited over ~110 k.y.). Woodbine fluvio-deltaic depositional systems are spatially and temporally variable, with different parts of the regional deposystem occupying different levels in the stratigraphy, reflecting variable sea level during the lowstand, transgressive, and highstand systems tracts (Ambrose et al., 2009; Hentz et al., 2014). However, surface exposures of the Woodbine are relatively understudied and have yet to be compared to results of subsurface studies. Detailed studies of the outcrop exposures at the AAS and LGS between 2015 and 2022 have yielded evidence for depositional environments (Figure 1) that include 1) continental fluvial-distributary channels and associated floodplains (including paleosols) on a distal coastal plain or subaerial delta plain (LGS, AAS), 2) a low-energy freshwater to brackish tidal coastal wetland with intermittent fluvial connections (AAS), 3) subaqueous channels and distributary mouth bars along the subaqueous delta front (LGS), and off-axis finer-grained interdistributary bay and potential backbarrier deposits (LGS, AAS). Paleoenvironmental interpretations are based on typical facies, facies relationships, ichnology (trace fossils), inclusive flora and fauna, stratal architectures, stratigraphic relationships, and stratal stacking pattern. Multiple transgressive/regressive cycles are documented through both changes in sedimentology, ichnofossils, body fossils, and palynomorphs.

A diverse flora is also emerging, representing relatively warm and humid temperate or subtropical conditions. The AAS and LGS preserves a diversity of plant remains, including mats of coalified remains, charcoal fragments, coalified and permineralized wood, impressions/compressions of foliage and reproductive material, and

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microscopic seeds, cuticle fragments, and pollen and spores. Diverse palynomorph assemblages consist of bryophytes, lycophytes, pteridophytes, gymnosperms (primarily conifers and cycads), angiosperms (monocots and dicots), fungal spores, green algae, dinoflagellates, and acritarchs. The AAS palynomorph assemblage is dominated by spores, primarily pteridophytes, followed by gymnosperms, then angiosperms, with an increase in overall abundance and diversity of dicots moving up section. Sections from both sites record rapid shifts in the

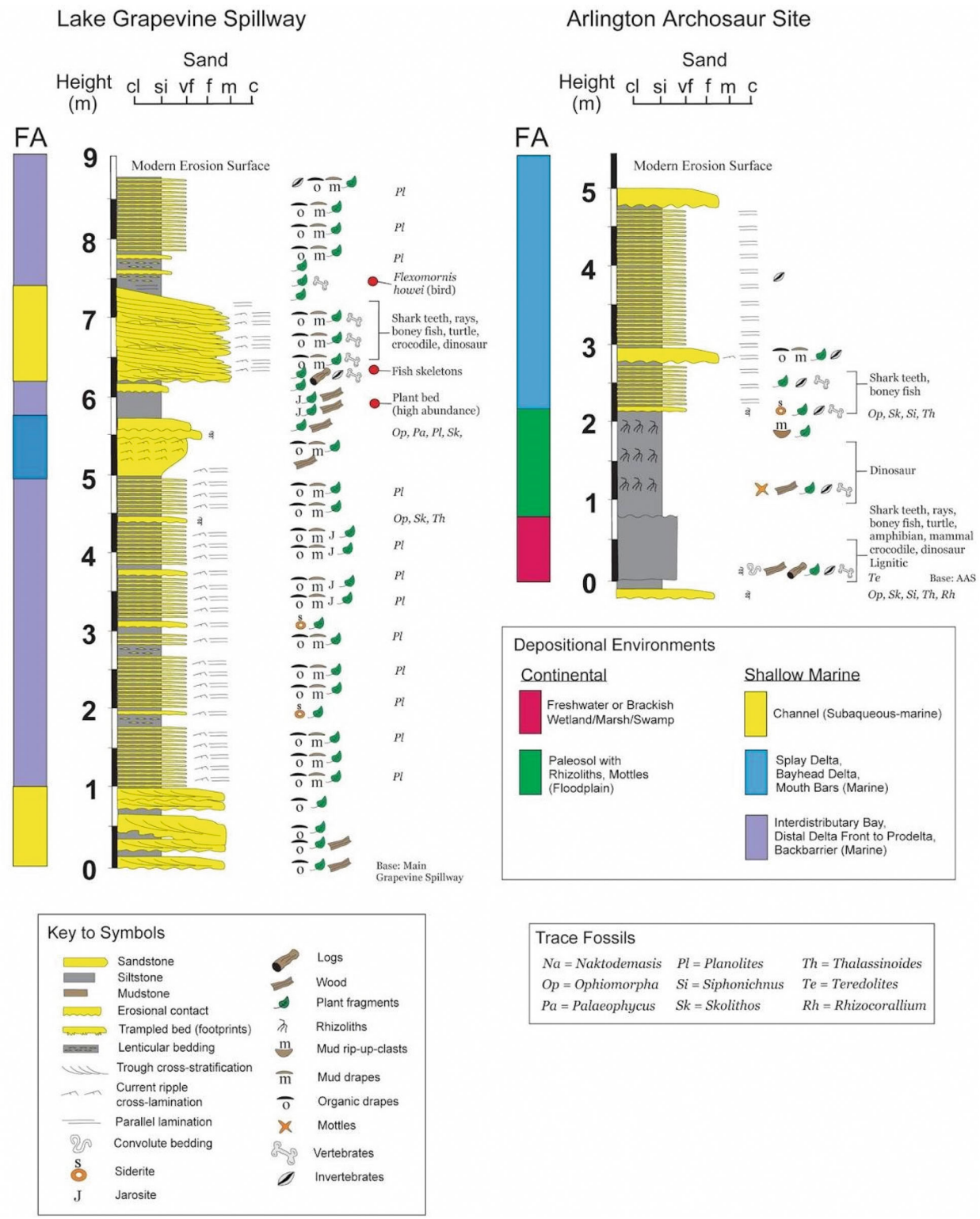


Figure 1. Stratigraphic sections for the Lake Grapevine Spillway and Arlington Archosaur Site including notable fossil distributions, ichnofossils, and paleoenvironmental interpretation.

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proportion of marine dinoflagellates from 2 to 30% and 1 to 25% of individual samples at the AAS and upper LGS, respectively. These shifts document changes in relative sea level and occasional inundation by high tides or storm tides. AAS strata preserve a shift from tidal wetland to splay/bayhead delta, while the upper LGS strata preserve shifts between distal delta plain/delta front and barrier island tidal wetlands. The palynomorph assemblages from both the AAS and upper section of the LGS are consistent with an early to middle Cenomanian age and are typical of similarly-aged associations around the WIS.

Additional climate proxies further support a warm and humid, albeit seasonal, climate. Mineralogical, chemical, and stable isotope proxies yield paleoclimatic conditions at the AAS were warm and humid with mean annual precipitation estimates of 1445 $\pm$ 110 mm/yr and paleotemperature estimates of 26 $\pm$ 3°C. The $\delta^{13}C$ of organic matter sampled at this locality ranges from -26.1 to -22.2‰ indicative of C_3 vegetation which dominated the Cretaceous landscape. The AAS experienced periodic, likely seasonal, dry periods as indicated by slickensides, desiccation cracks, and clastic dikes. Dry seasons were marked by periodic, large-scale wildfires, represented by abundant charcoal fragments and charcoal-rich clastic debris flows at both localities, and *in situ* burned root systems at the AAS.

The picture that emerges from this growing dataset shows that the Woodbine exposures in the Dallas area represent a biologically diverse ecosystem composed of multiple stacked coastal and fluvio-deltaic sequences that record the transition from shallow marine to continental deposits. The warm and humid climate may have varied from temperate to sub-tropical, with a pronounced seasonality, at times supporting periodic and widespread wildfires that likely played a large role in structuring the terrestrial communities of the Lewisville Formation (Brown et al., 2012). Multiple transgressive-regressive cycles are recorded between the AAS and LGS strata, coincident with changes in the relative abundance of marine and terrestrial palynomorphs, potentially providing new avenues for regional correlation of surface exposures. Importantly, this work helps refine the temporal range and stratigraphic sequence of Lewisville Formation outcrops. Finally, this new stratigraphic framework will enable more comprehensive analyses of the temporal and environmental distribution of the vertebrate fossil assemblage.

References

Ambrose, W. A., Hentz, T. F., Bonaffé, F., Loucks, R. G., Brown, L. F. Jr, Wang, F. P., & Potter, E. C. (2009). Sequence stratigraphic controls on complex reservoir architecture of highstand fluvial-dominated deltaic and lowstand valley-fill deposits in the Upper Cretaceous (Cenomanian) Woodbine Group, East Texas field: Regional and local perspectives. *American Association of Petroleum Geologists Bulletin, 93*, 231-269.

Denne, R. A., Breyer, J. A., Kosanke, T. H., Spaw, J. M., Callender, A. D., Hinote, R. E., Kariminia, M., Tur, N., Kita, Z., Lees, J. A., & Rowe, H. (2016). Part 1: Biostratigraphic and geochemical constraints on the stratigraphy and depositional environments of the Eagle Ford and Woodbine Groups of Texas. In J. A. Breyer (Ed.), *The Eagle Ford shale: A renaissance in U.S. oil production* (pp. 1-86). *American Association of Petroleum Geologists Memoir 110*.

Hentz, T. F., Ambrose, W. A., & Smith, D. C. (2014). Eaglebine play of the southwestern East Texas basin: Stratigraphic and depositional framework of the Upper Cretaceous (Cenomanian-Turonian) Woodbine and Eagle Ford Groups. *American Association of Petroleum Geologists Bulletin*, *83*, 2551-2580.

Zanno, L. E., & Makovicky, P. J. (2013). Neovenatorid theropods are apex predators in the Late Cretaceous of North America. *Nature Communications, 4*, 2827.

Poster Session 1 (Thursday, June 8, 2023)

USING SHELL ORNAMENTATION TO DOCUMENT PAN-TRIONYCHID TURTLE DIVERSITY AND DISTRIBUTION ACROSS THE K-PG BOUNDARY

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At the end of the Cretaceous, a bolide impact and its resulting winter caused one of the largest extinctions in Earth's history. Reentry of ejecta may have unleashed an hours-long pulse of infrared radiation that would have ignited the global terrestrial biosphere, essentially cooking all terrestrial organisms too small to seek refuge (Robertson et al., 2013). Computational modeling of paleocommunity dynamics suggests that atmospheric particulate suspension after the impact inhibited photosynthesis for up to 700 days (Roopnarine et al., 2021), and climate modeling suggests that global temperatures dropped below freezing for 3-16 years (Brugger et al., 2016). Despite the devastation, freshwater vertebrate ecosystem recovered quickly; Brownstein and Lyson (2022) recently described a new species of macropredatory gar in sediments deposited just 1.5-2.5 thousand years

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following the extinction event. The brief duration of this biological perturbation, in conjunction with the limited stratigraphic control of museum specimens, limits the extent to which the millennia following the extinction can be studied. Additionally, lithofacies changes at the boundary make it difficult to ascertain if any observed assemblage changes are climatic or taphonomic in nature.

Even so, coarse grouping of specimens into the several million years before and after the extinction (i.e., Maastrichtian vs Danian specimens), yields some broad, macroevolutionary patterns. It is generally agreed that members of Pan-Trionychidae show minimal change across the boundary both in terms of relative abundance and gross anatomy (Holroyd et al., 2014). Large, terrestrial nanhsiungchelyids like *Basilemys* are the only Pan-Trionychid group to definitively go extinct during the K/Pg event, but adocids, carettochelyids, and crown trionychids cross the boundary (Holroyd et al., 2014) with modest gross anatomical adaptations including expansion of the cranitemporal margin, and a dorsoventrally domed shell, with a highly ossified plastron (Lyson et al., 2019), all of which suggest an increase in mammalian predatory selective pressure during the early Paleocene (Lyson et al., 2019).

This study tests if the general consensus of Pan-Trionychid K-Pg survivorship holds true when examining an independently-gathered dataset: fragmentary specimens that were identified using shell ornamental morphology. The highly unique ornamentation on the external surface of the trionychid shell can often be used to identify even fragmentary specimens down to a genus and even species. Some genera, like *Helopanoplia*, *Adocus* and *Basilemys*, are readily identifiable with a high degree of confidence, while distinguishing amongst other closely-related genera like *Aspideretoides*, *Gilmoremys*, and *Atopsemys* can prove more challenging. While *Compsemys victa* is likely a non-Trionychid paracryptodiran, its distinct ornamentation and unique K-Pg survivorship patterns make it a valuable addition to the study group. Over 3,000 photos of fragments were collected across seven institutions, from which over 1,000 specimens were generically identified. These occurrence data, in conjunction with associated locality data like the specimen's geologic age, formation, and latitude, were statistically analyzed in R.

Welch two-sample t-test reveals that *Plastomenus* shows a preference for higher latitudes ($t = -2.8$, $p = 0.003375$) as compared against other Pan-Trionychids, regardless of geologic age. Pearson's chi-squared test demonstrates that there is a significant difference between the assemblage of Maastrichtian and Danian Pan-Trionychids ($X^2 = 98.091$, $p=0.0004998$). Extinction patterns broadly resemble those described by Holroyd et al (2014), where all Pan-Trionychids cross the boundary, with the exception of *Basilemys*. Ornamentation consistent with *Helopanoplia distincta* was identified within 22 deposits of purported Danian age, suggesting that the genus spans the boundary, though finer stratigraphic control is still needed. *Compsemys victa* increases in relative abundance across the boundary, comprising 18.9% of total Danian specimens, as opposed to 8.7% of total Maastrichtian specimens. Danian turtles also show a significant decrease in their latitudinal range ($t = -2.7709$, $p= 0.003375$). Further taphonomic work is needed to determine the extent to which these correlations are driven by climate, as opposed to changes in lithofacies across the boundary.

References

Brownstein, C. D., & Lyson, T. R. (2022). Giant gar from directly above the Cretaceous–Palaeogene boundary suggests healthy freshwater ecosystems existed within thousands of years of the asteroid impact. *Biology Letters, 18* (6), 20220118.

Brugger, J., Feulner, G., & Petri, S. (2017). Baby, it's cold outside: Climate model simulations of the effects of the asteroid impact at the end of the Cretaceous. *Geophysical Research Letters, 44*(1), 419-427.

Holroyd, P. A., Wilson, G. P., & Hutchison, J. H. (2014). Temporal changes within the latest Cretaceous and early Paleogene turtle faunas of northeastern Montana. *Geological Society of America Special Papers, 503*, 299-312.

Lyson, T. R., Miller, I. M., Bercovici, A. D., Weissenburger, K., Fuentes, A. J., Clyde, W. C., Hagadorn, J. W., Butrim, M. J., Johnson, K. R., Fleming, R. F., Barclay, R. S., Maccracken, S. A., Llyod, B., Wilson, G. P., Krause, D. W., & Chester, S. G. B. (2019). Exceptional continental record of biotic recovery after the Cretaceous–Paleogene mass extinction. *Science, 366* (6468), 977-983.

Robertson, D. S., Lewis, W. M., Sheehan, P. M., & Toon, O. B. (2013). K-Pg extinction: Reevaluation of the heat-fire hypothesis. *Journal of Geophysical Research: Biogeosciences 118*(1), 329-336.

Roopnarine, P., Wilson, G., DeMar, D., Angielczyk, K., Brinkman, D., Evans, D., Fowler, D., Holroyd, P., Goodwin, M., & Poust, A. (2021). Extraterrestrial impact overkill: Resistance, resilience, and collapse in an end Cretaceous Paleocommunity of the Hell Creek Formation. *American Geological Union, Fall Meeting Abstracts 2021*, B45P-08.

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Poster Session 3 (Saturday, June 10, 2023)

HAVE YOUR SNAKE AND EAT IT TOO: SNAKE MATERIAL FROM THE ARLINGTON ARCHOSAUR SITE (LEWISVILLE FORMATION, CENOMANIAN) OF NORTH-CENTRAL TEXAS

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The Arlington Archosaur Site (AAS) is a locality within the Lewisville Formation (Woodbine Group) of north-central Texas, outside the city of Dallas. The AAS has produced a rich terrestrial flora and fauna representing a complex coastal deltaic paleoecosystem. This site was located on the southeastern margin of the Western Interior Seaway and is an important representative of the poorly known mid-Cretaceous (Cenomanian) fauna. No other documented Appalachian sites from this time period contain a faunal diversity comparative to the AAS. Specimens described from the AAS to date have mainly consisted of larger vertebrates, including dinosaurs, multiple turtles, and crocodyliforms. In addition to these specimens there is a remarkable microvertebrate fauna currently under study. This project describes snake skeletal material including a dentary and eight isolated vertebrae.

Most of the microvertebrate specimens were recovered through small-scale screenwashing work of mudstone matrix recovered from field jackets collected over the last decade from the AAS. Matrix samples were placed in window screen bags and soaked in water for 24-48 hours, rinsed, and oven-dried at 100°C for 12-24 hours. These samples were sifted through nested geological sieves of 35, 10, and 5 micron mesh. The remaining matrix was analyzed under a dissecting microscope to separate out fossils, no matter their completeness or preservation, and categorize them. The general remains included isolated skeletal elements, mostly less than five millimeters in size, and consist of a wide variety of teeth, vertebrae, small limb elements, and scales. Of the snake elements recovered, all of the vertebrae were collected from screenwashing and six of the eight originated from the same general area while two are separated by at least 10 meters within the same bedding plane. The snake dentary was surface collected from the AAS dig quarry, but exact location information is unknown. Original matrix remains adhered to the external surface of many specimens, obscuring some morphology, but the extremely small size and delicate nature of the specimens precluded further manual preparation.

All snake specimens were μCT scanned at Friday Harbor Laboratories (San Juan Islands, Washington, USA) on a SkyScan 1173 at a 6.0 μm resolution to form 800 slices per scan. Scan image stacks were further processed using 3DSlicer (Federov et al. 2012) on a 2017 Dell Precision 5520. Scans of individual bones were separated and manually segmented by a single individual to digitally remove any sediment and secondary diagenetic minerals. Detailed 3-dimensional models of internal and external morphology were created from the segmented image stacks and used for primary anatomical description.

The right dentary (Figure 1, A1-3) is mostly complete. The dentary measures 12 mm length, 3.6 mm width, and 4 mm height. Snake-life features for the dentary include a bowed shape with a subdental lamina and large, single mental foramen near the anterior tip (Caldwell 2019). There are no teeth in the eight pleurae or replacement teeth visible internally. The μCT of the dentary did reveal a detailed internal neurovasculature. Of the eight vertebrae, five are complete and three are partial with seven precloacal and one caudal. The centra range in length from 3.3 mm – 3.6 mm and can be classified as snake based on the following characteristics: procoelous centra; a low, rounded neural arch with very short spinous process; neural canal with trefoil outline; well-developed zygosphenes and zygantra; and divided synapophyses with separate diapophysis and parapophysis (Figure 1, B1-3 shows typical vertebra) (Caldwell et al., 2021; Klein et al., 2017). Vertebral size yields an estimated total length of 400-600 mm.

Though the dentary and vertebrae cannot currently be attributed to the same taxon, these specimens possess unique combinations of features other than those commonly ascribed to *Coniophis*, and is thus considered distinct from this common form-taxon. These features indicate a more derived position for the AAS snake material, possibly within the crown-group. Ecologically, the greatly reduced neural spines, depressed neural arch, and lack of pachyostosis suggests a terrestrial, likely fossorial, lifestyle that fits well with the diverse mosaic of deltaic environments represented in the Lewisville Formation. Biogeographically, there are a few coeval deposits globally that correspond with the AAS snake including occurrences in the Western United States, Venezuela, Brazil, Argentina, Morocco, Libya, Modern Lebanon and the West Bank (marine species), Bosnia-Herzegovina, France, and Myanmar. The majority of the stem-snake fossil record is Gondwanan, with little Laramidian representation. Cenomanian-age snakes have been recovered from Laramidia, but this occurrence represents the first recorded Cenomanian snake from Appalachia and the first snake material identified within the Lewisville Formation, adding to the diversity of known fossil ophidians

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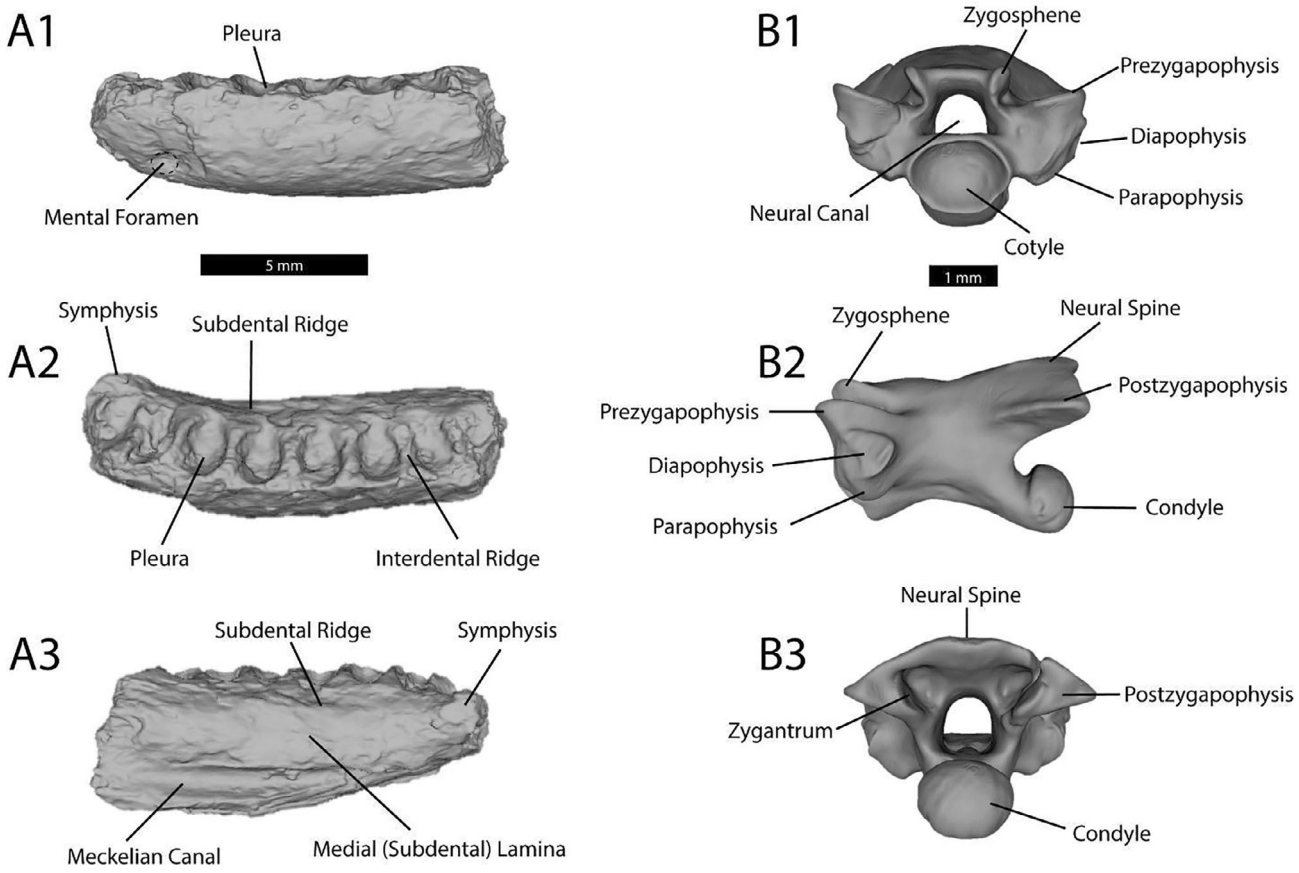


Figure 1. Selected new snake material recovered from the Arlington Archosaur Site. Images represent 3D models reconstructed from microCT scan data in 3DSlicer (Federov et al., 2012). A. Left dentary in lateral (1), occlusal (2), and medial (3) views. B. Pre-cloacal vertebra in cranial (1), left lateral (2), and caudal (3) views.

in North America. Therefore, it can provide a more complete knowledge of taxonomic diversity and biogeographic history within the fragmentary Appalachian fossil record.

References

Caldwell, M. W. (2019). *The origin of snakes: Morphology and the fossil record*. Taylor & Francis.

Caldwell, M. W., Simões, T. R., Palci, A., Garberoglio, F. F., Reisz, R. R., Lee, M. S. Y., & Nydam, R. L. (2021). *Tetrapodophis amplectus* is not a snake: Re-assessment of the osteology, phylogeny and functional morphology of an Early Cretaceous dolichosaurid lizard. *Journal of Systematic Palaeontology, 19*, 893-952.

Fedorov, A., Beichel, R., Kalpathy-Cramer, J., Finet, J., Fillion-Robin, J. C., Pujol, S., Bauer, C., Jennings, D., Fennessy, F., Sonka, M., & Buatti, J. (2012). 3D Slicer as an image computing platform for the Quantitative Imaging Network. *Magnetic Resonance Imaging, 30*, 1323-1341.

Klein, C. G., Longrich, N. R., Ibrahim, N., Zouhri, S., & Martill, D. M. (2017). A new basal snake from the mid-Cretaceous of Morocco. *Cretaceous Research, 72*, 134-141.

Technical Session 2: Paleoecology (Thursday, June 8, 2023, 2:15 PM)

FRESHWATER AQUATIC ECOSYSTEMS OF THE LOWER JURASSIC NAVAJO SANDSTONE, UTAH

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Although the Lower Jurassic Navajo Sandstone (Ss) is commonly cited as the largest sand desert (erg) and an example of a hyperarid desert, water was not absent from the system. Carbonate spring and lake deposits are scattered throughout the formation, particularly in the eastern, and possibly older, part of the erg, which covers

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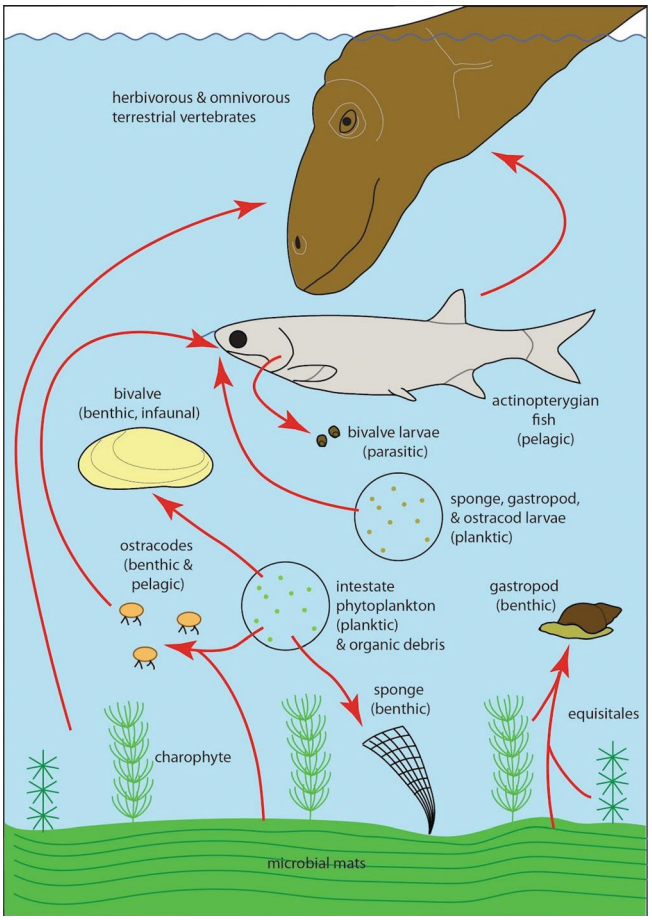


Figure 1. Proposed trophic web for Navajo Ss lakes. Red arrows show the direction of flow of nutrients. Organic debris includes material washed in from lake-margin environments. Illustrations of individual organisms are not to scale.

much of the Colorado Plateau. The lakes, which were fed by high groundwater and/or artesian springs, were shallow and oases for the surprisingly diverse terrestrial life that occupied the desert. The freshwater aquatic environments also contained a moderately diverse fauna and flora.

Primary producers in the aquatic environment were microbial mats, charophytes, and equisitales. Intestate phytoplankton were almost certainly present as well because such resources are nearly universal, but they would not have left a record. Leaves and stems of terrestrial plants are found in the lake-margin deposits, and stumps and logs of conifers are also common. Although these lake-margin plants were terrestrial, they almost certainly contributed organic debris to the aquatic environment and, thus, could have been an additional source of nutrients.

The aquatic fauna consisted principally of ostracodes (likely *Darwinula* sp.), which are abundant in many of the lake and spring carbonates, as well as less-common unionid bivalves, gastropods, and actinopterygian fish; a freshwater sponge was also tentatively identified in one sample. The fauna indicates that the water was generally fresh and cool and that the springs, therefore, were neither hot nor very saline.

The trophic structure of the freshwater aquatic ecosystem can be reconstructed by noting the ecologic roles of the individual organisms. Unionid bivalves were infaunal filter-feeders; they likely lived just below the sediment-water interface because modern ones have very short siphons. Gastropods were epifaunal organisms that fed on algae or detritus by grazing, whereas some may have been filter feeders, carnivores (e.g., feeding on mesoscale crustaceans), or omnivores. Ostracodes have a wide variety of life habits, from filter-feeding to carnivory, and even modern ones are so poorly studied that speculation on the habit(s) of the ones found in the Navajo Ss is impossible, but ostracodes can be consumed by filter feeders, so they were likely a food source for the bivalves and, possibly, the fish. Modern actinopterygian fish host unionid bivalve larvae, which are obligate parasites on the fish gills. Sponges are also filter feeders.

Trace-fossil evidence of dinosaurs (therapod, prosauropod), therapsids (and/or mammals) associated with ponds and lakes indicate that terrestrial vertebrates might have played a role in aquatic trophic structure as top predator. Didactyl and tridactyl scrape-mark traces of small quadrupedal or bipedal vertebrates in pond deposits suggest they actively swam in these water bodies, and may have fed on any fish that could have been present. Therapod tracks assignable to *Eubrontes* and prosauropod tracks assignable to *Otozoum* record the presence of these organisms along the margins and possibly in the shallow waters of larger carbonate lakes, where they fed on fish and plants, respectively.Because of the modest diversity of the biota, the trophic structure of the aquatic ecosystem in the Navajo Ss was relatively simple and is proposed in Figure 1.

Poster Session 1 (Thursday, June 8, 2023)

PALEOECOLOGY AND BIOFACIES OF THE LOWER JURASSIC NAVAJO SANDSTONE

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The Lower Jurassic Navajo Sandstone (Ss) represents the largest sand desert in Earth history. Although the scale and distribution of sand dunes that make up the bulk of the Navajo Ss suggest a very dry climate, in fact, the Navajo Ss has evidence of surface water, abundant groundwater in the form of lakes and springs, and large-scale soft-sediment deformation (SSD). The water provided favorable conditions for plant and animal growth. Most of the diversity of the Navajo Ss is expressed as trace fossils, including root traces and tetrapods, as well as a diverse fauna of arthropods. Macroscopic fossils also consist of leaves, stems, and wood.

We defined 6 biofacies in the Navajo Ss in southeastern Utah. Biofacies were constructed based on the co-occurrence of trace and body fossil assemblages, their taphonomic preservation, and lithofacies associations. We prefer the term "biofacies" rather than "communities" because the latter implies ecological relationships that may not be determined from the paleontologic record.

Biofacies I: Rhizoliths on lamina-deviation, bed-deviation, or bedset-deviation surfaces and on bedding planes in eolian sandstone; rhizoliths rare to few, shallow (<20 cm in depth), with few branches, indicating small, herbaceous, widely spaced plants; animal traces rare, and include *Cylindricum* and *Skolithos*, representing transient use by arthropods for shelter or as dwelling structures used for ambush predation; vertebrate tracks rare and reflect transit across the dunes between water sources. This biofacies occurs in the environments of shifting sands, which, in addition to the lack of water, prevented more extensive colonization, accounting for the sparsity of fossils and the very weak pedogenesis.

Biofacies II: Common to abundant rhizohaloes in pedogenically modified interdune deposits, small to large herbaceous plants more closely spaced than in Biofacies I; animal traces include *Naktodemasis* and *Planolites*, likely detritophagous feeding of larvae and nymphs; pedogenesis weak to moderate. The environment for Biofacies II is more stable because sedimentation rates are slower than in the environments where Biofacies I occurs.

Biofacies III: Few, widely spaced rhizoliths, representing herbs, small shrubs, in red to tan, planar-bedded interdune deposits, including playa deposits; animal traces common and include *Skolithos*, *Celliforma*, *Fictovichnus*, *Beaconites*, and *Planolites*, representing transient shelter burrows, ambush predation burrows, or temporary burrows used for reproduction; vertebrate tracks also found. Faster sedimentation rates resulted in weaker pedogenesis compared to Biofacies II. Runoff from adjacent dunes and intermittent rainfall were the likely sources of water.

Biofacies IV: Herbs, small shrubs, or trees represented by rhizocretions and rhizoliths along complex or, rarely, composite surfaces, small rhizohaloes; diverse flora of stems of cycadeoids, leaves, stumps; animal traces include *Naktodemasis*, *Maconopsis*, *Beaconites, Scoyenia, Entradaichnus*, *Termitichnus*,and *Planolites*, representing a wide variety of habits, including detritophagy, herbivory, and carnivory, and behaviors such as ambush predation, sheltering, reproduction, and so on; large-diameter vertebrate burrows; moderate to strong pedogenesis. This biofacies is found in conterminous fluvial, clastic-rich lake-margins, and stabilized eolian environments.

Biofacies V: Rhizomats, vertebrate tracks, and/or rare invertebrates on the tops of lacustrine carbonate beds where the tops are preserved; uncommon leaves, cones, cone scales, and stems of equisitales or other aquatic or semi-aquatic plants; animal traces surficial; pedogenesis very weak. These represent intervals of subaerial exposure of lake sediments.

Biofacies VI: Fish, freshwater invertebrates, and freshwater plants, as well as microbial mats; very rare vertebrate tracks; invertebrate tracks limited to *Saggittichnus*. This biofacies is aquatic, occurring in springs and lakes.

Overall, the landscape of the Navajo Ss was a mosaic of environments consisting of large sand dunes and their various components, areas between the dunes that might be dry or wet, interspersed with wetter environments, including wet interdunes, ephemeral ponds, lakes, springs, and ephemeral fluvial environments. The more persistent wet environments were oases for most animals and plants, some lasting long enough to allow the growth of trees. The nature of the mosaic changed through time as a result of climatic fluctuations and the resulting changes in the amount and sources of water.

Poster Session 2 associated with the Theme Session: Global Perspectives on Mesozoic Lacustrine Ecosystems (Thursday, June 8, 2023)

PLANT PRESERVATION IN LAKES FROM TRIASSIC BASINS OF ARGENTINA

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Lake systems represent unique systems that allow the preservation of plant remains with particular characteristics in each sub-environment (Behrensmeyer & Hook, 1992). Variations of plant assemblages in different subenvironments depend on the taxonomic composition of contributing plant communities and the dominant sedimentary processes of each subenvironment (Pedernera et al., 2021). Considering the proposal of lake basin types by Bohacs et al. (2000), in which each category (i.e., overfilled, balanced-fill, and underfilled lake basin type) presents characteristic sub-environments and processes it is expected that plant associations and their preservation present differences. We compare and discuss plant richness and possible taphonomic biases in four different lakes based on a review of the literature.

The Cuyana and Ischigualasto-Villa Unión basins are the most extensive Triassic rift basins from Argentina. In both basins, there are lacustrine sequences assigned to each different category of lake basin type. In the Cuyana Basin, the Agua de la Zorra and Cacheuta Formations (Upper Triassic) have been described as overfilled lakes, the Cerro de las Cabras Formation (Middle Triassic) as underfilled, and Santa Clara Abajo Formation (Middle Triassic) as balanced fill lake (Benavente et al., 2020, 2021; Pedernera et al., 2021). On the other hand, the Los Rastros Formation (Upper Triassic, Ischigualasto-Villa Unión Basin) has been described as an overfilled lake (Mancuso & Caselli, 2012).

The plant occurrence data was taken from Pedernera et al. (2022 and references in there). Rarefaction analysis was performed using the software Paleontological Statistics (PAST 4.02) (Hammer et al., 2001). The analyses were performed using the number of taxa at species level, and the number of genera per stage and indeterminate taxa were not included (Pardoe et al., 2021).

The highest richness was found in the overfilled lake basin type. The Los Rastros presented the highest number of species, followed by Cacheuta, and Agua de la Zorra. In the Santa Clara Abajo balanced-fill lake only one species was recorded. Finally, the underfilled Cerro de las Cabras had a similar richness to Agua de la Zorra. Rarefaction curves (Figure 1), indicate the Los Rastros and Cacheuta paleofloras are well represented. The Agua de la Zorra and Cerro de las Cabras curves suggest their paleofloras could be more diverse. In the case of Santa Clara Abajo, lower diversity seems to be a sampling bias issue.

In the three overfilled lakes previous taphonomic studies indicate that differences in the taphonomic processes are related to other factors, such as lake size and disturbance events like volcanic activity (Pedernera et al., 2021) rather than ecological differences. The similar richness observed in the overfilled Agua de la Zorra and underfilled Cerro de las Cabras paleolakes could indicate there is no relationship between lake basin type and diversity; however, a more detailed sampling in Santa Clara Abajo is required, and further studies of underfilled taphonomic lake-type basins.

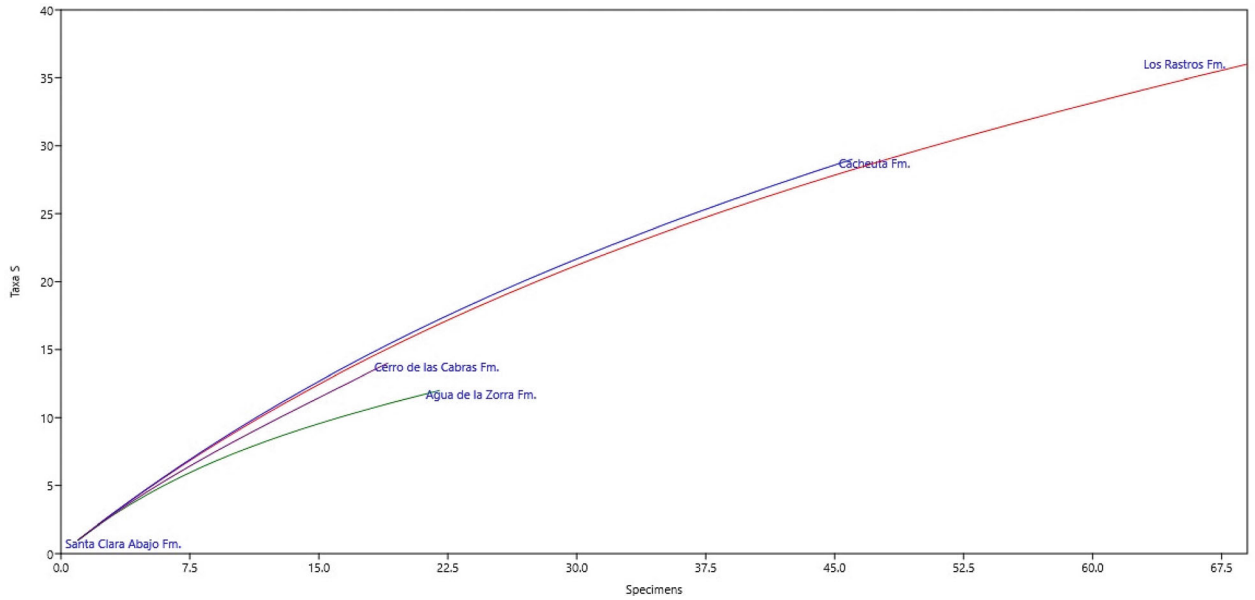


Figure 1. Plant rarefaction curves for the lake basin types from the Cuyana and Ischigualasto-Villa Unión basins.

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References

Behrensmeyer, A. K., & Hook, R. W. (1992). Paleoenvironmental contexts and taphonomic modes in the terrestrial fossil record. In A. K. Behrensmeyer, J. D. Damuth, W. A. DiMichele, R. Potts, H. D. Sues, & S. L. Wing (Eds.), *The evolutionary paleoecology of terrestrial plants and animals* (pp. 15-136). University of Chicago Press.

Benavente, C. A., Mancuso, A. C., & Bohacs, K. M. (2021). Chapter 14, Reconstructing paleoenvironmental conditions through integration of paleogeography, stratigraphy, sedimentology, mineralogy, and stable isotope data of lacustrine carbonates—an example from early Middle Triassic strata of southwest Gondwana, Cuyana Rift, Argentina. In M. R. Rosen, L. Park-Bousch & D. B. Finkelstein (Eds.), *Limnogeology: Progress, challenges and opportunities: A tribute to Beth Gierlowski-Kordesch* (pp. 471-509). Springer.

Bohacs, K. M., Carroll, A. R., Neal, J. E., & Mankiewicz, P. J. (2000). Lake-basin type, source potential, and hydrocarbon character: an integrated sequence-stratigraphic-geochemical framework. In E. H. Gierlowski-Kordesch & K. R. Kelts (Eds.), *Lake basins through space and time. American Association of Petroleum Geologists Studies in Geology, 46*, 3-34.

Hammer, Ø., Harper, D. A., & Ryan, P. D. (2001). PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica, 4*(1), 9.

Mancuso, A. C., & Caselli, A. T. (2012). Paleolimnology evolution in rift basins: The Ischigualasto–Villa Unión Basin (central-western Argentina) during the Triassic. *Sedimentary Geology, 275*, 38-54.

Pardoe, H. S., Cleal, C. J., Berry, C. M., Cascales-Miñana, B., Davis, B. A., Diez, J. B., Filipova-Marinova, M. V., Giesecke, T., Hilton, J., Ivanov, D., Kustatscher, E., Leroy, S. A. G., McElwain, J. C., Opluštil, S., Popa, M. E., Seyfullah, L. J., Stoll, E., Thomas, B. A., & Uhl, D. (2021). Palaeobotanical experiences of plant diversity in deep time. 2: How to measure and analyse past plant biodiversity. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *580*, 110618.

Pedernera, T. E., Mancuso, A. C., & Ottone, E. G. (2022). Triassic paleoclimate and paleofloristic trends of southwestern Gondwana (Argentina). *Journal of South American Earth Sciences, 116*, 103852.

Pedernera, T. E., Ottone, E. G., Mancuso, A. C., Erra, G., Larriestra, F., Benavente, C. A., Pineda Alvarez, J. A., Campos, C., Bustos-Escalona, E. L., Krapovickas, V., & Marsicano, C. A. (2021). A multiproxy analysis of the Triassic Agua de la Zorra Formation, Cuyana Basin, Argentina: palynofacies, geochemistry, and biotic record. *Journal of South American Earth Sciences*, *110*, 103374.

Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 5:25 PM)

REAPPRAISAL OF *XENOXYLON MORRISONENSE* LEADS TO RECOGNITION OF A NEW FOSSIL WOOD GENUS IN THE MORRISON FORMATION

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The fossil wood *Xenoxylon morrisonense* was described by Medlyn and Tidwell (1975). Its assignment to the genus *Xenoxylon* was questioned by Müller-Stoll and Schultze-Motel (1988:67), then by Philippe and Thévenard (1996:357). Despite these reservations, Medlyn and Tidwell (1998) still listed *X. morrisonense* as the most abundant fossil wood in the Morrison Formation. The type specimen of *X. morrisonense* is here reevaluated with two new specimens originating from the same area and stratum. The wood xylology is distinct and does not fit any fossil wood genera yet described. Therefore, a new genus will be proposed.

1 LOCATION

Fossil wood localities OPC2496 and OPC2501, southeastern UT, 16.41 km northeast of Ticaboo, UT, 11 km northeast of the *X. morrisonense* site; Morrison Formation, lower Brushy Basin Member.

2 SYSTEMATIC TREATMENT

Xenoxylon morrisonense Medlyn, DA and Tidwell, WD. 1975. Amer. J. Bot. 62:203, figs. 1–10. Holotype: Specimen BYU 926, Brigham Young University, Provo, UT; three slides.

3 DESCRIPTION OF THE HOLOTYPE OF *XENOXYLON MORRISONENSE*

1. A tracheidoxyl with complete and asymmetrical "D" and "E" growth rings present. The transition from the early to the latewood is abrupt, with a width of 3–5 cells. False rings were not observed. Numerous intercellular

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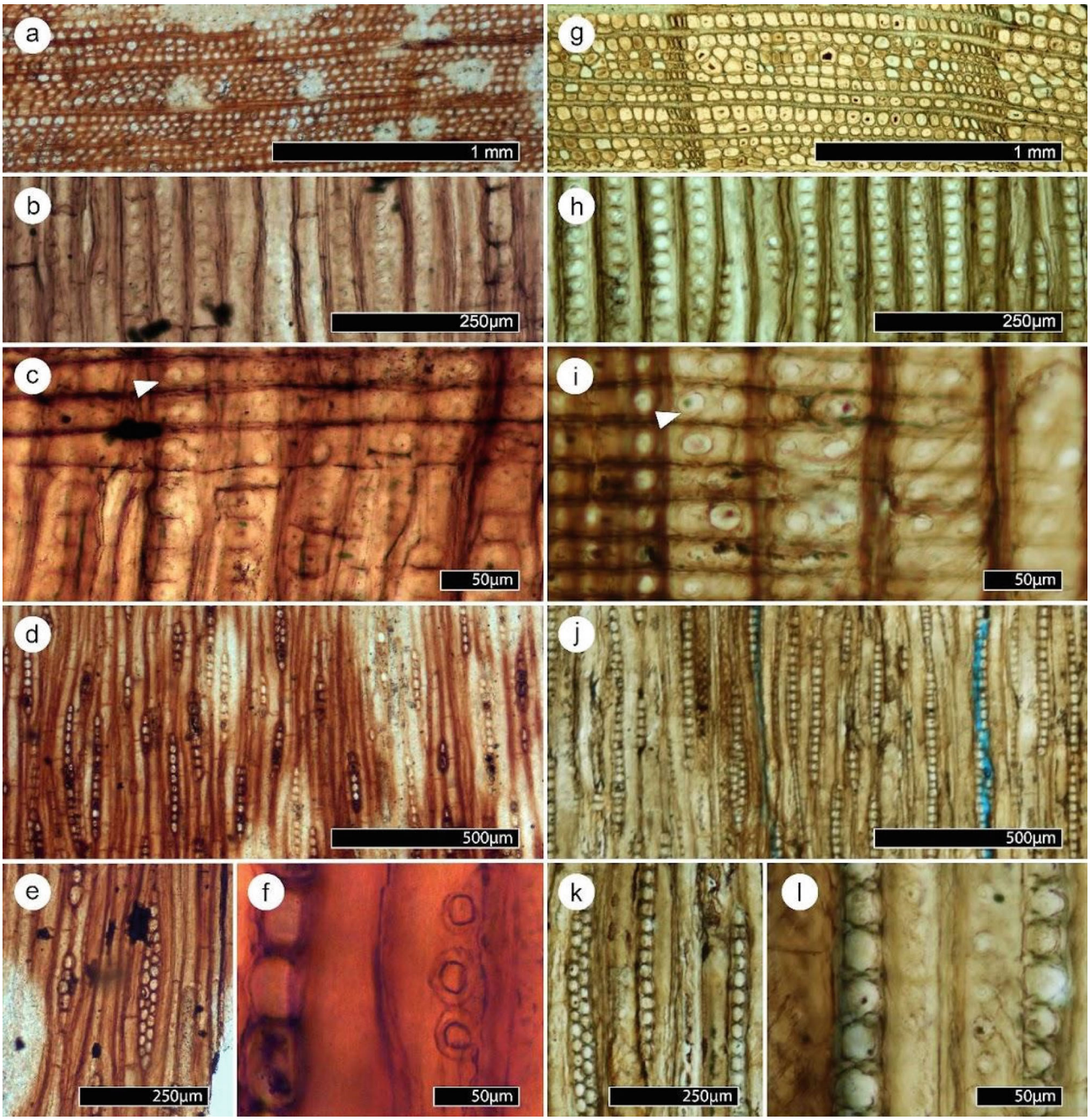


Figure 1. (a-f) *Xenoxylon morrisonense* Medlyn and Tidwell, holotype, BYU926. (a) growth ring; transverse section. (b) areolate intertracheary pits, note septae, radial section. (c) circopores (1 or 2 [at arrow]) in crossfields; radial section. (d) parenchymatous rays; tangential section. (e) close-up of a mostly biseriate ray; note septae; tangential section. (f) areolate intertracheary pits; tangential section. OPC2496 (g-l), (g) growth rings; transverse section. (h) areolate intertracheary pits, note septae, radial section. (i) circopores (1 or 2 [at arrow]) in crossfields, note growth ring marked by latewood (left)/earlywood (right) transition, radial section. (j) parenchymatous rays, note sparse septae, tangential section. (k) close-up of a biseriate ray; tangential section. (l) areolate intertracheary pits; tangential section.

spaces are likely due to lamellar dissolution from a fungal attack. The tracheids are opposite or alternate to their tangential neighbors. Rays are homogenous and homocellular, uniseriate, and locally biseriate. Rays are 2 to 38 cells high (average 14). There are no intercellular spaces between the ray cells.

2. Axial tracheids are polygonal but appear rounded from fungal and bacterial decay. The earlywood tracheid wall is noticeably thin relative to the lumen. The latewood walls are thicker and comprise one-fifth of the tracheid diameter. Intertracheary areolated pits on the radial wall are obround in long contiguous rows occupying the

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whole tracheid width; they are primarily uniseriate. However, intertracheary areolated pits can be biseriate locally, where they alternate and imbricate. Numerous septae are present. Sanio's rims, intertracheary pits on the tracheid tangential walls, tertiary thickenings, or other cell wall ornamentations were not observed.

3. Ray parenchyma cells in cross-section are rectangular and slightly rounded due to microbial decay. Transverse walls are poorly preserved, perpendicular, thin and unpitted. The axial walls are thin and only pitted in the crossfields. Earlywood crossfield pits are narrowly bordered circopores (possibly from microbial attack). Early crossfields usually comprise a single pit or rarely paired pits. The pits do not fill the crossfield. Latewood crossfield contains a single oopore that usually occupies most of the crossfield.

4. Ray tracheids, resin canals, axial parenchyma, and idioblasts were not observed.

4 DESCRIPTION OF THE NEW MATERIAL

Fossil wood specimens OPC2496 and OPC2501 are similar to the *X. morrisonense* type specimen. The specimens were also intensely attacked by microbes (bacteria and fungi). OPC2496 features septae; however, these are thinner than the *X. morrisonense* type. Its rays are 3 to 52 cells high (average 16). A sub-fusiform ray was observed, 21 cells high and biseriate on 19 levels. Enlarged crossfields pores may be from microbial wood. OPC2501 features thick septae. The rays are shorter, ranging from 2 to 40 cells high (average 8), and more densely distributed. Tangential intertracheary pits are locally present and are small, round, and distant. The new fossil wood has araucarian radial intertracheary pitting with its crossfields featuring one/two small circopore(s) per field. This fossil wood does match any description from Philippe and Bamford's (2008) taxonomical classification proposed for Mesozoic tracheidoxyls.

The rounded and spaced intertracheary pits suggest the radial pitting could be considered a mixed type indicative of the fossil wood *Primopodocarpoxylon* Süß et Schultka (Philippe & Bamford, 2008). However, the illustration by Süß and Schultka (2006) shows araucarian radial intertracheary pitting and araucarioid crossfields. Therefore, our wood should not be assigned to this genus.

Protocircoporoxylon Vogellehner (e.g., Ding et al., 2010; Zamuner & Artabe, 1994) is similar to the wood described above. However, the original identification of this genus is rather vague about the circopore size. The type specimen displays large rectangular pits occupying almost the entire earlywood crossfield (Walton, 1925, pl. III Figure 18; Vogellehner, 1968). Consequently, the genus *Protocircoporoxylon* Vogellehner is a taxonomic synonym of *Protophyllocladoxylon* Kräusel (Marguerier, 1977). *Protophyllocladoxylon* has pointed and oblique oopores in the earlywood crossfields (Philippe & Bamford, 2008; Zijlstra & Philippe, 2020). As a result, the studied fossil wood does not belong to *Protophyllocladoxylon*.

Vogellehner's (1968) description of *Protopolyporoxylon* states, "Radial intertracheary pitting araucarian or of the mixed type; crossfield pits (1) 2 (4), rarely more, small to medium-sized, usually round to oval oopores with horizontal, rarely somewhat oblique, long axis; other radial parenchyma cell walls unpitted, axial parenchyma missing" (our German translation). This description fits well with the studied wood; however, the genus type has numerous taxonomical problems and should not be used.

5 *MORRISONOXYLON* PHILIPPE ET AL.

Description: Tracheidoxyls with araucarian radial intertracheary pitting; earlywood crossfields with one/two small circopore to dacrydioid oopore(s); paired crossfield pits are distant. Axial parenchyma, resin canals, and ray tracheids were not observed. Type: *Morrisonoxylon morrisonense* (Medlyn DA and Tidwell WD) nov. comb., BYU 926, basionym *Xenoxylon morrisonense*.

6 RELATED MATERIAL

Two *Protocircoporoxylon* were described from the Triassic of Argentina, *P. cortaderitaense* (Menendez) Vogellehner and *P. marianaense* ('*marianaensis*') Zamuner and Artabe (1994). According to the limited evidence of the type specimens, these genera have larger oopore(s) in earlywood crossfields, occupying more of the crossfield.

Ding et al. (2011) described *Protocircoporoxylon mongolense*. Despite having shorter rays, this fossil wood is strikingly similar to that described here (see op. cit. pl. VI). Ding et al. (2011) also described *Circoporoxylon mongolense*. From published descriptions, these two Chinese fossil woods, especially the first, belong to this new genus. The fossil woods were previously described and illustrated by Ding et al. (2010), but they were described in Chinese, so they were not validly published at this time. The fossil wood locality is east of Dalanzadgad, a capital city in southeastern Mongolia. Fossil woods associated with the newly described specimens belong to the genera *Protaxodioxylon* Bamford and Philippe, *Protocedroxylon* Gothan, and *Xenoxylon* Gothan suggesting a high-latitude boreal forest for *Morrisonoxylon*.

References

Ding, Q., Fu, X., Li, Y., & Zhang, W. (2010). Late Mesozoic wood fossils from southeastern Mongolia. *Global Geology*, *29*, 527-536.

Ding, Q., Fu, X., Li, Y., & Zhang, W. (2011). New species of late Mesozoic wood fossils from

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

southeastern Mongolia. *Global Geology*, *14*, 59-66.
Gothan, W. (1905). Zur Anatomie lebender und fossiler Gymnospermen-Hölzer. *Abhandlungen der Königlich Preussischen Geologischen Landesanstalt, 44*, 1-108.
Marguerier, J. (1977). Sur la ponctuation simple dans les champs de croisement de quelques
structures Paléozoïques et mésozoïques. Act 102^{o} Cong nat soc sav:79-97.
Medlyn, D. A., & Tidwell, W. D. (1975). Conifer wood from the Upper Jurassic of UT. I *Xenoxylon morrisonense* nov. spec. *American Journal of Botany, 62*, 203-208.
Medlyn, D. A., & Tidwell, W. D. (1998). Petrified material related to the conifers from the Upper Jurassic Morrison Formation in the Western USA. *Mid-Continent Palaeobotanical Colloquium Abstracts*.
Müller-Stoll, W. R., & Schultze-Motel, J. (1988). Gymnospermen-Hölzer des Deutschen Jura.
Zeitschrift der Deutschen Geologischen Gesellschaft, 139, 63-81.
Philippe, M., & Bamford, M. K. (2008). A key to morphogenera used for Mesozoic conifer-like woods. *Review of Palaeobotany and Palynology, 148*, 184-207.
Philippe, M., Barbacka, M., Gradinaru, E., Iamandei, E., Iamandei, S., Kázmér, M., Popa, M., Szakmány, G., Tchoumatchenco, P., & Zatoń, M. (2006). Fossil wood and Mid-Eastern Europe terrestrial palaeobiogeography during the Jurassic-Early Cretaceous interval. *Review of Palaeobotany and Palynology, 142*, 15-32.
Philippe, M., & Thévenard, F. (1996). Repartition and palaeoecology of the Mesozoic wood genus *Xenoxylon*: Palaeoclimatological implications for the Jurassic of Western Europe. *Review of Palaeobotany and Palynology, 91*, 353-370.
Süß, H., & Schultka, S. (2006). Koniferenhölzer (Fusite) aus dem Oberjura vom Tendaguru
(Tansania, Ostafrika). *Palaeontographica Abteilung B: Palaeophytologie*, *275*, 133-165.
Vogellehner, J. (1968). Zur Anatomie und Phylogenie mesozoischer Gymnospermenhölzer,
Beitrag 7: Prodromus zu einer Monographie der Protopinaceae. II. Die Protopinoiden Hölzer des Jura. *Palaeontographica B, 124*, 125-162.
Watson, J. (1925). On some South African fossil woods. *Annals of the South African Museum, 3*, 1-26.
Zamuner, A. B., & Artabe, A. E. (1994). Estudio de un leño fósil, *Protocircoporoylon marianensis* n. sp., proveniente de las sedimentitas triásicas de la Formación Paso Flores, Provincia del Río Negro, Argentina. *Ameghiniana, 31*, 203-207.
Zijlstra, G., & Philippe, M. (2020). Proposal to conserve the name *Protophyllocladoxylon* (fossil Coniferophyta: Coniferales) with a conserved type. *Taxon, 69*, 403-413.

Theme Session: Greening of the Upper Jurassic Morrison Formation, USA: Huge advances in paleobotany with implications for dinosaur herbivory ecosystem reconstruction (Friday, June 9, 2023, 3:45 PM)

A STRANGE WOOD IN A STRANGE LAND: THE PALEOECOLOGY OF THE FOSSIL WOOD *XENOXYLON* IN THE LATE JURASSIC OF NORTH AMERICA

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The fossil wood genus *Xenoxylon* Gothan (Greek for "strange wood") is distinguished by obround contiguous intertracheary bordered pits on the radial wall that occupy the entire tracheid width (called xenoxylean radial tracheid pitting). The radial tracheid pitting height/width ratio should be equal to, or less than, 0.60 (Philippe et al., 2013; Richmond et al., 2019). The crossfields typically have fenestriform oopores that fill the crossfield. *Xenoxylon* may belong to the extinct coniferous family Miroviaceae (Philippe et al., 2013). Currently, there are no known fossil leaves, cones, or pollen with affinities to the genus (Xie et al., 2021). More than 31 species have been assigned to *Xenoxylon*, but the number has been reduced to eleven. Philippe et al. (2013) defined three informal morphological groups: *phyllocladoides*, *meisteri*, and *latiporosum*.
The earliest occurrences of *Xenoxylon* are from Late Triassic-age deposits in the Far East, suggesting *Xenoxylon* evolved in the region during or before that period. During the Jurassic and Cretaceous periods, its distribution increased, becoming abundant and widespread in Europe and Asia. *Xenoxylon* (*X. phyllocladoides*) first appeared in the North American fossil record in the Lower Jurassic strata of Greenland. *X. phyllocladoides* continued in high latitude regions until the Tithonian. Additionally, *X. latiporosum* has been reported from Lower to Upper Cretaceous strata in the northernmost latitudes of North America (Alaska, USA, and Ellesmere Island, Canada). However, occurrences of *Xenoxylon* in the North American Jurassic are rare. Previous Jurassic-age fossil woods referred to *Xenoxylon* are invalid (Medlyn & Tidwell, 1975; Parrish & Falcon-Lang, 2007; Tidwell et al., 1998). *Xenoxylon morrisonense* Medlyn is now redescribed as a new genus *Morrisonoxylon morrisonense* Philippe (this volume).
Dinosaur discoveries in the Morrison Formation of central Montana prompted a geologic investigation of the

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formation in the region. The investigation led to the discovery, description, and first confirmed occurrences of the fossil wood *Xenoxylon meisteri* in the Upper Jurassic Morrison Formation of North America. Previously *X. meisteri* was known only from Russia, China, and Japan. Ten occurrences of *X. meisteri* in the Morrison Formation have presently been identified in central Montana. The Morrison Formation in central Montana is 71 m thick and is undivided. The *Xenoxylon* fossil wood sites range stratigraphically from 34–51 m above the underlying marine Swift Formation. Recently, four additional fossil wood genera have been identified in the formation, including *Circoporoxylon*, *Cupressinoxylon*, *Piceoxylon*, and *Protocedroxylon*. These contemporaneous fossil wood genera have also been reported for the high-latitude boreal forests of the Cretaceous of North America (Harland et al., 2007). The numerous fossil wood sites and their stratigraphic range indicate that *Xenoxylon* was an integral part of the Jurassic paleoforest and that the climate in central Montana was suitable for its proliferation.

In northeastern Utah, in the Miners Draw area, south of the Dinosaur National Monument, a fossil log was discovered as part of a wood reconnaissance project. The fossil log has been newly described as *Xenoxylon utahense* Xie et Gee (Xie et al., 2021). The fossil log is stratigraphically in the lower part of the Salt Wash Member of the Morrison Formation. *X. utahense* is of the *phyllocladoides* morphogroup. However, it lacks xylem parenchyma and Sanio's rims and occasionally has two oopores per cross-field. Xie et al. (2021) determined that the *X. utahense* specimen was at least 40 m tall.

A recent geologic review of the Morrison Formation in the Oklahoma panhandle resulted in the discovery of *Xenoxylon meisteri* with the genera *Agathoxylon* and *Cupressinoxylon*. This occurrence is the southernmost locality of *Xenoxylon* yet known. The three wood fossils were found nearby in the same stratigraphic horizon of

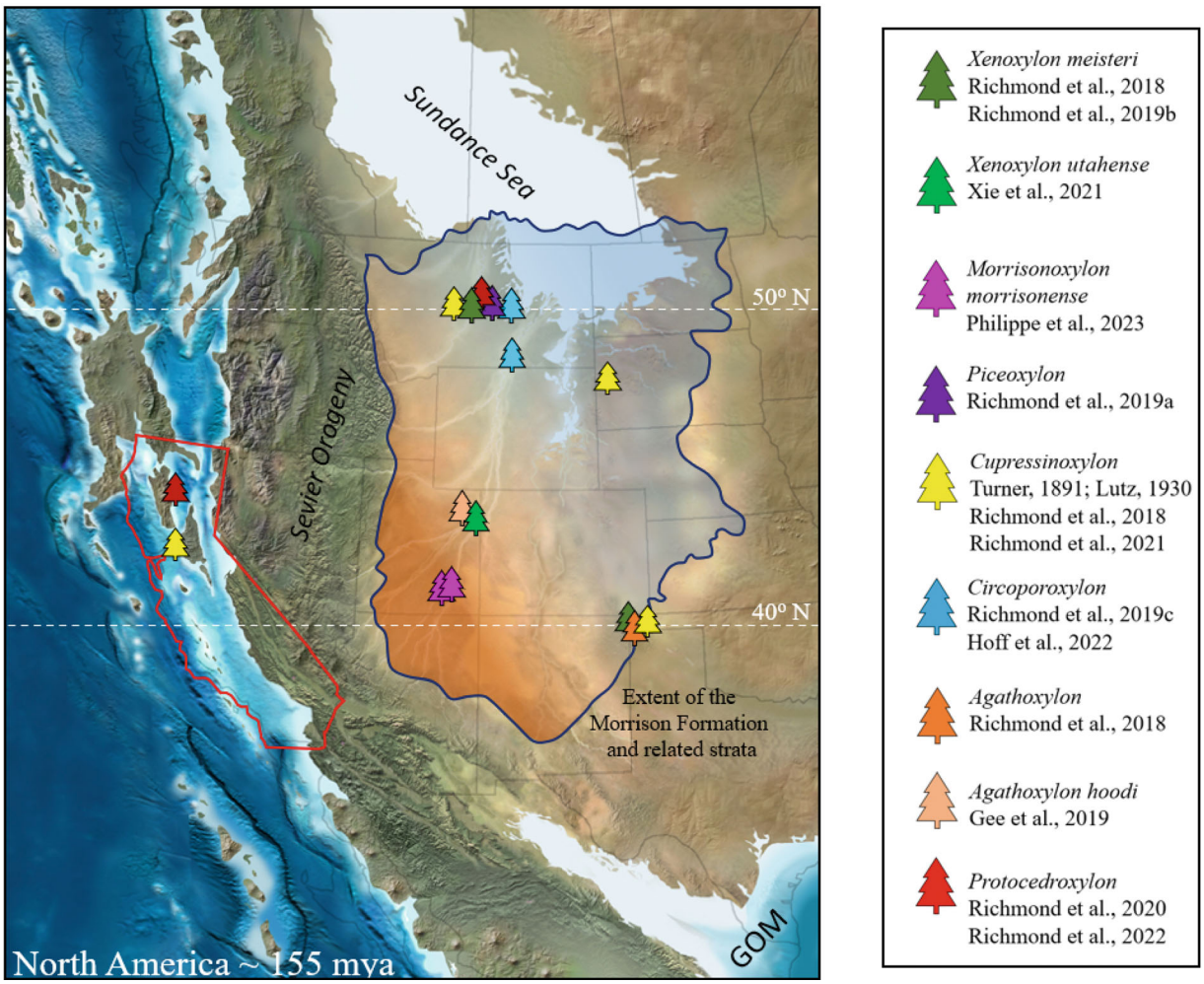


Figure 1. Modified R. Blakey map of the Late Jurassic of North America showing select fossil wood genera. The Morrison Formation is outlined. The color shades display a generalized interpretation of the temperature and precipitation (orange-warm/dry; blue-cool/wet) across the Morrison foreland basin.

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the newly named Boise Member of the Morrison Formation (Richmond et al., 2020). Due to their differing climatic preferences, the three fossil wood genera are rarely associated in the fossil record. The Boise Member is the eastward lateral equivalent of the Salt Wash Member of the Colorado Plateau.

The fossil woods *Xenoxylon* and *Protocedroxylon* occur at significantly higher paleolatitudes and generally indicate cooler/wetter climates. The distribution of *Agathoxylon*, *Brachyoxylon*, *Protaxodioxylon*, and *Simplicioxylon* in the more southern latitudes signifies warmer/drier climates (Philippe et al., 2017). Terrestrial paleotemperatures are often difficult to quantify; however, geology can be used to infer relative precipitation. Based on the geology of central Montana (e.g., mound springs) and the Oklahoma panhandle (Boise Member, e.g., perennial lacustrine carbonates), these regions experienced a wetter climate. The up-section increase in grain size in the Salt Wash Member distributive fluvial system may signify an increase in precipitation during deposition (Owen et al., 2017). Based on a review of the growth rings of *X. utahense*, Xie et al. (2021) suggests the tree grew in a warm and humid climate during the deposition of the Salt Wash Member. The occurrences of *Xenoxylon*, and other fossil wood genera, support the interpretation that some localities of the Morrison foreland basin experienced wetter climates.

References

Harland, M., Francis, J. E., Brentnall, S. J., & Beerling, D. J. (2007). Cretaceous (Albian–Aptian) conifer wood from Northern Hemisphere high latitudes: Forest composition and palaeoclimate. *Review of Palaeobotany and Palynology, 143*, 167-196.

Medlyn, D. A., & Tidwell, W. D. (1975). Conifer wood from the Upper Jurassic of Utah. I *Xenoxylon morrisonense* nov. spec. *American Journal of Botany, 62*, 203-208.

Owen, A., Nichols, G. J., Hartley, A. J., & Weissmann, G. S. (2017). Vertical trends within the prograding Salt Wash distributive fluvial system, SW United States. *Basin Research, 29*, 64-80.

Parrish, J. T., & Falcon-Lang, H. J. (2007). Coniferous trees associated with interdune deposits in the Jurassic Navajo Sandstone Formation, Utah, USA. *Palaeontology, 50*, 829-843.

Philippe, M., Puijalon, S., Suan, G., Mousset, S., Thévenard, F., & Mattioli, E. (2017). The paleolatitudinal, distribution of fossil wood genera as a proxy for European Jurassic terrestrial climate. *Palaeogeography, Palaeoclimatology, Palaeoecology, 466*, 373-381.

Philippe, M., Thévenard, F., Nosova, N., Kim, K., & Naugolnykh, S. (2013). Systematics of palaeoecologically significant boreal Mesozoic fossil wood genus, *Xenoxylon* Gothan. *Review of Palaeobotany and Palynology, 193*, 128-140.

Richmond, D. R., Hunt, T. C., & Cifelli, R. L. (2020). Stratigraphy and sedimentology of the Morrison Formation in the western panhandle of Oklahoma with reference to the historical Stovall dinosaur quarries. *Journal of Geology, 129*, 477-515.

Richmond, D. R., Lupia, R., Philippe, M., & Klimek, J. (2019). First occurrence of the boreal fossil wood *Xenoxylon meisteri* from the Jurassic of North America: Morrison Formation of central Montana, USA. *Review of Palaeobotany and Palynology, 267*, 39-53.

Tidwell, W. D., Britt, B. B., & Ash, S. R. (1998). Preliminary floral analysis of the Mygatt-Moore Quarry in the Jurassic Morrison Formation, west-central Colorado. *Modern Geology, 22*, 341–378.

Xie, A., Gee, C. T., Bennis, M. B., Gray, D., & Sprinkel, D. A. (2021). A more southerly occurrence of *Xenoxylon* in North America: *X. utahense* Xie et Gee sp. nov. from the Upper Jurassic Morrison Formation in Utah, USA, and its paleobiogeographic and paleoclimatic significance. *Review of Palaeobotany and Palynology, 192*, 104451.

Poster Session 2 (Friday, June 9, 2023)

FIRST REPORT OF VERTEBRATE BURROWS IN THE EARLY JURASSIC AZTEC SANDSTONE OF SOUTHERN NEVADA

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The Aztec Sandstone is a Lower Jurassic, eolian sandstone that crops out in southern Nevada and eastern California. It is correlative with the Navajo and Nugget sandstones of Arizona, Utah, Idaho, and Colorado. These three formations collectively formed one of the largest ergs in Earth history. Body fossils are scarce in all three of these formations, but trace fossils are common, most of which record the activity of invertebrates (Ekdale et al., 2007; Irmis, 2005). Vertebrate burrows attributed to therapsids and/or mammals have been reported in the Navajo Sandstone (Lucas et al., 2006; Riese et al., 2011) and in the Nugget Sandstone (Engelmann et al., 2014), but none have previously been reported from the Aztec Sandstone. Here we report the discovery of vertebrate

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burrows in the Aztec Sandstone. They occur at two localities in Valley of Fire State Park, and at one locality in Gold Butte National Monument, both of which are in southern Nevada.

In Valley of Fire S.P. the best exposed burrow is nearly straight, oriented N45°W, with a terminal chamber at the northwestern end (Figure 1). The burrow is 8.5 cm wide and 7.5 to 8.5 cm thick. It is 3.4 m long, although the southeastern end has been partially removed by erosion, so the original length is unknown. This burrow lies approximately parallel to the laminae of the sandstone, near the base of a cross-bedded set. It was originally horizontal, or possibly slightly inclined upward, in the direction of the terminal chamber. This burrow was preferentially cemented, so it has weathered out in three-dimensional relief. A morphologically similar, but less well exposed burrow was discovered a few hundred meters away from this one, in the same area within the park.

The dimensions and simple non-branching architecture of these two Valley-of-Fire burrows compare favorably with "Type II" burrows of Riese et al. (2011) in the Navajo Sandstone of southeastern Utah. Those authors suggested that their "Type II" burrows were excavated by large tritylodontid therapsids. Rowland and Mercadante (2014) reported the occurrence of abundant vertebrate tracks at one Valley of Fire locality which they also attributed to tritylodontids.

In Gold Butte National Monument another set of vertebrate burrows has been identified, and these are very different from the Valley of Fire burrows. The Gold Butte burrow complex consists of a cluster of variously oriented, cylindrical sandstone structures, each of which is 7-9 cm in diameter. Two of the cylinders are oriented at a very steep angle, another is approximately horizontal, while others plunge at different angles. All of the cylinders appear to roughly converge toward an unexposed region which we interpret to have been a chamber. As in the case of the Valley of Fire burrows, these rock cylinders stand out in three-dimensional relief, due to preferential cementation.



Figure 1. Burrow in the Aztec Sandstone in Valley of Fire State Park. The calibrated rod is 1.5 m long, calibrated in decimeters.

The morphology of this Gold Butte burrow complex compares favorably with "Type 1" burrows of Riese et al. (2011) in the Navajo Sandstone of southeastern Utah. The taxonomic affinity of the burrowers is unknown.

References

Ekdale, A. A., Bromley, R. G., & Loope, D. B. (2007). Ichnofacies of an ancient erg: a climatically influenced trace fossil association in the Jurassic Navajo Sandstone, southern Utah, USA. In W. M. Miller III (Ed.), *Trace fossils: Concepts, problems, prospects* (pp. 562-574). Elsevier.

Engelmann, G. F., Chure, D. J., & Good, T. R. (2014). Large burrows in the dunes of the Nugget Sandstone, Early Jurassic? of NE Utah. In M. G. Lockley & S. G. Lucas (Eds.), *Fossil footprints of western North America. New Mexico Museum of Natural History and Science Bulletin, 62*, 197-203.

Irmis, R. B. (2005). A review of the vertebrate fauna of the Lower Jurassic Navajo Sandstone in Arizona. *Mesa Southwest Museum Bulletin, 11*, 55-71.

Lucas, S. G., Gobetz, K. E., Odier, G. P., McCormick, T., & Egan, C. (2006). Tetrapod burrows from the Lower Jurassic Navajo Sandstone. In J. D. Harris, S. G. Lucas, J. A. Spielman, M. G. Lockley, A. R. C. Milner, & J. I. Kirkland (Eds.), *New Mexico Museum of Natural History and Science Bulletin, 37*, 147-154.

Riese, D. J., Hasiotis, S. T., & Odier, G. P. (2011). Synapsid burrows and associated trace fossils in the Lower Jurassic Navajo Sandstone. *Journal of Sedimentary Research, 81*, 299-325.

Rowland, S. M., & Mercadante, J. M. (2014). Trackways of a gregarious, dunefield-dwelling, therapsid in the Aztec Sandstone of Southern Nevada. *Palaios, 29*, 539-552.

Technical Session 3: Terrestrial Ecosystems – Late Jurassic (Friday, June 9, 2023, 1:30 PM)

REVIEW OF *DRACOPELTA ZBYSZEWSKII*, AN ANKYLOSAUR FROM THE UPPER JURASSIC OF PORTUGAL

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Ankylosaurs are one of the most iconic groups of dinosaurs. Their most conspicuous characters are the pervasive parasagittal dermal ossification, heavily ornamented, hyperossified skull, and, in ankylosaurines, fusion of the posterior half of the tail, forming the recognizable tail club. Fossils ascribed to Ankylosauria have been identified worldwide, dating at least from the Middle Jurassic to the latest Cretaceous. While in the Cretaceous ankylosaurs achieve maximum diversity and a ubiquitous presence in terrestrial ecosystems, in the Jurassic, occurrences are rare and often fragmentary, and predominantly restricted to Laurasia (Arbour & Currie, 2015; Francischini et al., 2017; Kirkland et al., 1998; Maidment et al., 2021; Rosa et al., 2018). The earliest known ankylosaurs, such as *Sarcolestes leedsi* Lydekker 1893, from the middle Callovian of England, or *Tianchisaurus nedegoapeferima* Dong 1983, from the Bathonian-Callovian of China, are known from a handful of specimens, usually too fragmented or incomplete to provide a solid diagnosis and reliable phylogenetic positioning. The Upper Jurassic has a more complete record, with most of the known specimens from the Morrison Formation, USA, although belonging to just two genera, *Mymoorapelta maysi* Kirkland and Carpenter 1994, and *Gargoyleosaurus parkpinorum* Carpenter et al. 1998 (Carpenter et al., 1998; Kilbourne & Carpenter, 2005; Kirkland & Carpenter, 1994; Kirkland et al., 1998).

The Upper Jurassic of Portugal has an extensive and well documented dinosaur fossil record, and the Lourinhã Formation (late Kimmeridgian-latest Tithonian/?earliest Berriasian) shows a close paleoecological relationship with the approximately coeval Morrison Formation, expressed in the closely related dinosaur taxa, such as the genera *Torvosaurus*, *Allosaurus*, *Ceratosaurus*, *Supersaurus*, *Miragaia*, and *Stegosaurus* (e.g., Antunes & Mateus, 2003, 2006; Costa & Mateus, 2019; Hendrickx & Mateus, 2014; Lapparent & Zbyszewski, 1957; Malafaia et al., 2014, 2017; Mateus et al., 2006; Tschopp et al., 2015). However, the presence of ankylosaurs has been restricted to the poorly known *Dracopelta zbyszewskii* Galton 1980, dated from the upper Tithonian (Galton, 1980, 1983; Pereda-Suberbiola et al., 2005; Russo & Mateus, 2021). Despite being first considered as a likely nodosaurid, *Dracopelta* has consistently been regarded as an ankylosaur of uncertain affinities, or even as a *nomen dubium*, due to the often-considered undiagnostic characteristics of the holotype (Carpenter, 2001; Pereda-Suberbiola et al., 2005; Vickaryous et al., 2004). Here we revisit the holotype specimen (MG5787), and redescribe it in detail, including hitherto unknown elements of the axial skeleton, such as a partial right hindlimb, composed of a partial femur, tibia, fibula, and articulated autopodium (MG 3), which is reidentified as a right pes, as well as a reassessment of the type locality. Additionally, we describe a new, mostly complete, articulated specimen of *D. zbyszewskii*, recovered from the coastal cliffs one kilometer North from the beach of Porto da Calada, Mafra, about 40 km North of Lisbon, dated from the uppermost Tithonian (~ 145 Mya). It consists of a nearly complete skull, left mandible, complete articulated cervical and dorsal vertebral series, sacrum, and 13 caudal vertebrae, articulated and disarticulated ribs, pectoral and partial pelvic girdles, left humerus, femora, and abundant *in situ* and displaced dermal armor. This specimen is the most complete dinosaur in Portugal and the most complete ankylosaur from the Jurassic. The new material (FCT 702) shares at least six unique characters with the holotype, such as the anteriorly placed lateral processes of the dorsal vertebrae, dermal armor arrangement of rows of parasagittal circular ossicles, dorsolateral keeled scutes, and dorsal keeled lateral plates, or a double pair of cervicodorsal medial semicircular keeled ossicles, with thickened rims. This allows us to conclusively attribute this second specimen to *D. zbyszewskii*. Thus, we rediagnose *D. zbyszewskii* based on a unique combination of characters, including nine autapomorphies: maxillary tomial crest medially deflected at the premaxillary/maxillary contact, completely separating the buccal emargination from the premaxillary palate, anteriorly narrow tooth rows relative to the posteriormost width of the tooth row (strongly concave), transverse processes of the cervical and dorsal vertebrae located anteriorly, at the edge of the anterior articulation facet of the centrum, two dorsolaterally positioned bilateral bundles of three ossified tendons, deeply excavated intertrochanteric and intercondylary fossae of the femur, medial femoral condyle twice the size of the lateral condyle, three cervical bands of armor made up of coossifed osteoderms forming quarter rings, dermal armor arrangement of rows of four dorsal parasagittal subcircular ossicles, dorsolateral keeled scutes, and lateral dorsally keeled plates, and two pairs of cervicodorsal medial semicircular keeled ossicles, with thickened rims. To clarify its position, phylogenetic analyses were performed using both maximum parsimony and Bayesian inference approaches, with *D. zbyszewskii* consistently recovered as sister taxa of *G. parkpinorum*, from the Upper Jurassic of Morrison Formation, USA, in a basal ankylosaur group that also includes the other Morrison Formation ankylosaur, *M. maysi*, as the sister taxa to the grouping of *D. zbyszewskii* + *G. parkpinorum*. These results add a new datapoint from a hitherto untested clade, which further reinforces the close relationship between Late Jurassic Portuguese and North American dinosaur faunas. Moreover, *D. zbyszewskii* is restricted to the topmost part of the Lourinhã Formation (Upper Tithonian), slightly younger than its American

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counterparts (~145 Mya vs. ~ 148-152 Mya). Paleobiogeographically, this may be indicative of a secondary land connection and dispersal event (in the Tithonian) between North America and Iberia.

References

Antunes, M. T., & Mateus, O. (2003). Dinosaurs of Portugal. *Comptes Rendus Palevol, 2*(1), 77-95

Arbour, V. M., & Currie, P. J. (2015). Systematics, phylogeny and palaeobiogeography of the ankylosaurid dinosaurs. *Journal of Systematic Palaeontology, 14*(5), 385-444.

Carpenter, K., Miles, C., & Cloward, K. (1998). Skull of a Jurassic ankylosaur (Dinosauria). *Nature, 393*(6687), 782-783.

Carpenter, K. (2001). Phylogenetic analysis of the Ankylosauria. In K. Carpenter (Ed.), *The armored dinosaurs* (pp. 455-483). Indiana University Press.

Costa, F., & Mateus, O. (2019). Dacentrurine stegosaurs (Dinosauria): a new specimen of *Miragaia longicollum* from the Late Jurassic of Portugal resolves taxonomical validity and shows the occurrence of the clade in North America. *PLoS ONE, 14*(11), e0224263.

de Lapparent, A. F., & Zbyszewski, G. (1957). Les dinosauriens du Portugal. *Serv Geol Portugal, 2*, 1-63.

Francischini, H., Sales, M. A. F., Dentzien-Dias, P., & Schultz, C. L. (2017). The presence of ankylosaur tracks in the Guará Formation (Brazil) and remarks on the spatial and temporal distribution of Late Jurassic dinosaurs. *Ichnos, 25*(2-3), 177-191.

Galton, P. M. (1980). Partial skeleton of *Dracopelta zbyszewskii* n. gen. and n. sp., an ankylosaurian dinosaur from the Upper Jurassic of Portugal. *Geobios, 13*(3), 451-457.

Galton, P. M. (1983). Armored dinosaurs (Ornithischia: Ankylosauria) from the Middle and Upper Jurassic of Europe. *Palaeontographica, Abteilung A: Palaozoologie - Stratigraphie, 182*(1-3), 1-25

Hendrickx, C., & Mateus, O. (2014). *Torvosaurus gurneyi* n. sp., the largest terrestrial predator from Europe, and a proposed terminology of the maxilla anatomy in nonavian theropods. *PLoS One, 9*(3), e88905.

Kilbourne, B., & Carpenter, K. (2005). Redescription of *Gargoyleosaurus parkpinorum*, a polacanthid ankylosaur from the Upper Jurassic of Albany County, Wyoming. *Neues Jahrbuch für Geologie und Paläontologie, 237*, 111-160.

Kirkland, J. I., & Carpenter, K. (1994). North America's first pre-cretaceous ankylosaur (Dinosauria) from the Upper Jurassic Morrison Formation of Western Colorado. *Brigham Young University Geology Studies, 40*, 25-42.

Kirkland, J. I., Carpenter, K., Hunt, A. P., & Scheetz, R. D. (1998). Ankylosaur (Dinosauria) specimens from the Upper Jurassic Morrison Formation. *Modern Geology, 23*, 145-177.

Lydekker, R. (1893). On the jaw of a new carnivorous dinosaur from the Oxford Clay of Peterborough. *Quarterly Journal of the Geological Society of London, 49*(1-4), 284-287.

Maidment, S. C. R., Strachan, S. J., Ouarhache, D., Scheyer, T. M., Brown, E. E., Fernandez, V., Johanson, Z., Raven, T. J., & Barrett, P. M. (2021). Bizarre dermal armour suggests the first African ankylosaur. *Nature Ecology & Evolution, 5*(12), 1576-1581.

Malafaia, E., Ortega, F., Escaso, F., & Silva, B. (2015). New evidence of Ceratosaurus (Dinosauria: Theropoda) from the Late Jurassic of the Lusitanian Basin, Portugal. *Historical Biology, 27*(7), 938-946.

Malafaia, E., Mocho, P., Escaso, F., & Ortega, F. (2017). New data on the anatomy of *Torvosaurus* and other remains of megalosauroid (Dinosauria, Theropoda) from the Upper Jurassic of Portugal. *Journal of Iberian Geology, 43*(1), 33-59.

Mateus, O. (2006). Late Jurassic dinosaurs from the Morrison Formation (USA), the Lourinha and Alcobaça formations (Portugal), and the Tendaguru Beds (Tanzania): A comparison. *New Mexico Museum of Natural History Science Bulletin, 36*, 223-231.

Mateus, O., Walen, A., & Antunes, M. T. (2006). The large theropod fauna of the Lourinhã Formation (Portugal) and its similarity to that of the Morrison Formation, with a description of a new species of *Allosaurus*. *New Mexico Museum of Natural History Science Bulletin*, 36, 1-7.

Pereda-Suberbiola, X., Dantas, P., Galton, P. M., & Sanz, J. L. (2005). Autopodium of the holotype of *Dracopelta zbyszewskii* (Dinosauria, Ankylosauria) and its type horizon and locality (Upper Jurassic: Tithonian, Western Portugal). *Neues Jahrbuch für Geologie und Paläontologie*, *235*(2), 175-196.

Rosa, R. A. R., León, M. P. V., Arellano-Gil, J., & Lozano-Carmona, D. E. (2018). Middle Jurassic ankylosaur tracks from Mexico. *Boletín de la Sociedad Geológica Mexicana, 70*(2), 379-395.

Russo, J., & Mateus, O. (2021). History of the discovery of the ankylosaur *Dracopelta zbyszewskii* (Upper Jurassic), with new data about the type specimen and its locality. *Comunicações Geológicas, 108*(1), 27-34.

Tschopp, E., Mateus, O., & Benson, R. B. (2015). A specimen-level phylogenetic analysis and taxonomic revision of Diplodocidae (Dinosauria, Sauropoda). *PeerJ, 3*, e857.

Vickaryous, M. K., Maryańska, T., & Weishampel, D. B. (2004). Ankylosauria. In D. B. Weishampel, P. Dodson, & H. Ozmólska (Eds.), *The Dinosauria* (2nd ed.) (pp. 363-392). University of California Press.

Zhiming, D. (1993). An ankylosaur (ornithischian dinosaur) from the Middle Jurassic of the Junggar Basin, China. *Vertebrata PalAsiatica, 31*(04), 257-266.

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Technical Session 3: Terrestrial Ecosystems – Late Jurassic (Friday, June 9, 2023, 1:15 PM)

SURF AND TURF: A WINDOW INTO LATE JURASSIC SAUROPOD AND THEROPOD POPULATIONS FROM LACUSTRINE AND COASTAL AREAS AT THE PURGATOIRE VALLEY (USA) AND JURA (SWITZERLAND) TRACK SITES

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Fossil track sites represent unique repositories of palaeobiological and palaeoecological information. Large and regionally extensive palaeosurfaces, some of which can be categorized as megatracksites (Lockley & Meyer, 2022), showcase the abundance and diversity of dinosaur trackmakers and are associated with sea- or lake-level changes and the sedimentary dynamics of ancient coastal plains and basin depositional systems. These palaeosurfaces can provide tantalizing clues as to the presence of certain animals, their behaviour, ichnodiversity, community dynamics, etc; and, moreover, may serve as snapshots of localised or larger-scale migration patterns. When approached holistically, their sedimentological and other palaeontological signals illustrate the greater palaeoecological picture at the time of deposition and provide a unique window into dinosaur populations in deep time.

Our current work focuses on two large and regionally extensive track sites in the Purgatoire Valley (Colorado, U.S.A) and the Canton Jura (NW Switzerland) because of similarities in age (Late Jurassic, Kimmeridgian), ichnofauna and ichnotaxa, and conversely their differing depositional environments. The renowned Purgatoire Valley dinosaur track site from Colorado is the largest dinosaur track site in North America (Lockley et al., 1986). The site has undergone documentation to various degrees since the early 1900s. In recent years, excavation on the north side of the Purgatoire River has revealed more than 800 additional tracks in a 2,600 m^2 area (Lockley & Schumacher, 2021; Schumacher & Lockley, 2014, 2022). Some new trackways are of significant lengths (~88 m) and remain wholly dominated by sauropod and theropod tracks. The Purgatoire track site is situated in the Ralston Creek Member of the Morrison Formation (Carpenter & Lindsey, 2019), and numerous track-bearing surfaces formed along the margin of a freshwater carbonate wetland-lake system. Conversely, the Swiss track sites are part of a shallow marine carbonate platform that hosts several stratigraphic levels bearing tracks and trackways (herein Jura sites). These have been historically documented (Meyer, 1993) and their extent (both geographically and stratigraphically) expanded due to the construction of the Swiss federal Highway A16 (Marty, 2008). The Jura sites represent tidal-flat deposits of the Reuchenette Formation and uniquely illustrate periods of recurrent emersion of the Jura carbonate platform. This affords the creation of several track-bearing palaeosurfaces that are contemporaneous and can be correlated laterally over an extended area and regionally. As at Purgatoire, trackmakers have been linked to sauropods and theropods but also potentially ornithischians.

Our work aims to provide a reappraisal and synthesis of recent and previous studies at these track sites; additionally, new fieldwork has been underway to document, compare and integrate ichnological data. At the Purgatoire site, photogrammetry and sedimentological field techniques documented ichnological and sedimentological aspects of the site, and high-resolution videos of the entire Purgatoire site (historic and new areas) were made with a Drone (DJI Mavic 2 Pro) in fall 2022. This has provided an unparalleled, detailed view of the entire extent of the currently exposed track-bearing palaeosurfaces. At both track sites, descriptive and quantitative data were obtained from trackways in addition to casts and 3D models. Given the large number of tracks and trackways and overall morphological similarity, emphasis is placed on the statistical treatment of the data to test differences between ichnotaxa reported at these geographically separate sites. Moreover, other factors, such as directional data (from trackways and sedimentological structures) and substrate deformation (e.g., soft-sediment deformation – 'dinoturbation') related to trackmakers were captured to document trackmaker movement and substrate rheology.

Our provisional results indicate that the sauropod-assigned trackways from the Purgatoire and Jura sites are similar in morphology displaying various gauge-types (predominately narrow gauge) with a strong heteropody. Most of them can be assigned to the ichnogenus *Parabrontopodus* as defined by Lockley, Farlow and Meyer (1994). At both sites, sauropod trackways often occur as parallel series of

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numerous individuals, providing compelling evidence for gregarious behaviour. Fieldwork at Purgatoire produced the first high-resolution 3D models of the paratype and other topotypes of *Parabrontopodus* at its type locality for comparison with similarly assigned trackways from the Swiss Jura. *Megalosauripus* is known from both sites and represents a large theropod trackmaker, although an abundance of smaller, likely theropod-made track types are still under evaluation. At Purgatoire, recent ichnological observations (e.g., crayfish burrows) supplement the previous palaeontological material which illustrates a diversity of freshwater invertebrates, from unionid bivalves and gastropods to conchostracans, ostracods, characeans and plant fossils (i.e., *Equisetum*). This ongoing study enhances our understanding of the distribution of Late Jurassic ichnofauna, their associated palaeoenvironments and biotic communities, and snapshots geographically separate Upper Jurassic ecosystems with shared ichnofaunas. Both the palaeosurfaces of the Morrison and Reuchenette formations provide census assemblages that allow comparison of the structure and composition of dinosaur populations at similar palaeolatitudes in terrestrial basins and on marine carbonate platforms.

References

Carpenter, K., & Lindsey, E. (2019). Redefining the Upper Jurassic Morrison Formation in the Garden Park National Natural Landmark and Vicinity, Eastern Colorado. *Geology of the Intermountain West, 6*, 1-30. doi:10.31711/giw.v6.pp1-30.

Lockley, M. G., & Schumacher, B. A. (2021). The process of ranking the Geo-Heritage 'values' of dinosaur tracksites in the USA and globally. *New Mexico Museum of Natural History and Science Bulletin, 82*, 177-184.

Lockley, M. G., & Meyer, C. A. (2022). The Megatracksite phenomenon: implications for tetrapod palaeobiology across terrestrial-shallow marine transitional zones. In C. Cónsole-Gonella, S. de Valais, I. Díaz-Martínez, P. Citton, M. Verde, & D. McIlroy (Eds.), *Ichnology in shallow-marine and transitional environments. Geology Society Special Publications, 522*.

Lockley, M. G., Houck, K. J., & Prince, N. K. (1986). North America's largest dinosaur trackway site: Implications for Morrison Formation paleoecology. *Geological Society of America Bulletin, 97*(10), 1163-1176.

Lockley, M. G., Farlow, J. O., & Meyer, C. A. (1994). *Brontopodus* and *Parabrontopodus* ichnogen nov. and the significance of wide- and narrow-gauge sauropod trackways. In M. G. Lockley, V. F. dos Santos, C. A. Meyer, & A. P. Hunt (Eds.), *Aspects of sauropod paleobiology. GAIA Vol. 10* (pp. 135-146).

Marty, D. (2008). *Sedimentology, taphonomy, and ichnology of Late Jurassic dinosaur tracks from the Jura carbonate platform (Chevenez-Combe Ronde tracksite, NW Switzerland): insights into the tidal-flat palaeoenvironment and dinosaur diversity, locomotion, and palaeoecology* [Doctoral dissertation, Université de Fribourg].

Meyer, C. A. (1993). A sauropod megatracksite from the Late Jurassic of Northern Switzerland.
Ichnos, 2, 1-10.

Schumacher, B. A., & Lockley, M. G. (2014). Newly documented trackways at "Dinosaur Lake," the Purgatoire Valley Dinosaur Tracksite. *New Mexico Museum of Natural History and Science Bulletin, 62*, 261-267.

Schumacher BA, Lockley MG. (2022). North America's largest assemblage of Late Jurassic
dinosaur trackways, a new look at the Purgatoire Valley dinosaur tracksite (Dinosaur Lake), Morrison Formation, southeastern Colorado, United States. *Historical Biology, 5*, 1-16.

Theme Session: Laramidia to Asia: Biota and Biogeography of Interconnected Iconic Late Cretaceous Ecosystems (Saturday, June 10, 2023, 4:35 PM)

NEW SPECIMENS FROM THE UPPER CAMPANIAN OF 'SOUTHERN' LARAMIDIA REVEAL UNEXPECTED COMPLEXITY IN "*PENTACERATOPS*-LIKE" CHASMOSAURINE RICHNESS

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The Late Cretaceous record from the Western Interior of North America presents an incomparable opportunity to examine nonmarine biotic evolution along a latitudinal gradient and within a relatively constrained geochronologic framework (~83 to 70 Ma). Distributed along the alluvial and coastal plains of Laramidia, differences between dinosaur assemblages have been broadly divided into two regions, with well-sampled localities in Montana and southern Alberta representing 'northern' biotas and localities in Utah, New Mexico, Texas and Coahuila, Mexico representing 'southern' biotas. Recent discoveries from underexplored regions of Laramidia, many in the

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south, together with increased attention to stratigraphic position, geochronology, and regional ecologies, have instigated new hypotheses regarding local and regional patterns of dinosaur distribution and evolution on Laramidia (e.g., Gates et al., 2010; Loewen et al., 2013; Sampson et al., 2010). Among the most important groups for generating these new insights is the geographically widespread and morphologically diverse Ceratopsidae. Among ceratopsids, revised interpretations and new discoveries of chasmosaurine taxa have revealed surprising radiations and patterns of evolution that began soon after their first appearance in the middle Campanian. This is perhaps most striking among "*Pentaceratops*-like" chasmosaurines, an informal grouping of taxa with a deeply embayed posterior parietal often supporting dorsally directed first epiparietals.

The emerging upper Cretaceous record of southern Utah is capped by the remarkable dinosaur ecosystems of the

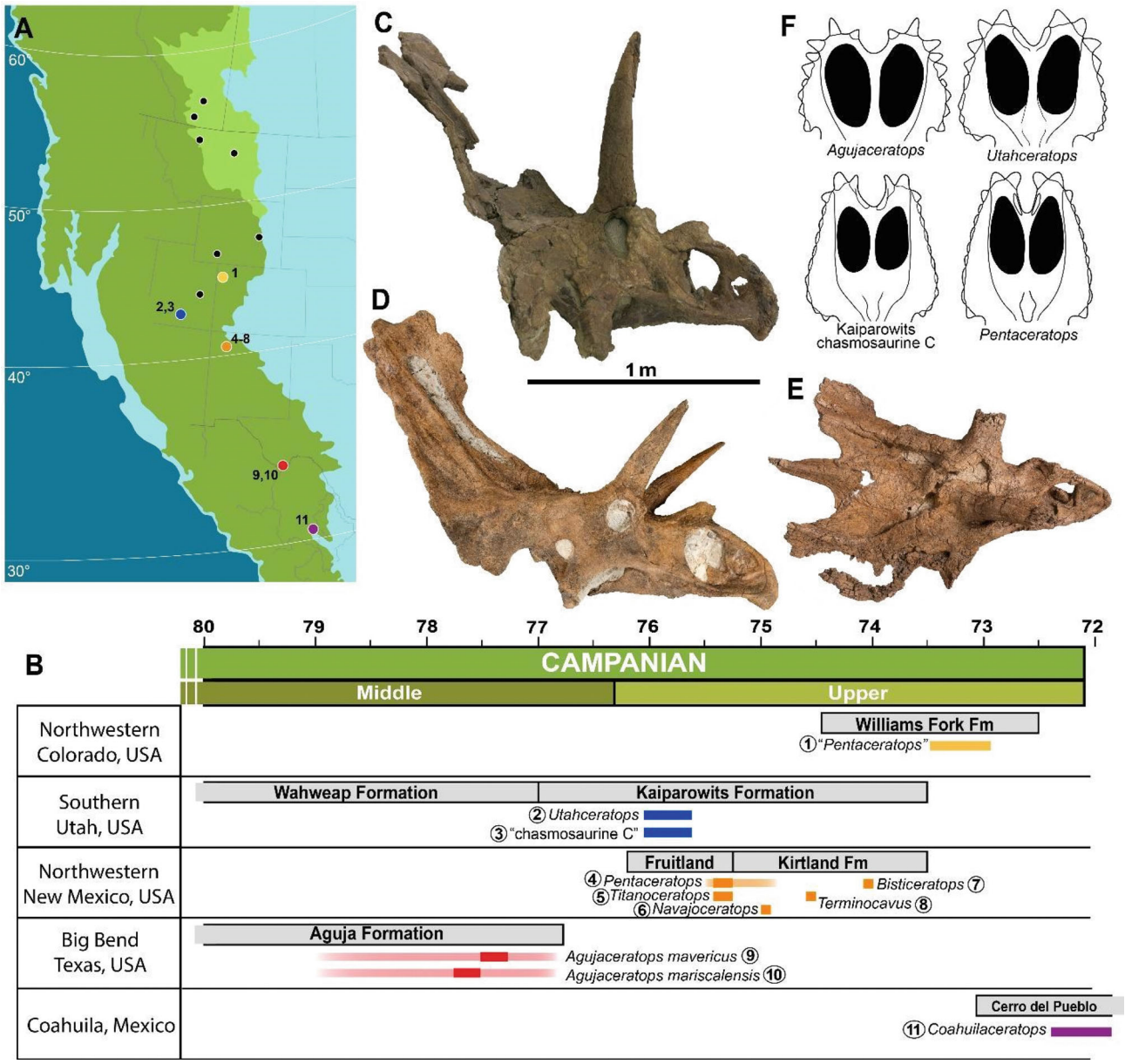


Figure 1. Distribution of significant chasmosaurine ceratopsid occurrences across Laramidia (A), including geographic and temporal distribution (B) of select chasmosaurine taxa (numbered) in the middle and upper Campanian. Map coastlines derived from Blakey and Ranney (2018), with dark green representing ~75 Ma and light green representing ~77 Ma. Skulls of (C) 'Kaiparowits chasmosaurine C' specimen DMNH EPV.100000 in left lateral view (reversed), (D) c.f. *Pentaceratops sternbergii* DMNH EPV.uncataloged from the Fossil Forest Member of the Fruitland Formation in right lateral view, and (E) c.f. "*Pentaceratops*" sp. DMNH EPV.uncataloged from the lower Hunter Wash Member of the Kirtland Formation in dorsal view. (F) Reconstructions of the parietosquamosal frills of select 'southern' chasmosaurine taxa.

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Kaiparowits Formation, deposited in an alluvial plain setting between ~77 and 73.5 Ma. In particular, the lower middle unit of the Kaiparowits (~76.3-75.8 Ma) has produced abundant remains of ceratopsids including the centrosaurine *Nasutoceratops* (Sampson et al., 2013) and the chasmosaurines *Kosmoceratops* and *Utahceratops* (Sampson et al., 2010). New discoveries over the past decade include at least seven individuals of a previously unidentified chasmosaurine taxon from the same stratigraphic interval, suggesting unparalleled sympatric ceratopsid diversity in the Kaiparowits ecosystem. The new form, referred to here as 'Kaiparowits chasmosaurine C,' is characterized by the presence of elongate and medially curving postorbital horns, an elongate squamosal with ten episquamosals, and a deeply embayed posterior parietal. While the new chasmosaur is similar in morphology to the stratigraphically younger *Pentaceratops sternbergii* from the San Juan Basin, it can be distinguished from *Pentaceratops* by the presence of a small epijugal, a laterally compressed epinasal horn, a relatively shorter and broader parietal, an enlarged third epiparietal (ep3), and confluent first and second epiparietals (ep1 and ep2), among other features. Many morphologic features of the skull resemble the stratigraphically older *Agujaceratops mavericus* from the Aguja Formation of Texas, suggesting that Kaiparowits chasmosaurine C possibly represents an intermediate form between *A. mavericus* and *Pentaceratops sternbergii*.

The well-known dinosaur assemblages of the Fruitland and Kirtland formations of the San Juan Basin in northwestern New Mexico have produced abundant chasmosaurine remains for over a century. New emphasis on placing historic finds into a relative stratigraphic framework have led to a number of recent hypotheses and questions. Long viewed as the exemplar ceratopsid spanning much of the upper Fruitland and Kirtland formations, *Pentaceratops sternbergii*, is now recognized as a likely accumulation of multiple distinct taxa (e.g., Fowler, 2017), some sympatric (e.g., *Titanoceratops*; Longrich, 2011), and the validity of the holotype of *P. sternbergii* itself has been called into question due to the absence of a diagnosable posterior parietal and lack of solid stratigraphic position (Fowler & Freedman Fowler, 2020). A new, complete skull recovered from the Fossil Forest Member of the Fruitland Formation with good stratigraphic control permits critical reassessment of *P. sternbergii* by linking facial morphology present in the holotype to a diagnosable posterior parietal. Additional new specimens from the lower Hunter Wash Member of the Kirtland Formation assist with establishing the stratigraphic and temporal range of *P. sternbergii* but have also revealed new diversity possibly representing additional sympatric taxa. A recent hypothesis of relatively rapid anagenetic evolution of a single chasmosaurine lineage that includes *Utahceratops* and *Pentaceratops* (Fowler & Freedman Fowler, 2020) is called into question by these new discoveries. A partial skull from the lower Hunter Wash Member of the Kirtland Fm is similar to the parietal of the stratigraphically higher *Terminocavus* in having a posterodorsally inclined first epiparietal (ep1) and broad posterior parietal bar but differs in having a more open medial embayment. Further, this new skull overlaps stratigraphically with the holotype of *Navajoceratops* and possibly with other specimens historically referred to *Pentaceratops*, supporting an emerging pattern of multiple sympatric chasmosaurine taxa in many 'southern' Laramidia biotas. Critical reassessment and stratigraphic reevaluation of other 'southern' forms, including *Agujacertops*, is needed. Furthermore, more detailed evaluation of facial characters stemming from these new finds could be used to link important southern taxa missing the phylogenetically critical posterior parietal (e.g., *Agujaceratops mavericus*, *Bisticeratops*, *Titanoceratops*, *Coahuilaceratops*).

References

Blakey, R. C., & Ranney, W. D. (2018). *Ancient landscapes of western North America: A geologic history with paleogeographic maps* (1st ed.). Springer.

Fowler, D. W. (2017). Revised geochronology, correlation, and dinosaur stratigraphic ranges of the Santonian-Maastrichtian (Late Cretaceous) formations of the Western Interior of North America. *PLoS ONE, 12*, e0188426.

Fowler, D. W., & Freedman Fowler, E. A. (2020). Transitional evolutionary forms in chasmosaurine ceratopsid dinosaurs: evidence from the Campanian of New Mexico. *PeerJ, 8*, e9251 doi.org/10.7717/peerj.9251

Gates, T. A., Sampson, S. D., Zanno, L. E., Roberts, E. M., Eaton, J. G., Nydam, R. L., Hutchison, J. H., Smith, J. A., Loewen, M. A., & Getty, M. A. (2010). Biogeography of terrestrial and freshwater vertebrates from the Late Cretaceous (Campanian) Western Interior of North America. *Palaeogeography, Palaeoclimatology, Palaeoecology, 291*, 371-387.

Loewen, M. A., Irmis, R. B., Sertich, J. J. W., Currie, P. J., & Sampson, S. D. (2013). Tyrant dinosaur evolution tracks the rise and fall of Late Cretaceous oceans. *PLoS ONE, 8*, e79420.

Longrich, N. R. (2011). *Titanoceratops ouranos*, a giant horned dinosaur from the Late Campanian of New Mexico. *Cretaceous Research, 32*, 264-276. doi:10.1016/j.cretres.2010.12.007

Sampson, S. D., Loewen, M. A., Farke, A. A., Roberts, E. M., Forster, C. A., Smith, J. A., & Titus, A. L. (2010).

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New horned dinosaurs from Utah provide evidence for intracontinental dinosaur endemism. *PLoS ONE, 5*, e12292. https://doi.org/10.1371/journal.pone.0012292-Sampson, S. D., Lund, E. K., Loewen, M. A., Farke, A. A., & Clayton, K. E. (2013). A remarkable short-snouted horned dinosaur from the Late Cretaceous (late Campanian) of southern Laramidia. *Proceedings of the Royal Society B: Biological Sciences, 280*, 20131186. doi:10.1098/rspb.2013.1186

Poster Session 1 (Thursday, June 8, 2023)

MODERATELY HUMID PALEOCLIMATES IN WESTERN PANGAEA DURING THE LATE TRIASSIC: EVIDENCE FROM DETRITAL COMPOSITIONS OF THE CHINLE FORMATION IN SOUTHWESTERN UTAH

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During the Late Triassic, the Pangaean monsoonal circulation is considered to have been at maximum strength, and western Pangaea began to shift from extremely humid to wet-and-dry seasonal climatic conditions (Lucas & Tanner, 2018; Nordt et al., 2015). Although these climatic changes are interpreted to have been documented in fluvial and lacustrine deposits that formed in the present western USA, the Upper Triassic successions in southwestern Utah have not yet been investigated regarding this point. Here, we analyzed temporal changes in detrital compositions of sandstone framework grains and clay minerals from the Upper Triassic Chinle Formation that is distributed in and around Zion National Park in southwestern Utah to reconstruct Late Triassic climatic condition in a part of the western Pangaea.

The Chinle Formation in this region is characterized by fluvial deposits, and is subdivided into the Shinarump (~40 m thick) and Cameron (~95 m thick) members, and the "purple pedogenic beds" (~25 m thick), in ascending order (Martz et al., 2017). A total of 53 medium- to very coarse-grained sandstone samples were collected from the Shinarump and Cameron members for analyzing framework composition of sandstones. In addition, a total of 74 mudstone samples were also taken from the Shinarump and Cameron members as well as from the "purple pedogenic beds" for X-ray diffraction (XRD) analyses of clay mineral composition. To investigate diagenetic modification of clay mineral composition, we also conducted SEM analysis of the mudstone samples.

The Chinle Formation sandstones are generally represented by higher contents of quartzose grains in association with minor feldspar grains and lithic fragments, but its members show slightly different framework composition: the Shinarump Member is characterized by a larger proportion of quartzose grains than the Cameron Member, which has more feldspar grains and lithic fragments than the Shinarump. Clay mineral composition of the Shinarump Member is represented by nearly equal amounts of illite and kaolinite, and less amounts of chlorite. In contrast, the Cameron Member and the "purple pedogenic beds" are characterized by the dominance of kaolinite and smectite, with minor contents of illite and chlorite. The amounts of kaolinite and smectite inversely change, and their relative abundance shows three cycles with a zigzag pattern, and an overall increase in smectite through the Cameron Member and the "purple pedogenic beds".

The stratigraphic variations in the framework compositions of sandstones, which are represented by an upward increase in feldspars and lithic fragments, are considered to have been controlled by a temporal change in the intensity of either chemical weathering or volcanic activity in the hinterlands. Because relative abundances of volcanic lithic fragments within the total lithic fragments are limited in both the Shinarump and Cameron members, the effect of the temporal change in the intensity of volcanic activity in the hinterlands can be excluded as a major cause. Consequently, the stratigraphic variation in the sandstone framework composition is interpreted to document a temporal change in the intensity of chemical weathering in the hinterlands.

SEM images of the mudstone samples do not show any distinct authigenic structures. This suggests that diagenetic modification of sampled mudstones were insignificant after deposition, and clay minerals from mudstone samples are mainly interpreted to be detrital in origin. The mudstone samples of the Shinarump Member include kaolinite and do not contain smectite. This clay mineral composition implies that wet-and-dry seasonal condition had not yet developed, and the climate was probably humid during the deposition of the Shinarump. In contrast, smectite and kaolinite in the mudstone samples of the Cameron Member and the "purple pedogenic

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beds", whose relative abundance is inversely proportional and exhibits zigzag pattern cycles, are interpreted to reflect periodic changes of humid and wet-and-dry seasonal conditions in the hinterlands. In addition, the temporal increase in smectite upsection suggests that climates gradually changed into a more seasonal condition.

The framework composition of sandstones and clay mineral assemblages of mudstones of the Chinle Formation imply that major climates may have shifted from humid to wet-and-dry seasonal conditions. Compared to modern tropical regions, such as Brazil and central Africa, whose soils contain a limited amount of illite and chlorite (Ito & Wagai, 2017) as a result of their instability under warm and humid climatic conditions, moderate amounts of illite and a slightly smaller amounts of chlorite in the Shinarump Member mudstones likely indicate that the intensity of chemical weathering during the deposition of the Shinarump Member in southwestern Utah was weaker than that of the present-day, low-latitude tropical regions. Consequently, the deposition of the lowermost part of the Chinle Formation is interpreted to have been influenced by moderately humid climates rather than by typically humid climates that have been interpreted by the previous studies.

References

Ito, A., & Wagai, R. (2017). Global distribution of clay-size minerals on land surface for biogeochemical and climatological studies. *Scientific Data, 4*, 170103, DOI: 10.1038/sdata.2017.103.

Lucas, S. G., & Tanner, L. H. (2018). Record of the Carnian wet episode in strata of the Chinle Group, western USA. *Journal of the Geological Society, 175*, 1004-1011.

Martz, J. W., Kirkland, J. I., Milner, A. R. C., Parker, W. G., & Santucci, V. L. (2017.) Upper Triassic lithostratigraphy, depositional systems, and vertebrate paleontology across southern Utah. *Geology of the Intermountain West, 4*, 99-180. https://doi.org/10.31711/giw.v4.pp99-180

Nordt, L., Atchley, S., & Dworkin, S. (2015). Collapse of the Late Triassic megamonsoon in western equatorial Pangea, present-day American Southwest. *Geological Society of America Bulletin, 127*, 1798-1815.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 10:45 AM)

DIFFERENCES IN ARCHOSAUROMORPH FUNCTIONAL MORPHOLOGY REVEAL A SHIFT IN APEX CARNIVORE ECOLOGIES DURING THE RISE OF THE DINOSAURS.

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The Triassic saw many different clades diversify as life recovered from the devastation of the Permo-Triassic mass extinction. A series of faunal turnovers produced more modern-style ecosystems and archosauromorph reptiles were a key part of these turnovers, undergoing multiple radiations and becoming the dominant large tetrapods in most terrestrial faunas. A succession of different archosauromorph clades evolved to occupy top predator niches through the Triassic. As high-level consumers typically placed within the upper echelons of their trophic networks, predators may act as indicators of wider ecosystem change. Therefore, patterns of carnivore guild evolution may give some indication of how the Triassic turnovers unfolded and eventually resulted in dinosaur domination of the terrestrial realm at the onset of the Jurassic. Applying morphometric methods, we track the evolution of carnivorous archosauromorphs using their eco-functional anatomy and find that dinosaurs seemingly pursued a different trophic strategy as apex predators from their archosauromorph predecessors and rivals. Dinosaurs assumed control of the terrestrial carnivore guild in the latest Norian but remained relatively small and generally unsuited to tackling large prey, despite some improvements in their jaw performance. Potential prey grew larger towards the end of the Triassic but large macrocarnivores disappeared and did not re-emerge until later in the Early Jurassic. Early carnivorous dinosaurs specialised to feed on small, fast prey, and this allowed them to thrive as environmental and faunal changes reshaped terrestrial ecosystems across the Triassic-Jurassic transition.

Poster Session 3 (Saturday, June 10, 2023)

LOCOMOTION IN THE HERBIVOROUS THEROPOD *NOTHRONYCHUS* AND ITS POSITION IN THE TURONIAN FAUNAL ECOSYSTEM

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Therizinosaurs were herbivorous theropods from the Upper Cretaceous. They are typically found in depositional environments closely associated with water. *Nothronychus graffami* was a large species from the Turonian of southern Utah, near Big Water. *N. mckinleyi* was a similar animal from the Zuni Basin of west-central New Mexico. Both are known from single individuals. Much of the *Nothronychus* hindlimb, including the acetabulum and proximal femur, is quite well-preserved with minimal taphonomic deformation. This project uses an extant avian model to illustrate locomotion in *Nothronychus* based on hard and inferred soft tissue.

An opisthopubic pelvis convergent with extant Neornithes is assumed for tendon and muscle reconstruction. Locomotion is regarded as similar to that of a walking ostrich. Although ostriches are quite capable of running, limb proportions in *Nothronychus* indicate that such behavior was highly unlikely. Therefore, one limb would be in contact with the ground at all times and a discrete launch phase characteristic of running would be absent. The tail was reduced so the center of mass would have been anterior to the acetabulum. Therefore, the femur would be rotated anteriorly, bringing the knee nearly ventral to that point. However, the dimensions lie on a non-avian theropod allometric curve, precluding a completely avian horizontal orientation.

The hip is reconstructed with a dominantly ground-dwelling bird model. The preacetabular labrum is highly ossified and continuous with the iliofemoral ligament and synovial capsule. Therefore, femoral protraction was limited. The ischiofemoral ligament merged with the pubofemoral ligament. The combined ligamentum teres was longer, but the origin is less ossified, as stress associated with body weight was reduced there. As a result of the extensive preacetabular ossification, femoral retraction was limited to about 7^{o} of arc, following observed motion in the extant helmeted guinea fowl. This result is a function of speed, but an adult *Nothronychus*, is regarded as incapable of cursorial locomotion. In extant birds, the development of an enlarged preacetabular blade is related to femoral abduction during locomotion. The *Nothronychus* femur is modelled with such an orientation.

In making inferences about the knee of *Nothronychus*, it is important to distinguish between habitual movement during walking and what position the animal was mechanically capable of performing. At the knee, the tibia would not hyperextend beyond the long axis of the femur. As a first approximation, the knee would have been permanently flexed. Flexion would increase during the swing phase. When sitting, the tibiae can be rotated nearly parallel with the femora.

A digitigrade posture is assumed for *Nothronychus*, similar to an ostrich. The ostrich exhibits a flexed tarsometatarsus while walking. During the stance phase, the tarsometatarsus remains flexed relative to the tibia. As the swing phase progresses, the tarsometatarsus is retracted towards the tibia, such that motion here exceeds that at the knee. This motion would presuppose minimal plantar flexion of the pes. *Nothronychus* does not exhibit a fused tarsometatarsus, so rotation would have occurred between the astragalus/calcaneum and the distal tarsals. Dorsiflexion about that joint would become exaggerated while sitting.

In summary, using the animals of the nearby Zuni Basin as a Turonian faunal hypodigm, *Nothronychus* would have been one of the largest herbivores in the area. Therefore, the adults would have relied on size rather than locomotion to avoid predation. The animal would probably have fed at a somewhat higher level than the closely associated ceratopsian *Zuniceratops*. Limb development is highly indicative of a waddling gait. Such a model is not inferred for more basal therizinosaurs, including *Falcarius*.

References

Gatesy, S. (1999). Guineafowl hindlimb function I: Electromyographic analysis and speed effects. *Journal of Morphology, 240*, 115-125.

Kirkland, J. I., & Wolfe, D. G. (2001). First definitive therizinosauroid (Dinosauria: Theropoda) from North America. *Journal of Vertebrate Paleontology, 21*, 410-414.

Manafzadeh, A., & Padian, K. (2018). ROM mapping of ligamentous constraints on avian hip mobility: Implications for extinct ornithodirans. *Proceedings of the Royal Society B: Biological Sciences, 285*, 20180727.

Tsai, H. & Holliday, C. (2015). Articular soft tissue anatomy of the archosaur hip joint: structural homology and functional implications. *Journal of Morphology, 276*, 601-630.

Tsai, H., Middleton, K., Hutchinson, J., & Holliday, C. (2018). Hip-joint articular soft tissues of non-dinosaurian dinosauromorphs and early Dinosauria: evolutionary and biomechanical implications for Saurischia. *Journal of Vertebrate Paleontology*, *38*, e1427593.

Zanno, L. E., Gillette, D. D., Albright, L. A., & Titus, A. L. (2009). A new North American therizinosaurid and the role of herbivory in 'predatory' dinosaur evolution. *Proceedings of the Royal Society B: Biological Sciences, 276*, 3505-3511.

Poster Session 3 (Saturday, June 10, 2023)

THE ORIGINS OF UPPERMOST CRETACEOUS FOSSIL TURTLE ASSEMBLAGES IN NORTHWESTERN NEW MEXICO

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Recent work in the greater San Juan Basin stratigraphic sequence (SJB) in New Mexico prior to the latest Cretaceous has recorded fauna that illuminates development of some of the most robust latest Cretaceous fossil assemblages known from the southwest Cretaceous interior (e.g., Sullivan et al., 2013). These units (Moreno Hill and Menefee formations) serve as important evolutionary, temporal, and geographic counterparts to the well-known, dinosaur-rich Late Cretaceous assemblages of Utah, Montana, and Alberta. The Turonian Moreno Hill Formation documents the presence of a transitional turtle assemblage, similar to its dinosaurs (Nesbitt et al., 2019). It fills a world-wide middle Cretaceous gap in the fossil record, largely resulting from a middle Cretaceous sea level maximum and poor preservation of terrestrial facies (Nesbitt et al., 2019).

The SJB fossil turtle assemblage revealed complex evolutionary and biogeographic patterns that clarify regional paleoenvironmental conditions in the southern Western Interior (Figure 1). Comparisons of fossil turtle assemblages can be made within the stratigraphic sequence of the greater SJB in ascending order from the Moreno Hill, Menefee, Fruitland, and Kirtland Formations (Fms.) (Fowler, 2017; Lichtig & Lucas, 2015; Sullivan et al., 2013).

In the earliest part of the sequence, the Turonian Moreno Hill Fm. is exposed near the southwest periphery of SJB in the Zuni Basin (e.g., Cilliers et al., 2021; Craigg, 2001; Kelley, 1957, 1967; Molenaar et al., 2002; Wolfe, 1989). The Turonian is part of a significant temporal hiatus in the terrestrial fossil record of western North America, and the Moreno Hill turtle fauna was only recently described (Adrian et al., 2023). It contains the novel and earliest-known derived baenid, *Edowa zuniensis* (Adrian et al., 2023), which shares a "*Plesiobaena* grade" morphology with later taxa from northern Laramidia. A stem turtle, *Naomichelys sp*. is represented (Adrian et al., 2023), and a trionychid has been documented, but not described (Wolfe et al., 1997). Moreno Hill turtles therefore consist of an aquatic, endemic form of surprisingly derived nature for its early occurrence (*Edowa zuniensis*), a semi-terrestrial relict form (*Naomichelys* sp.), and a highly aquatic, early representative of an Asian migration (trionychid) (Figure 1). These three families were widely distributed in North America by the Late Cretaceous and form the foundation of many younger Late Cretaceous turtle assemblages in North America (Brinkman, 2003; Hirayama et al., 2000; Holroyd & Hutchison, 2002).

There is overlap in the turtle taxa represented in the Campanian portion of the SJB sequence, the Menefee and Fruitland/Kirtland Fms. *Naomichelys* has been reported from the Menefee Fm. (Lichtig & Lucas, 2015), and was recently recovered in our field efforts. The derived baenid *Denazinemys nodosa* is abundant in the Fruitland/Kirtland Fms. (Sullivan et al., 2013), and has been reported in the Menefee Fm. (Lichtig & Lucas, 2015). The large baenid *Scabremys ornata* is reported for the first time by a mostly complete shell and numerous fragments in the Allison Member (Mbr.) of the Menefee Fm., representing a stratigraphic range extension back to the middle Campanian. We also recovered a nearly complete shell of the stem baenid *Neurankylus baueri* in the Menefee Fm., where it has previously been reported (Lichtig & Lucas, 2015). It is also known from the Kirtland and Fruitland Fms. (Sullivan et al., 2013).

We have tentatively identified three distinct trionychid forms in the Allison Mbr. The most common is identified as cf. "*Trionyx*" (*Aspideretoides*) *robustus* as it is consistent with the finer pitting of specimens from the Kirtland and Fruitland Fms. Unpublished specimens consistent with this morphology also occur in the Moreno Hill Fm., constituting a range extension of approximately 15 Ma. A second trionychid, consistent with "*T*." *austerus* from Fruitland/Kirtland Fms., is less abundant than its congener in the Menefee Fm. (Sullivan et al., 2013). A third Menefee Fm. trionychid does not correspond with other known SJB taxa, and is characterized by a distinct texture with large, irregularly shaped, widely spaced pits. Two species of *Adocus* (*A. kirtlandius* and *A. bossi*) are known from the Kirtland and Fruitland Fms. (Sullivan et al., 2013). *Adocus* material in the Menefee Fm. has been previously ascribed to the larger *A. bossi* (Lichtig & Lucas, 2015), while the material we identified from the Menefee Fm. is more consistent with the smaller *A. kirtlandius*.

Several other turtle taxa have been identified in the diverse Fruitland/Kirtland Fms. that have no representation in the older Menefee or Moreno Hill Fms. The terrestrial, herbivorous, Asian immigrant *Basilemys gaffneyi* reflects a cosmopolitan component similar to *Adocus*. Similarly, the pleurosternid *Compsemys*, plastomenine trionychid *Gilmoremys gettyspherensis*, and an indeterminate kinosternoid are known from the Fruitland/Kirtland Fms. but not earlier in the stratigraphic sequence (Figure 1). Two species of the baenid genus *Thescelus* have been identified only in the Kirtland Fm., although

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one (*T. hemispherica*) is considered a *nomen dubium* pending further preparation (Joyce & Lyson, 2015; Sullivan et al., 2013). Finally, the pleurodiran bothremydid *Chedighaii hutchisoni* has been identified in the lower Hunter Wash Mbr. of Kirtland Fm. but is not known earlier in the SJB sequence. An additional bothremydid from the Menefee Fm. was referred to *Elochelys perfecta* from the Campanian of Europe, based on poorly defined

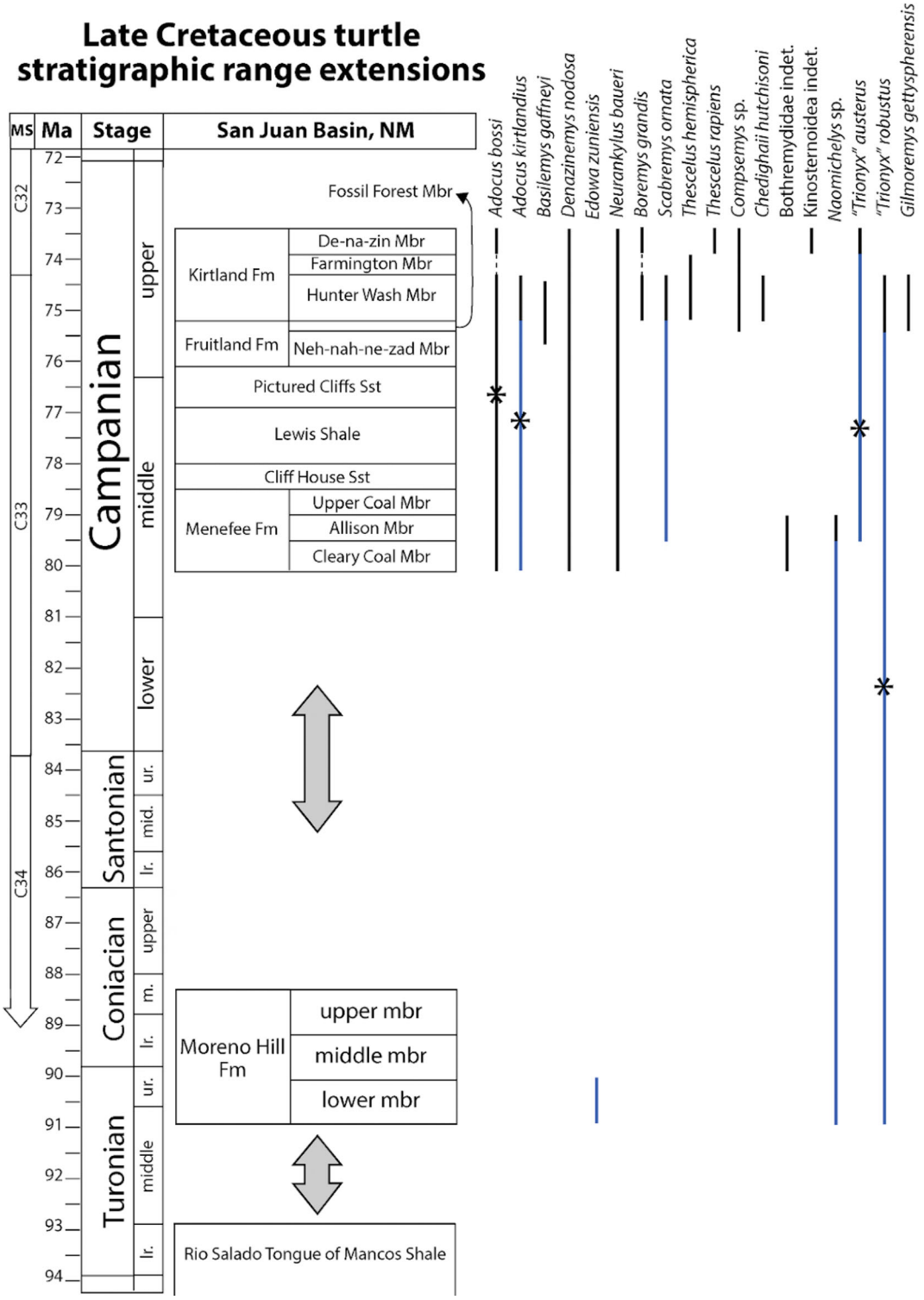


Figure 1. Late Cretaceous turtle stratigraphic ranges in the Zuni and San Juan basins of New Mexico. Black lines indicate previously published ranges, while blue lines indicate range extensions in the current study. Dotted lines indicate gaps in the fossil record with inferred presence. Asterisks indicate segments with taxonomic uncertainty. Abbreviations: Fm= formation; lr. = lower; m.= middle; Ma= million years ago; Mbr = Member; MS= magnetostratigraphy; NM= New Mexico; Sst =sandstone, ur= upper.

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reasoning (Lichtig & Lucas, 2015; Nopcsa, 1931; Santucci et al., 2014). As its description notes similarities with *Chedighaii*, which occurs later stratigraphically, we consider this specimen more likely to belong to this genus.

In summary, the turtle fossil record of the Late Cretaceous in northwestern New Mexico demonstrates a trend of increasing species richness, diversity, and body size from the Turonian to upper Campanian (Figure 1). The assemblage expands from three taxa representative of relatively ubiquitous clades in the Turonian Moreno Hill Fm. to over a dozen turtle species from numerous lineages filling a diversity of niches in the upper Campanian Kirtland and Fruitland Fms. This trend is consistent with patterns of increasing species richness and a latitudinal diversity gradient through the Late Cretaceous of Utah and northern Laramidia (Brinkman, 2003; Hutchison et al., 2013). The presence of the early derived baenid *Edowa zuniensis* also recalls a pattern observed in the known dinosaurs from Moreno Hill (a tyrannosauroid, neoceratopsian, and hadrosauromorph), where the taxa are relatively small in size and phylogenetically positioned just outside the major Late Cretaceous radiations of their respective clades (Nesbitt et al., 2019). This pattern may also reflect more limited sampling in the Moreno Hill Fm., an unknown bias against large remains, or relatively limited deposits due to transient shorelines and volatile eustasy.

References

Adrian. B., Smith, H. F., Kelley, K., & Wolfe, D. G. (2023). A new baenid, *Edowa zuniensis* gen. et sp. nov., and other fossil turtles from the Upper Cretaceous Moreno Hill Formation (Turonian), New Mexico, USA. *Cretaceous Research, 144*, 1-20.

Brinkman, D. B. (2003). A review of nonmarine turtles from the Late Cretaceous of Alberta. *Canadian Journal of Earth Sciences*, *40*, 557-571.

Cilliers, D., Tucker, R. T., Crowley, J. L., &. Zanno, L. E. (2021). Age constraint for the Moreno Hill Formation (Zuni Basin) by CA-TIMS and LA-ICP-MS detrital zircon geochronology. *PeerJ*, *9*, e10948.

Craigg, S. D. (2001). Geologic framework of the San Juan structural basin of New Mexico, Colorado, Arizona, and Utah, with emphasis on Triassic through Tertiary rocks. *United States Geological Survey Professional Paper, 1420*, 65.

Fowler, D. W. (2017). Revised geochronology, correlation, and dinosaur stratigraphic ranges of the Santonian-Maastrichtian (Late Cretaceous) formations of the Western Interior of North America. *PLoS One*, *12*, e0188426,

Hirayama, R., Brinkman, D. B., & Danilov, I. C. (2000). Distribution and biogeography of non-marine Cretaceous turtles. *Russian Journal of Herpetology*, *7*, 181-198.

Holroyd, P. A., & Hutchison, J. H. (2002). Patterns of geographic variation in latest Cretaceous vertebrates: Evidence from the turtle component. *Geological Society of America Special Paper, 361*, 179-190.

Hutchison, J. H., Knell, M. J., & Brinkman, D. B. (2013). Turtles from the Kaiparowits Formation, Utah. In A. L. Titus & M. A. Loewen (Eds.), *At the top of the Grand Staircase: The Late Cretaceous of southern Uta*h (pp. 295-318). Indiana University Press.

Kelley, V. C. (1957). Tectonics of the San Juan Basin and surrounding areas: Geology of Southwestern San Juan Basin. In *New Mexico Geological Society 2nd Field Conference Guidebook*, pp. 44-52.

Kelley, V. C. (1967). Tectonics of the Zuni-Defiance region, New Mexico and Arizona. In *New Mexico Geological Society 18th Annual Fall Field Conference Guidebook*, pp. 28-31.

Joyce, W. G., Sterli, J., & Chapman, S. D. (2014). The skeletal morphology of the solemydid turtle *Naomichelys speciosa* from the Early Cretaceous of Texas. *Journal of Paleontology, 88*, 1257-1287.

Joyce, W. G. (2017). A review of the fossil record of basal Mesozoic turtles. Bulletin of the *Peabody Museum of Natural History, 58*(1), 65-113.

Lichtig, A. J., & Lucas, S. G. (2015). Cretaceous turtles of New Mexico. *New Mexico Museum of Natural History and Science Bulletin, 67*, 129-137.

Lucas, S. G., & Sullivan, R. M. (2006). *Denazinemys*, a new name for some Late Cretaceous turtles from the Upper Cretaceous of the San Juan Basin, New Mexico. *New Mexico Museum of Natural History and Science Bulletin, 35*, 223-227.

Molenaar, C. M., Cobban, W. A., Merewether, E. A., Pillmore, C. L., Wolfe, D. G., & Holbrook, J. M. (2002). Regional stratigraphic cross sections of Cretaceous Rocks from East-Central Arizona to the Oklahoma Panhandle. Miscellaneous field studies map MF-2382. *United States Geological Survey*.

Nesbitt, S. J., Denton Jr., R. K., Loewen, M. A., Brusatte, S. L., Smith, N. D., Turner, A. H., Kirkland, J. I., McDonald, A., & Wolfe, D. G. (2019). A mid-Cretaceous tyrannosauroid and the origin of North American end-Cretaceous dinosaur assemblages. *Nature Ecology & Evolution, 3*, 892-899.

Nopcsa, B. F. (1931). Sur des nouveaux restes de Tortues du Danien du Midi de la France. *Bulletin de la Societe Geologique de France, 1*, 223-236.

Santucci, V. L., Tweet, J., Bustos, D., Von Haden, J., & Varela, P. (2014). Vertebrate paleontological resources from National Park Service areas in New Mexico. *New Mexico Museum of Natural History and Science Bulletin, 64*, 1-9.

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Sullivan, R. M., Jasinski, S. E., & Lucas, S. G. (2013). Re-assessment of Late Campanian (Kirtlandian) turtles from the Upper Cretaceous Fruitland and Kirtland formations, San Juan Basin, New Mexico, USA. In D. A. Brinkman, P. A. Holroyd, & J. D. Gardner (Eds.), *Morphology and evolution of turtles* (pp. 337-387). Springerlink, Vertebrate Paleobiology and Paleoanthropology Series.

Wolfe, D. G. (1989). *The stratigraphy and paleoenvironments of middle Cretaceous strata along the central Arizona-New Mexico Border* [Master's thesis, University of Colorado].

Wolfe, D. G., Kirkland, J. I., Denton, R., & Anderson, B. G. (1997). A new terrestrial vertebrate record from the Moreno Hill Formation (Turonian, Cretaceous), west-central New Mexico. *Journal of Vertebrate Paleontology*, *17*, 85A.

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 8:45 AM)

DROUGHT-AFFLICTED TETRAPODS IN THE EARLY TRIASSIC KAROO BASIN, SOUTH AFRICA

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The End-Permian Mass Extinction Event (EPME) approximately 251.9 Ma is widely regarded as Earth's greatest biological crisis (e.g., Wignall, 2007). A global increase in mean annual temperature of at least 10°C over 10-50 kyr (the hyperthermal of Benton, 2018) likely resulted from sustained atmospheric pollution accompanying massive volcanic eruptions in northern Pangaea, as evidenced by the Siberian and Emeishan large igneous provinces (e.g., Renne et al., 1995). Currently, debate is less about the numbers of species that disappeared or survived, but more concerned with the ultimate causes (precession versus volcanism), the kill mechanisms (hypoxia versus acid rain), and synchroneity of extinctions in different geographic areas and surface environments (e.g., continents versus oceans) relative to the Permo-Triassic Boundary.

Field investigation of the sedimentology and taphonomy of numerous in-situ fossils from earliest Triassic strata (Induan) in the southern Karoo Basin of South Africa is presented as evidence for episodes of drought-induced mass death of the resident tetrapods. Within an 800x800m study block 170 skeletons are preserved in a 2m-thick tabular silty-sandstone capping a multi-storeyed low-sinuosity channel sandstone interpreted as a wide shallow channel that became progressively abandoned, with more ephemeral flow regime than in the underlying channels and subjected to intermittent flows of low-density sediment-laden floodwaters. Areal distribution of in-situ tetrapod fossils shows several clusters of up to eight closely spaced articulated *Lystrosaurus* skeletons preserved in prone and spread-eagled body position. These are interpreted as drought-stricken carcasses that collapsed and died of starvation in and alongside dried-up water sources. Two of the specimens display an unusual micritic envelope with a distinctive pustular texture interpreted as permineralized mummified skin indicative of rapid desiccation after death (Fig 1).

Bonebeds of disarticulated bones of multiple juvenile *Lystrosaurus* occur in shallow depressions within the rubified mudstones (redbeds). Layering of different skeletal elements suggests some hydraulic sorting but the initial aggregation was likely a behavioural response to drought. Osteohistology of spread-eagled *Lystrosaurus* (*L. declivis* and *L. murrayi* species) skeletons show that they represent early juvenile stage which is in accordance with previous findings that throughout Pangaea Early Triassic *Lystrosaurus* died relatively young due to environmental stressors.

Interpreting the prevailing physical conditions during the burial of these skeletons from the lithofacies sequences, sedimentary structures and stacking patterns indicates seasonally dry floodplains with some loessic input and essentially ephemeral discharge regime in wide shallow low sinuosity rivers with numerous crevasse splays. The host strata and taphonomic modes of the 170 in-situ tetrapod fossils indicate that many of the articulated *Lystrosaurus* carcasses were clustered alongside, and within, abandoned low sinuosity channels. The distinctive reworked pedogenic nodule conglomerates that occur in both channel and overbank environments are here interpreted as evidence of denuded loessic soils and their presence confirms that the sediments and fossils accumulated under generally warm dry climatic conditions with unpredictable, monsoonal-type, bouts of torrential rainfall onto de-vegetated floodplains and that "badlands-type" dust storms were likely a regular occurrence. Our sampling of in-situ skeletons reinforces previous osteohistological findings that the vast majority of the

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Lystrosaurus remains are of juveniles and early subadults, and we go further to present taphonomic evidence of clusters of fully-articulated prone and spread-eagled juvenile skeletons, some preserving impressions of mummified skin as well as a monotaxic bonebed of at least nine juvenile *L. declivis* skeletons as evidence for episodes of drought-induced die-off.

Considering the position of the post-extinction Karoo Basin within the interior of southern Pangaea our findings suggest that there were times when the well-documented volcanically generated global hyperthermal conditions caused atmospheric instability resulting in successive years of less than average rainfall leading to severe drought conditions. The concomitant die-off among the Karoo tetrapod communities especially afflicted the juveniles of *Lystrosaurus*- the most common resident herbivores during the earliest Triassic. We propose that in the aftermath of the End-Permian mass extinction event, a succession of climatic drying episodes orchestrated a series of fully functioning terrestrial ecosystems that were markedly different to those of the pre-extinction, and likely had a profound and lasting influence on the evolution of tetrapods.

References

Benton, M. J. (2018). Hyperthermal-driven mass extinctions: killing models during the Permian–Triassic mass extinction. *Philosophical Transactions of the Royal Society of London A, 376*, 20170076. https://doi.org/10.1098/rsta.2017.0076



Figure 1. Preserved skin textures of *Lystrosaurus murrayi* specimen SAM-PK-K10971. A, prone and spread-eagled *L. murrayi* skeleton after collection with enveloping layer interpreted as calcite replacement of mummified skin. Scale bar = 10cm. B, vertebral column showing penetration of neural spines and transverse processes through the enveloping layer. Scale bar = 1cm. C, close-up of the pustular surface texture of interpreted mummified skin. Scale bar = 5mm. D, detail of *Lystrosaurus* zone scene reproduced with kind permission of artist John Sibbick showing skin textures similar to that of SAM-PK-K10971

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Renne, P. R., Zichao, Z., Richards, M. A., Black, M. T., & Basu, A. R. (1995). Synchrony and causal relationship between Permian-Triassic boundary crises and Siberian flood volcanism. *Science, 209*, 1413-1416.
Wignall, P. (2007). The End-Permian mass extinction–how bad did it get? *Geobiology, 5*, 303-309.

Theme Session: Global Perspectives on Mesozoic Lacustrine Ecosystems (Thursday, June 8, 2023, 4:00 PM)

LOCATING THE TRIASSIC-JURASSIC BOUNDARY WITHIN THE MOENAVE FORMATION: IMPLICATIONS FOR CLIMATIC, FAUNAL, AND ENVIRONMENTAL CHANGE OF THE LACUSTRINE WHITMORE POINT MEMBER FOLLOWING THE END-TRIASSIC EXTINCTION EVENT

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The continental record of the latest Triassic to earliest Jurassic transition in North America has historically been best documented in the Newark Supergroup of the Newark Basin. However, strata from the Glen Canyon Group of the Colorado Plateau in western Pangea, particularly the Moenave Formation, recently revealed a remarkable array of trace fossils, invertebrate and vertebrate body fossils, and plant fossils that span the Triassic-Jurassic boundary (Antonietto et al., 2018; Cornet & Waanders, 2006; Kirkland et al., 2014; Lucas & Heckert, 2001; Lucas & Milner, 2006; Milner et al., 2009, 2012). To compare the fauna from the Moenave Formation to the well-dated fauna of the Newark Basin and other units globally, a high-resolution geochronologic framework needs to be completed. Here we provide a novel age model for the Moenave Formation by using C-isotope chemostratigraphy and U-Pb analysis of detrital zircon to put the lacustrine fauna and flora of the Moenave Formation's Whitmore Point Member into a temporal context. We also describe the invertebrate fauna of the Whitmore Point Member and present some preliminary biomarkers and compound specific isotope analysis of *n*-alkanes from the unit.

Samples were collected from three sections of the Moenave Formation: 1) Potter Canyon in northern Arizona; 2) Blacks Canyon at Zion National Park, Utah; and 3) "Olsen Canyon" within Warner Valley to the southeast of St. George, Utah. Samples were collected every 25 cm for bulk organic C-isotope chemostratigraphy. Between 5 and 10 samples were collected for U-Pb geochronology from each section. C-isotope samples were analyzed via EA-IRMS, U-Pb detrital zircon samples were screened via LA-ICP-MS, and young grains were analyzed via CA-TIMS. Ostracodes were extracted from rock using 30% hydrogen peroxide wash to fragment samples, followed by sieve screening and picking using a stereomicroscope. Conchostracans were examined on rock surfaces. Both ostracode and conchostracan samples were imaged using scanning electron microscopy. Selected samples that yielded higher organic C percentages were extracted for the aliphatic and aromatic fraction of the total lipid extract. Samples were analyzed via gas chromatography. Samples that had identifiable *n*-alkanes or polycyclic aromatic hydrocarbons in sufficient amounts were analyzed for C-isotopes using GC-IRMS.

Detrital zircon U-Pb dates from CA-TIMS from the Dinosaur Canyon Member yield a maximum depositional age of 201.23 $\pm$ 0.07 Ma above a distinctive negative C-isotope excursion (NCIE) at Olsen Canyon and a maximum deposition age of 201.88 $\pm$ 0.06 Ma below a distinctive NCIE at Blacks Canyon. Within the Whitmore Point Member, maximum depositional ages are 201.33 $\pm$ 0.12 Ma at Potter Canyon and 201.2 $\pm$ 0.11 Ma at Blacks Canyon. C-isotope chemostratigraphy suggests this distinctive negative C-isotope excursion of ~-5‰ is similar to other end-Triassic extinction event (ETE) C-isotope excursions (the "initial NCIE") observed globally. The integration of CA-TIMS U-Pb dating with C-isotope chemostratigraphy suggest that the ETE interval occurs within the middle to upper portion of the Dinosaur Canyon Member and the fauna and flora from the overlying lacustrine Whitmore Point Member are earliest Jurassic (Hettangian). The ostracode fauna comprise taxa from the parthenogenetic suborder Darwinulocopina, as is characterized by low specific diversity, with only

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Suchonellina globosa, *S. stricta*, and two unidentified species of *Whippella* preserved (Antonietto et al., 2018). Conchostracans occur in some assemblages alongside ostracodes; although they are generally poorly preserved, they can be attributed to the Order Spinicaudata. The presence of spinicaudatans is indicative of wet-dry cycles within the lake environment. Vertebrate trace fossils from the upper part of the Dinosaur Canyon Member and the Whitmore Point Member include *Grallator* and *Batrachopus*, as well as rare *Eubrontes* and cf. *Anomoepus*. *Eubrontes* and *Anomoepus* tracks become more numerous within the Whitmore Point Member.

At Blacks Canyon, biomarker analysis records an increase in the Pristane/Phytane (Pr/Ph) ratio within the initial negative C-isotope excursion of the Dinosaur Canyon Member, followed by a decrease in the Pr/Ph ratio during deposition of the overlying lacustrine Whitmore Point Member. An initial increase in the total pyrogenic polycyclic aromatic hydrocarbon (ΣPAH (ng/g)) during the NCIE is followed by an immediate decrease; then an increase in ΣPAH (ng/g) in the upper part of the Whitmore Point Member is observed within the aromatic fraction of the total lipid extract. No biomarkers at Blacks Canyon were preserved in sufficient amounts for compound specific isotope analysis. At Potter Canyon, which primarily preserves the Whitmore Point Member, a negative C-isotope excursion in the bulk organic C that Suarez et al. (2017) identified as a local NCIE or a separate global event preserves Pr/Ph ratios less than 1.0 indicating reducing conditions. Four samples from Potter Canyon had sufficient material preserved for isotopic analysis. Those samples that did preserve sufficient sample for isotopic composition of *n*-alkanes are within the negative C-isotope excursion within Potter Canyon. Samples WPRS-6 and -7 have the lowest bulk C-isotope values of -30.09‰ and -30.26‰ respectively. These two samples only preserved C-17, Pristane, Phytane, and C-18 in sufficient amounts for CISA. For WPRS-6, C-17 = -29.45‰, Phytane = 31.45‰, and C-18 = -27.78‰. For WPRS-8, Phytane = -29.69‰ and C-18 = -27.57‰. WPRS-8 has a bulk organic C-isotope value of -26.89‰, while *n*-alkanes C-25 to C-31 range between -30.95‰ to -31.56‰, which is significantly more depleted in ^{12}C than the bulk value. WPRS-11, a sample above the NCIE, has a bulk C-isotope value of -24.24‰ and C-22 to C-27 values that range between -26.59‰ to -22.09‰, similar to the bulk organic C-isotope value.

The chronostratigraphic framework of the Moenave Formation indicates that the ETE is preserved within the middle to upper portion of the Dinosaur Canyon Member and as such, the lacustrine ecosystem of the Whitmore Point Member is entirely earliest Jurassic. The similarity between most bulk organic C-isotope values and the *n*-alkane values from the same sample suggests the bulk value is representative of the average plant C-isotope value. The C-isotope excursion preserved within the Dinosaur Canyon Member is associated with a carbon perturbation to the global C-cycle as a result of the eruption of the Central Atlantic Magmatic Province (CAMP). The CAMP resulted in an initial decrease in temperature as a result of SO_2 and ash release (Olsen, et al., 2022) followed by a 2-2.5x increase in pCO_2 (Schaller et al., 2012, 2015; Mmasa 2021). It has been suggested that the resulting increase in temperature caused an intensified hydrologic cycle (Fox et al., 2020) as well as increases in wildfire occurrences (Fox et al., 2020; Williford et al., 2014). The record for the Moenave Formation seems to support this. The increase in hydrologic cycle intensity could have contributed to the formation of lacustrine deposition of Lake Whitmore as preserved as the Whitmore Point Member. This interpretation is also supported by an initial increase in wildfire biomarkers both immediately within the ETE NCIE as well as those preserved within the overlying Whitmore Point Member. This interpretation is also supported by the initial increase in Pr/Ph ratios within the ETE NCIE of the Dinosaur Canyon Member as increased weathering and oxidation occurred (as a result of increased atmospheric CO_2 concentrations) followed by the decrease in Pr/Ph ratios supporting reducing conditions as local base-level reached a "high stand" (following an intensified hydrologic cycle). The ostracode fauna preserved within the Whitmore Point Member also supports a stressed ecosystem. The low diversity is similar to post-Permian-Triassic freshwater ostracode assemblages, which relied on fast-paced asexual reproduction to counter environmental instability. The low-diversity ostracode fauna seems to have lasted until the Middle Jurassic Cytherocopine/Cypridocopine radiation. This stressed ecosystem is also reflected by the conchostracan fauna which records periodic drying of the lake, or at least lake margins due to fluctuating hydrologic conditions. A similar conclusion was found by Kürschner et al. (2013) in that *Classopolis* pollen grains from the Whitmore Point Member at Potter Canyon exhibit aberrant tetrad, triad, and dyad grains indicating polyploid speciation due to environmental stress. Taken together, the lacustrine ecosystem represents a "refuge" following the environmental degradation associated with climate change and the ETE event, in which organisms utilized various resilient traits to survive soon after the extinction event. Although the invertebrate biota seems to represent a stressed environment, vertebrate traces indicate the survivors of the ETE thrived, especially members of the non-avian dinosaurs. Further geochemical and stratigraphic assessment of invertebrate and vertebrate fossils

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(both trace and body) will help us to understand the continental recovery from the ETE event.

References

Antonietto, L. S., Park-Boush, L., Suarez, C. A., Milner, A. R. C., & Kirkland, J. I. (2018). The "Last Dawn of the Reigning Darwinulids"? A review of the Ostracoda (Arthropoda: Crustacea) from the Whitmore Point Member, Moenave Formation, Lower Jurassic (Hettangian), Arizona and Utah, USA. *Journal of Paleontology, 92*(4), 648-660.

Cornet, B., & Waanders, G. L (2006). Palynomorphs indicate Hettangian (Early Jurassic) age for the middle Whitmore Point Member of the Moenave Formation, Utah and Arizona. In *The Triassic-Jurassic terrestrial transition, New Mexico Bulletin of Natural History and Science, 37*, 390.

Fox, C. P., Cui, X., Whiteside, J. H., Olsen, P. E., Summons, R. E., & Grice, K. (2020). Molecular and isotopic evidence reveals the end-Triassic carbon isotope excursion is not from massive exogenous light carbon. *Proceedings of the National Academy of Sciences, 117*(48), 30171-30178.

Kirkland, J. I., Milner, A. R. C., Olsen, P. E., & Hargrave, J. (2014). The Whitmore Point Member of the Moenave Formation in its type area in Northern Arizona and its age and correlation with the section in St. George, Utah: Evidence for two major lacustrine sequences. In *Geology of Utah's far South* (pp. 322-355). Utah Geological Association.

Kürschner, W. M., Batenburg, S. J., & Mander, L. (2013). Aberrant *Classopollis* pollen reveals evidence for unreduced (2n) pollen in the conifer family Cheirolepidiaceae during the Triassic–Jurassic transition. *Proceedings of the Royal Society B: Biological Sciences, 280* (1768), 20131708.

Lucas, S. G., & Heckert, A. B. (2001). Theropod dinosaurs and the Early Jurassic age of the Moenave Formation, Arizona-Utah, USA. *Neues Jahrbuch für Geologie und Paläontologie, 2001*, 435-488.

Lucas, S. G., & Milner, A. R. C. (2006). Conchostraca from the Lower Jurassic Whitmore Point Member of the Moenave Formation, Johnson Farm, southwestern Utah. In J. Harris, S. G. Lucas, J. A. Spielmann, M. G. Lockley, A. R. C. Milner, & J. I. Kirkland (Eds.), *The Triassic-Jurassic terrestrial transition. New Mexico Museum Bulletin of Natural History, 37*, 421-423.

Milner, A. R., Harris, J. D., Lockley, M. G., Kirkland, J. I. & Matthews, N. A. (2009). Bird-like anatomy, posture, and behavior revealed by an Early Jurassic theropod dinosaur resting trace. *PLoS ONE, 4*(3), e4591.

Milner, A. R. C., Birthisel, T., Kirkland, J. I., Breithaupt, B. H., Matthews, N. A., Lockley, M., Santucci, V. L., Gibson, S. Z., DeBlieux, D. D. Hurlbut, M., Harris, J., & Olsen, P. E. (2012). Tracking Early Jurassic dinosaurs across southwestern Utah and the Triassic-Jurassic transition. In *Nevada State Museum, Paleontological Papers 1 – 71st Annual Meeting of the Society of Vertebrate Paleontology* (p. 108).

Mmasa, D. (2021). *Effects of the Triassic-Jurassic Central Atlantic magmatic event recorded in continental strata in western Pangea: The $\delta^{13}C$ record of Warner Valley & Zion National Park* [Master's Thesis, University of Arkansas].

Olsen, P., Sha, J., Fang, Y., Chang, C., Whiteside, J. H., Kinney, S., Sues, H.-D., Kent, D, Schaller, M., & Vajda, V. (2022). Arctic ice and the ecological rise of the dinosaurs. *Science Advances, 8*(26), eabo6342.

Schaller, M. F, Wright, J. D., & Kent, D. V. (2015). A 30 Myr record of Late Triassic atmospheric pCO2 variation reflects a fundamental control of the carbon cycle by changes in continental weathering. *Geological Society of America Bulletin, 127*(5-6), 661-671.

Schaller, M. F., Wright, J. D., Kent, D. V., & Olsen, P. E. (2012). Rapid emplacement of the Central Atlantic Magmatic Province as a net sink for CO_2. *Earth and Planetary Science Letters, 323*, 27-39.

Suarez, C. A., Knobbe, T. K., Crowley, J. L., Kirkland, J. I., & Milner, A. R. C. (2017). A chronostratigraphic assessment of the Moenave Formation, USA using C-isotope chemostratigraphy and detrital zircon geochronology: Implications for the terrestrial end Triassic extinction. *Earth and Planetary Science Letters, 475*, 83-93.

Williford, K. H., Grice, K., Holman, A., & McElwain, J. C. (2014). An organic record of terrestrial ecosystem collapse and recovery at the Triassic–Jurassic boundary in East Greenland. *Geochimica et Cosmochimica Acta, 127*, 251-263.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 10:15 AM)

UPDATES ON THE CHRONOSTRATIGRAPHIC FRAMEWORK OF THE CEDAR MOUNTAIN FORMATION OF UTAH AND IMPLICATIONS FOR FAUNAL COMPARISONS AND THE CRETACEOUS TERRESTRIAL REVOLUTION

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The Lower Cretaceous of Utah preserves a multitude of dinosaur taxa, records the spread of angiosperms on the North American continent, along with the evolution of marsupial and eutherian mammals. Despite this importance, the timing of deposition of these rocks, unconformities within the record and depositional rates are poorly understood. Important fossil-bearing units as well as correlation of these units must be determined to understand climatic and tectonic controls on these biological events. Recent work from our group is clarifying the age distribution and depositional rates of the Cedar Mountain Formation of east-central Utah by using a combination of detrital zircon geochronology, C-isotope chemostratigraphy of bulk organic matter, and biostratigraphy. Here we present the first full C-isotope chemostratigraphic curve for the Cedar Mountain Formation (CMF) on the western end of the depositional belt and compare it to some of the ages and chemostratigraphy from other locations in the CMF.

Bulk organic C, carbonate C, and detrital zircon geochronology samples were taken from near Moore Cutoff Road (UT Hwy 803), approximately 25 km south of Castle Dale, Utah, within southwestern Emery County. Organic C samples were taken every 25 cm where possible and detrital zircon samples were taken at key stratigraphic intervals. A detailed measured section was taken from the top of the Morrison Formation to the base of the Naturita Sandstone. Members of the CMF described include the Yellow Cat, Ruby Ranch, Short Canyon Conglomerate, and Mussentuchit. Within the Yellow Cat Member, pre-excursion values are $\delta^{13}C \approx$ -26‰ VPDB, followed by a small negative C-isotope excursion (NCIE) of -2.5‰ magnitude at 6.5 m. This is followed by a double peaked positive C-isotope excursion (PCIE) that reaches a maximum of -22.8‰ at 9.7 m. C-isotopes values then decrease consistently from this point throughout the remainder of the Yellow Cat Member. A CA-ID-TIMS generated detrital zircon sample gives a weighted mean age of 126.45 ± 0.08 Ma sampled between 4.75 to 6.25 m at the base of the PCIE suggests the PCIE must be younger than 126.45 Ma. The Ruby Ranch Member preserves at least three PCIE. Background values start ∼ -24‰ and increase to -22.8‰ then decrease to pre-excursion values. The main PCIE expressed in the section ranges between 40 m above the Morrison Formation boundary to 60 m above the Morrison Formation boundary and is a double peaked PCIE with a magnitude of ∼ +5‰ to a maximum value of -19.3‰ and then decreases to a minimum of -26.0‰. A third, less extreme PCIE of magnitude +4‰ occurs starting at ∼ 60 m before decreasing in C-isotopic composition to ∼ -24‰. No C-isotope chemostratigraphic samples were taken from the cobble conglomerate lithology of the Short Canyon Conglomerate; however, a detrital zircon sample was taken from the medium to fine grain sands at the top of the member and resulted in a youngest maximum depositional age no older than 103.08 ± 0.05 Ma. The Mussentuchit Member has a background $\delta^{13}C_{org}$ value between -23 to -24‰ before a moderate PCIE occurs with a magnitude of ∼+4‰ between 8.5 and 10.75m above the Short Canyon Conglomerate with a maximum value of -19.98‰ and then rapidly decreases in C-isotopic composition to ∼ -25.5‰. The youngest aged ash zone for the Mussentuchit Member is 98.931 ± 0.054 Ma (Tucker et al., in press) suggesting that the majority of the Mussentuchit Member was deposited in the early Cenomanian.

Based on these values, the Yellow Cat Member at Moore Cutoff Road on the western side of the outcrop belt preserves the PCIE consistent with the OAE1a; a C-cycle perturbation caused by the eruption of the Ontong-Java large igneous province, which formed between 126 and 119 Ma. The Ruby Ranch Member preserves a sustained broad PCIE relative to underlying and overlying units that has been described as the C10 PCIE by (Bralower et al., 1999). This interval ranges in age between ∼117 Ma to ∼112 Ma. The addition of the 103.08 Ma maximum depositional age for the upper part of the Short Canyon Conglomerate suggests the Ruby Ranch Member here is mostly Late Aptian to Albian. Although the PCIE from the Mussentuchit Member is reminiscent of the mid-Cenomanian Event (96.4 – 95.8 Ma), newly described ash ages from Tucker et al (in press) suggests the Mussentuchit Member deposition ranges between 99.95 to 98.931 Ma (Cenomanian) suggesting the PCIE within our section is a local PCIE that is not related to global C-cycle perturbations, however, additional detrital zircon ages from within this section will test this. Overall, the Moore Cutoff Road section preserves a near-

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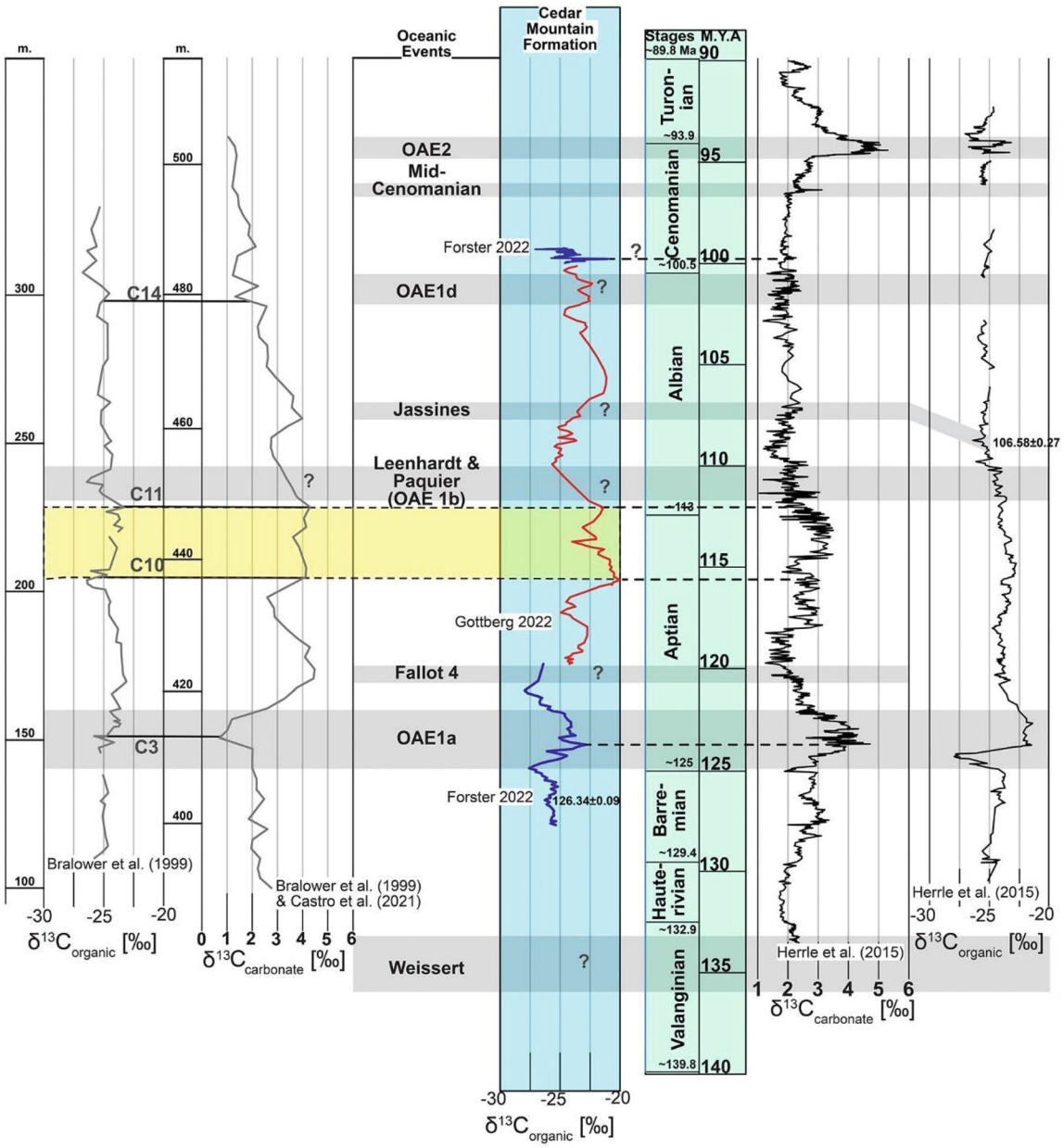


Figure 1. Comparison of C-isotope chemostratigraphic records along with known ocean anoxic events (OAEs) from the Cretaceous to the C-isotope record from the CMF at Moore Cutoff Road (UT-803). The CMF curve is fitted to the chemostratigraphic section and bounding conditions according to (Bralower et al., 1999) and compared to (Castro et al., 2021), (Herrle et al., 2015). All values are compared to VPDB

continuous depositional record (albeit with some unconformities) between a maximum of 126.45 Ma and a minimum of 98.931 Ma.

Relative to other studied sections of the CMF, one clear trend seems to occur. Ages for the Yellow Cat facies from the western part of the CMF outcrop belt preserve maximum depositional ages from detrital zircons, C-isotope chemostratigraphic ages, and magnetostratigraphy of Lower Aptian age (~126 Ma) while sections on the eastern edge of the outcrop belt (east of the Salt Valley Anticline) preserved maximum ages from detrital zircon, C-isotope chemostratigraphy, as well as biostratigraphy (pre-angiosperm pollen, ostracods and charophytes) much older than this, as old as Berriasian (145.0 – 139.4 Ma) (Joeckel et al., 2019; Martín-Closas et al., 2013; Sames et al., 2010). This has significant influence on the faunal assemblages' interpreted age distributions and interpreted faunal turnover. These age discrepancies may be related to differing tectonic control on depositional basins, with the Sevier Fold and Thrust Belt creating

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depositional basins and source sediment in the west and salt tectonics controlling depositional basins in the east (Kirkland et al., 2016). Additional high resolution chronostratigraphic work will help us to correlate fauna from the CMF to each other as well as fauna from other units along the Western Interior Basin such as the Cloverly, Kootenai, and Blackleaf formations. This painstaking work is crucial to interpreting the climatic and tectonic controls on the Cretaceous terrestrial revolution, latitudinal faunal zones, and paleobiogeography.

References

Bralower, T. J. CoBabe, E., Clement, B., Sliter, W. V., Osburn, C. L., & Longoria, J. (1999). The record of global change in Mid-Cretaceous (Barremian-Albian) sections from the Sierra Madre, northeastern Mexico. *Journal of Foraminiferal Research, 29*, 418-437.

Castro, J. M., Ruiz-Ortiz, P. A., de Gea, G. A., Aguado, R., Jarvis, I., Weissert, H., Molina, J. M., Nieto, L. M., Pancost, R. D., Quijano, M. L., Reolid, M., Skelton, P. W., López-Rodríguez, C., & Martínez-Rodríguez, R. (2021). High-resolution C-Isotope, TOC and biostratigraphic records of OAE 1a (Aptian) from an expanded hemipelagic cored succession, Western Tethys: A new stratigraphic reference for global correlation and paleoenvironmental reconstruction. *Paleoceanography and Paleoclimatology, 36*, e2020PA004004.

Herrle, J. O., Schröder-Adams, C. J., Davis, W., Pugh, A. T., Galloway, J. M., & Fath, J. (2015). Mid-Cretaceous high Arctic stratigraphy, climate, and oceanic anoxic events. *Geology, 43*, 403-406.

Joeckel, R. M., Ludvigson, G. A., Möller, A., Hotton, C. L., Suarez, M. B., Suarez, C. A., Sames, B., Kirkland, J. I., & Hendrix, B. (2019). Chronostratigraphy and terrestrial palaeoclimatology of Berriasian–Hauterivian strata of the Cedar Mountain Formation, Utah, USA. *Geological Society of London, Special Publication*, SP498-2018-133.

Kirkland, J. I., Suarez, M. B., Suarez, C. A., & Hunt-Foster, R. (2016). The Lower Cretaceous in east-central Utah—the Cedar Mountain Formation and its bounding strata. *Geology of the Intermountain West, 3*, 101-228.

Martín-Closas, C., Sames, B., & Schudack, M. E. (2013). Charophytes from the Upper Berriasian of the Western Interior Basin of the United States. *Cretaceous Research, 46*, 11-23.

Sames, B., Cifelli, R. L., & Schudack, M. E. (2010). The nonmarine Lower Cretaceous of the North American Western Interior foreland basin: new biostratigraphic results from ostracod correlations and early mammals, and their implications for paleontology and geology of the basin—an overview. *Earth-Science Research, 101*, 207-224.

Tucker, R. T., Crowley, J. I., Renault, R. K., Makovicky, P. J., Cifelli, R. L., & Zanno, L. E. (In Press). Exceptional age constraint on a fossiliferous sedimentary archive preceding the Cretaceous Thermal Maximum. *Geology*

Theme Session: Global Perspectives on Mesozoic Lacustrine Ecosystems (Thursday, June 8, 2023, 3:30 PM)

A WINDOW TO THE EARLY CRETACEOUS NORTH AMERICAN CLIMATE AND ENVIRONMENT: THE 'LAKE CARPENTER' LACUSTRINE STRATA OF THE CEDAR MOUNTAIN FORMATION

Suarez, Marina B.[1], Al-Suwaidi, Aisha[2], Kirkland, James I.[3] Snell, Kathryn[4], Möller, Andreas[1], McLean, Noah[1], Suarez, Celina A.[5], Montgomery, Elizabeth[6], Paige, Marquise[7]

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The Cedar Mountain Formation is thought to span a significant portion of the lower Cretaceous and the base of the upper Cretaceous (Valanginian to Cenomanian). As such, the Cedar Mountain Formation is important for understanding the transition of terrestrial ecosystems from those characterized by pre-angiosperm ecosystems of the Jurassic to the angiosperm-dominated ecosystems that characterized the height of dinosaur diversity in the later part of the Cretaceous. Lacustrine strata offer unique opportunities to shed light on environmental and climate conditions of the past. This study presents results from a multi-proxy study of lacustrine strata in the Cedar Mountain Formation termed "Lake Carpenter." The

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sequence of strata is about ~30 m thick and located near Arches National Park. The lower ~7 m is characterized by dark organic-rich mudstones, shales, and tan limestones and dolostone. The middle portion between about 7 and 25m consists of more massive carbonate-rich strata with abundant aquatic fossils including ostracodes, charophytes, and fish scales. The upper portion to about 30 m consists of green to tan mudstones with carbonate nodules and increases in siliciclastic content. Carbonate mineralogies include calcite, high-magnesium calcite, and dolomite (including dolomicrites) based on XRD analyses.

To put the lacustrine sequence into stratigraphic context, bulk organic C isotope values were utilized to construct a chemostratigraphic record and four suspected ashes were analyzed using LA-ICP-MS. Carbon isotope values range from -32.3‰ to -21.1‰ vs. VPDB. Of the four horizons for which zircons were analyzed, one produced Cretaceous numerical ages that were also concordant. This sample was analyzed using CA-ID-TIMS and produced a date of 115.65 ± 0.18 Ma. Based on the chemostratigraphic record and the U-Pb date, the deposition of the lacustrine sequence occurs in the mid to late Aptian and spans a time that is thought to have resulted in a cold snap based on marine records.

Carbon and oxygen stable isotope analyses of the carbonates within the lacustrine sequence ranges from -9.2‰ to +5.4‰ vs. VPDB for carbon and -9.3 to -0.3‰ vs. VPDB for oxygen. Overall, carbonate isotope data is positively covariant and along with the minerology, seems to suggest that the lake was a closed-basin, alkaline lake and would have likely experience significant evaporation. To investigate paleotemperature, selected samples were analyzed for clumped isotope values (Δ_{47}) to determine temperature of formation. Preliminary temperature estimates of calcite formation range from 27°C to 41°C. Estimates for dolomite range from 19°C to 21°C. Lacustrine carbonate formation typically is biased toward spring and summer and as such some of these temperatures (particularly the values for dolomites) seem slightly lower than expected for a greenhouse climate but may be consistent with a "cold-snap" during the late Aptian. Palustrine carbonates from the type section of the Ruby Ranch Member range from 19.8°C to 44.5°C (Suarez et al., 2021) and suggests the lacustrine strata records a similar range in temperatures during the Aptian Stage in this part of North America.

Reference

Suarez, M. B., Knight, J., Snell, K. E., Ludvigson, G. A, Kirkland, J. I., & Murphy, L. (2020). Multiproxy paleoclimate estimates of the continental Cretaceous Ruby Ranch Member of the Cedar Mountain Formation. In A.-V. Bojar, A. Pelc, & C. Lecuyer (Eds.), *Stable isotopes studies of water cycle and terrestrial environments. Geological Society of London, Special Publication 507*. https://doi.org/10.1144/SP507-2020-85

Theme Session: Laramidia to Asia: Biota and Biogeography of Interconnected Iconic Late Cretaceous Ecosystems (Saturday, June 10, 2023, 4:50 PM)

TYRANNOSAURID DINOSAUR DIVERSITY IN MIDDLE AND UPPER CAMPANIAN (LATE CRETACEOUS) ECOSYSTEMS OF LARAMIDIA: NEW INFORMATION FROM THE KAIPAROWITS FORMATION OF SOUTHERN UTAH, USA

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The coastal and alluvial plains of eastern Laramidia (~85-70 Ma) hosted one of the most diverse and well-studied series of dinosaur assemblages in the world, with rich faunas that included tyrannosaurids, deinonychosaurians, pachycephalosaurians, ceratopsids, hadrosaurids, and ankylosaurians. Among large-bodied carnivorous theropods, it has been long accepted that two major late Campanian lineages of tyrannosaurids (Albertosaurinae and Daspletosaurini) lived sympatrically in the well-studied northern Laramidian region of western North America (Montana, USA; Alberta, Canada) in several stratigraphic intervals/formations (e.g., Dinosaur Park Formation *Daspletosaurus* cf. *D. wilsoni*, *Gorgosaurus libratus*). The coexistence of these two apex predators has been explained as possible niche partitioning or differential landscape utilization (Farlow & Pianka, 2002). However, prior to 2014, there was no evidence for more than one tyrannosaurid taxon at any given time in the entirety of the Campanian in more southern regions of Laramidia despite a proliferation of new discoveries from southern Utah (Wahweap and Kaiparowits formations), northwestern New Mexico (Menefee and Kirtland formations), and West Texas (Aguja Formation).

The single named tyrannosaurid taxon from the upper Campanian Kaiparowits Formation (~77-73 Ma),

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Teratophoneus curriei, is known from at least two stratigraphically distinct localities in the middle unit (~76 Ma), and the two known specimens comprise a juvenile and sub-adult. Recent work on material collected from the 'Rainbows and Unicorns' bonebed (UMNH VP Locality 1869), which preserves a mass mortality of at least four individuals of different ontogenetic stages, and a largely complete, articulated subadult specimen excavated in 2017 (UMNH VP Locality 2239), demonstrate that there are substantial morphological differences between the crania of these newer specimens and both specimens of *T. curriei*. The new specimens all share similar morphologies, and differ from *T. curriei* in morphology of the jugal, lacrimal, postorbital, parietal, and frontal architecture, as well as maxillary tooth counts and overall snout depth. This leads us to hypothesize the new specimens represent a new tyrannosaurid taxon, possibly representing a separate clade. Although the hypodigm of *T. curriei* and the new specimens do not directly overlap stratigraphically, the highest occurrence of this new taxon and the lowest occurrence of *T. curriei* are within 100 meters of each other. With available radioisotopically-constrained age-stratigraphic models for the Kaiparowits Formation, this thickness probably represents less than 100,000 years of time (Ramezani et al., 2022; Roberts et al., 2013), leaving a significant possibility that the two tyrannosaurid taxa are sympatric. Given the emerging evidence for greater richness in many other Campanian vertebrate groups in southern Laramidia (e.g., Ceratopsidae), it is not surprising that its apex predator diversity is at least equal to that observed to the north, with similar ecological and biogeographic implications.

References

Farlow, J. O., & Pianka, E. R. (2002). Body size overlap, habitat partitioning and living space
requirements of terrestrial vertebrate predators: Implications for the paleoecology of large theropod dinosaurs. *Historical Biology, 16*, 21-40.

Roberts, E. M., Sampson, S. D., Deino, A., & Bowring, S. (2013). The Kaiparowits Formation: a remarkable record of Late Cretaceous terrestrial environments, ecosystems and evolution in western North America. In A. L. Titus & M. A. Loewen (Eds.), *At the top of the Grand Staircase: The Late Cretaceous of southern Utah* (pp. 85-106). Indiana University Press.

Ramezani, J., Beveridge, T. L., Rogers, R. R., Eberth, D. A., & Roberts, E. M. (2022). Calibrating the zenith of dinosaur diversity in the Campanian of the Western Interior Basin by CA-ID-TIMS U-Pb geochronology. *Scientific Reports, 12*, 16026.

Technical Session 3: Terrestrial Ecosystems – Late Cretaceous (Saturday, June 10, 2023, 1:45 PM)

HOODOO-THUNKIT? THE BEGINNINGS OF A LATE CRETACEOUS PALEONTOLOGY PROGRAM AT BRYCE CANYON NATIONAL PARK

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In the hundred years since Bryce Canyon National Park (BRCA) was first designated as a national monument in 1923, over 61 million visitors have marveled at its spectacular vistas of Eocene-age pink hoodoos. These geological icons have overshadowed the park's Cretaceous rocks, which include the terrestrial Wahweap and Straight Cliffs formations and the deep marine Tropic Shale. This relative neglect is despite BRCA's close proximity to Grand Staircase-Escalante National Monument (GSENM) and Dixie National Forest, which have both produced famous dinosaur faunas from the Campanian Kaiparowits and Wahweap formations and Turonian-Santonian Straight Cliffs Formation. The overlap in fossiliferous rock formations between BRCA and its neighboring public lands (e. g. GSENM) suggests that the park has high potential for fossils of similar age and faunal composition.

Despite extensive paleontological research in the region, fossils at BRCA have historically been overlooked save for the efforts of Dr. Jeffrey Eaton, Professor Emeritus of Geosciences at Weber State University, and his students. From 1989 to 2013, they documented and collected from 172 fossil-bearing localities within BRCA's borders (Eaton, unpublished field notes). Most of these sites occur in the Wahweap and Straight Cliffs formations and have produced abundant invertebrates, plants, and vertebrates. Among the collected fossils are four microvertebrate holotypes: the multituberculate mammal *Dakotamys shakespeari* (Eaton, 2013) and the paramacellodid scincomorph lizard *Monocnemodon syphakos* (Nydam, 2013) from the Straight Cliffs, and the sclerorhynchid sawfish *Columbusia deblieuxi* and *Texatrygon brycensis* from the Wahweap (Kirkland et al., 2013). Most of Dr. Eaton's collected fossils are housed at the Natural History Museum of Utah (UMNH). Just a small number of fossils from BRCA are housed at Zion National Park, where space is

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extremely limited. To date, BRCA lacks its own collections facility and management program.

Though Dr. Eaton did not document new localities after 2013, the need for continued paleontological management in BRCA became ever more apparent due to road construction that destroyed eight UMNH localities in the Wahweap Formation in 2015 and 2020 (Meyers and Knauss, 2021). Emergency paleontological monitoring of the 2020 construction activities resulted in fossil collection from 29 localities, 26 of which were newly documented.

Dr. Eaton's prolific work and the recent destruction of some of BRCA's most vulnerable Cretaceous fossils motivated the park's Resource Management Division to establish a new internal paleontology management program. In the 2022 field season, we embarked upon the relocation and assessment of Dr. Eaton's previously reported UMNH sites with the help of his extensive field notes. By mid-November, we documented 105 localities across the park's four paleontologically significant geological formations (Eocene-aged Claron Formation; Campanian Wahweap, Turonian-Santonian Straight Cliffs, and Turonian Tropic Shale). Of these, 59 are newly recorded. The park's terrestrial Cretaceous rocks are the best represented among the 2022 dataset, exemplified by 85 total localities (49 Straight Cliffs, 36 Wahweap). These include several sites that require annual monitoring due to the presence of either highly abundant, diverse, or diagnostic fossils in rapidly eroding and/or easily accessible places. Trace fossils, snails, plants, and macrovertebrates such as turtles, crocs, and dinosaurs comprise the fossils encountered in the park. A particularly important new discovery is the first recorded instance of a hadrosaur trackway in BRCA's 100-year history, which needs to be digitized for posterity through photogrammetry and 3D printing (Figure 1E). Fossil collection in 2022 has been limited to a small handful of specimens due to the lack of adequate space; however, collected specimens include crocodilian and dromaeosaur teeth and large (~20 cm) condyles of ornithischian dinosaur limbs (Figure 1A, C, and D). At least three hadrosaur-bearing sites will ultimately require excavation and collection in the coming years.

Given the developments of the 2022 field season, BRCA aims to expand its capacity to preserve and protect its fossils for the scientific education and enjoyment of future generations. Strategies toward achieving this goal could include erecting collections and laboratory facilities, collaborating with outside researchers, and educating the public through engaging citizen science and outreach



Figure 1. Newly discovered Cretaceous fossils in Bryce Canyon National Park. **(A)** crocodilian tooth **(B)** willow leaf impressions, **(C)** dromaeosaurid tooth, **(D)** ornithischian tibia condyle, and **(E)** hadrosaur footprint, human foot for scale. Scale bar in (A) in cm, scale bar in (D) in both cm and mm.

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programs. It is important to consider all protective measures at this crucial time, as BRCA is on the cusp of two centennial celebrations: one for its National Monument designation in 2023, the next for its National Park designation in 2028. These celebrations will likely increase visitation and public engagement, which would serve both as a logistical challenge and an excellent opportunity for outreach. Deliberate and decisive action taken over the next few years can help establish BRCA as a successful fossil park and connect its natural history to the paleontological stories of the Southern Utah region.

References

Eaton, J. G. (2004). Bryce Paleo sites. Unpublished field notes.

Eaton, J. G. (2011a). BCNP Localities 2006-10 Locs. 772-869. Unpublished field notes.

Eaton, J. G. (2011b.) Localities 2006-10 - Locs. 1062 up. Unpublished field notes.

Eaton, J. G. (2011c). BCNP Invertebrate and Paleobotany Localities 2006-10. Unpublished field notes.

Eaton, J. G. (2011d). UMNH VP Localities Pre-Inventory Locs. 417-569. Unpublished field notes.

Eaton, J. G. (2011e). 2011 BCNP Localities Complete. Unpublished field notes.

Eaton, J. G. (2013a.) Eaton BCNP Fossil Localities 2013. Unpublished field notes.

Eaton, J. G. (2013b). Late Cretaceous mammals from Bryce Canyon National Park and vicinity, Paunsaugunt Plateau, southwestern Utah. In A. L. Titus, & M. A. Loewen (Eds.), *At the top of the Grand Staircase: The Late Cretaceous of southern Utah* (pp. 329-369). Indiana University Press.

Kirkland, J. I., Eaton, J. G., & Brinkman, D. B. (2013). Elasmobranchs from Upper Cretaceous freshwater facies in Southern Utah. In A. L. Titus, & M. A. Loewen (Eds.), *At the top of the Grand Staircase: The Late Cretaceous of southern Utah* (pp. 153-194). Indiana University Press.

Meyers, V. L., & Knauss, G. E. (2021). *Paleontological monitoring and mitigation report for UDOT State Route 12 stabilization and improvements project, Bryce Canyon National Park, Garfield County, Utah. SWCA Paleontological Resources Report No. UT20-63508-04*. SWCA Environmental Consultants.

Nydam, R. L. (2013). Lizards and snakes from the Cenomanian through Campanian of southernUtah: Filling the gap in the fossil record of Squamata from the Late Cretaceous of the Western Interior of North America. In A. L. Titus, & M. A. Loewen (Eds.), *At the top of the Grand Staircase: The Late Cretaceous of southern Utah* (pp. 370-423). Indiana University Press.

Poster Session 2 (Friday, June 9, 2023)

CHALLENGES AND SUCCESSES OF DATING MESOZOIC TERRESTRIAL ROCKS: AN UPDATE ON THE MORRISON FORMATION DATING PROJECT

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1 INTRODUCTION

The Upper Jurassic Morrison Formation (MF) of the western interior of North America is one of the most prolific fossil-bearing rock units in the world. Many different aspects of the formation, from sedimentology and stratigraphy to paleontology and paleoecology have been studied in detail across its depositional area since its first fossils were discovered in the mid-1800s.

Long-distance correlations of this widespread formation are difficult for many reasons, including the inherent variability of terrestrial systems, a lack of biostratigraphically useful fossils, and a lack of widespread definitive marker horizons. Isotopic dating can help overcome these issues and aid in correlations across the formation.

2 PROJECT AND METHODS

Since 2007, the Morrison Formation Dating Project has been working to obtain precise and accurate isotopic dates for the formation using U-Pb methods. We have been working from a hypothesis that primary, ash-fall zircons can be identified and dated in sediments of the MF because volcanic ash was a part of the fine-grained input to the formation. Even though most of the ash in the MF is not found in discrete ash beds, these zircons are assumed to have had minimal reworking and most likely represent the maximum depositional ages of the sediments.

To produce the most precise and accurate dates possible, we use CA-ID-TIMS (chemical abrasion-isotope dilution-thermal ionization mass spectrometry) to obtain our zircon dates. Isotope dilution (ID) uses well-calibrated, isotopic tracers to determine the U and Pb isotopic abundances in dissolved zircons accurately and precisely. The tracer in use at the University of Wyoming (UW) lab (ET535) has been independently calibrated through

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several, multi-institutional cross-calibration experiments and dates that are produced from the UW lab can be safely compared to those from other U-Pb labs without concern of any potential laboratory bias. ID has been the gold standard for isotopic determinations for 70+ years, as it avoids potential matrix mismatches between standards and unknowns that limit the accuracy and precisions of spot-zircon dating methods such as laser ablation (LA-ICP-MS) and secondary ion (SIMS and SHRIMP) mass spectrometry. These matrix mismatch effects can produce spot zircon dates that are either too old or too young, without any independent means to assess accuracy. CA-ID-TIMS additionally uses chemical abrasion of grains prior to analysis to remove metamict, U-rich zircon domains that have incurred Pb-loss and would thus result in dates that are too young. Chemical abrasion (Mattinson, 2005) has been proven to produce consistent dates that are free of the effects of Pb loss through numerous studies from multiple labs worldwide, and CA-ID-TIMS methods can produce accurate dates with precisions of 0.1% or better.

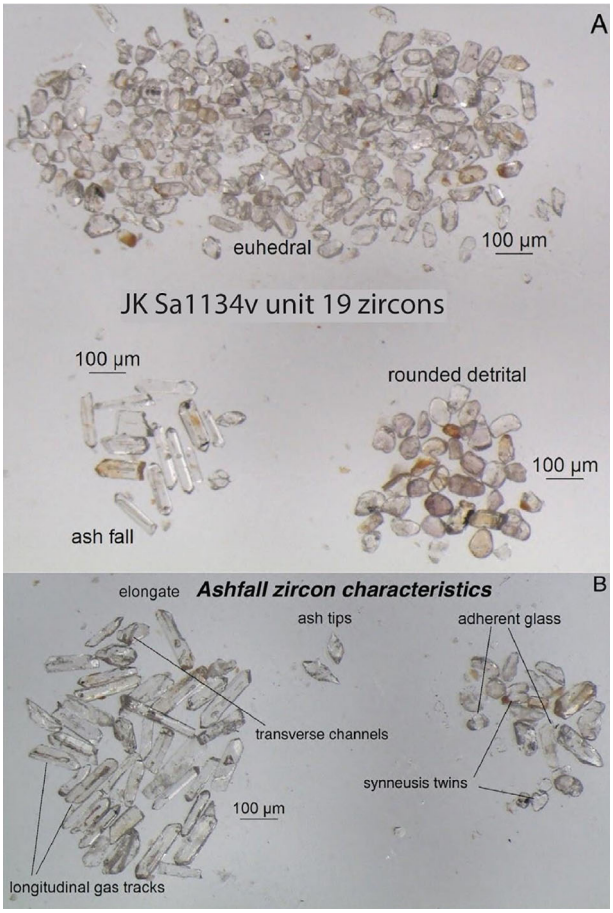


Figure 1. A) Classifications of zircons recovered from Morrison Fm. sample JK Sa1134v (Jurassic Salad Bar), showing proportional abundances. Mechanically rounded zircons in lower right are clearly detrital, but many of those classified as euhedral are as well. B) Subpopulation of zircons with ashfall characteristics from the same sample.

To produce dates with the most utility for paleontology, we have focused on: 1) dating individual fossil localities in the MF to place them into temporal context; and 2) obtaining multiple dates from stratigraphic sections. The ultimate goal of the project is to create a stratigraphic framework based on isotopic dates for the formation as a whole. Many researchers from various institutions and governmental agencies have contributed matrix as well as funding to support the dating of their individual samples.

To date, we have worked with 45 separate samples from the MF, and produced many new, high-precision U-Pb dates from geographically and stratigraphically diverse fossil localities in the MF (e.g., Davis et al., 2022; Kirkland et al., 2020; Trujillo et al., 2014, 2015). Eight samples were collected from within Dinosaur National Monument, with the goal of sampling as complete a section as possible from one area. Five samples from an area near Bluff in SE Utah were also collected with this same goal in mind. Several other samples are from parts of the formation that have not been dated before, while others were chosen to provide temporal context for specific fossils. These U-Pb dates, along with recalibrated legacy $^{40}Ar/^{39}Ar$ dates (Trujillo & Kowallis, 2015) are also being used to test previously published correlations of fossil localities (e.g., Turner & Peterson, 1999) as well as newer correlation techniques such as non-marine sequence stratigraphy (e.g., Maidment & Muxworthy, 2019).

3 DISCUSSION

While we have had many successes over the years of this project, we have also faced many challenges in dating these terrestrial rocks. One of these challenges is related to the relatively low level of radiogenic lead contained within the zircons from the MF, typically less than 10 picograms. Because the crystals are both young and small, they often have such a low level of radiogenic lead that only methods utilizing an ultra-low Pb blank can produce robust data. This necessitated bringing the level of common lead in the lab blank well below levels previously used. This also meant that contamination from outside sources (such as smoke from nearby wildfires and diesel fumes) created serious issues. Through years of concentrated work these issues have been overcome, and the ultra-low Pb lab blank now in use (< 1 pg to as low as 0.4 pg) is allowing the UW U-Pb Geochronology Lab to date single, small, ash-fall zircons with greater precision and accuracy.

Another ongoing challenge in this project has been discerning between primary, ash-fall zircons, pre-eruptive, volcanic

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zircons, and detrital zircons from older sources. For many Morrison samples, the pristine, euhedral zircons that may relate to ash-fall may only comprise 5 to 10% of recovered grains. We focus on specific morphologies of zircons that we and others believe support volcanic origins and ash-fall deposition: long, slender crystals, elongate tips, longitudinal gas tracks, transverse channels, grains with adherent glass and those that display broad, muted, medium-scale cathodoluminescent (CL) patterns (Figure 1.) Even this subpopulation, however, can yield a range of dates, some of which are too old for ash-fall deposition.

We have recently begun to pre-screen zircons for dissolution using LA-ICP-MS. This method uses a laser beam to evaporate small parts of a mounted zircon crystal, and it can be used to quickly determine a zircon's age. By annealing the zircons prior to LA-ICP-MS, we minimize the matrix mismatch affects that can compromise accuracy. Laser ablation spot-dates are typically 2 to 4% precise, which is sufficient to identify grains with likely ash-fall origins. We then pluck these grains for follow-up, higher precision CA-ID-TIMS dates.

With these new techniques in hand as well as a renewed focus on the project in 2023, we look forward to working with other researchers to identify potentially dateable horizons and localities. We are very interested in pursuing dates from members other than the Brushy Basin, as well as new geographic areas such as the Bighorn Basin and the Black Hills. We encourage interested researchers to contact us to discuss these and other possibilities for the future of the Morrison Formation Dating Project.

References

Davis, B. M., Jager, R. K., Rougier, G. W., Trujillo, K. C., & Chamberlain, K. R. (2022). A morganucodontan mammaliaform from the Upper Jurassic Morrison Formation, Utah, USA. *Acta Palaeontologica Polonica, 67*, 77-93.

Kirkland, J. I., DeBlieux, D. D., Hunt-Foster, R. K.., Foster, J. R., Trujillo, K. C., & Finzel, E. (2020). The Morrison Formation and its bounding strata on the western side of the Blanding Basin, San Juan County, Utah. *Geology of the Intermountain West, 7*, 137-195.

Maidment, S. C. R., & Muxworthy, A. (2019). A chronostratigraphic framework for the Upper Jurassic Morrison Formation, Western USA. *Journal of Sedimentary Research, 89*, 1017-1038.

Mattinson, J. M. (2005). Zircon U-Pb chemical abrasion ("CATIMS") method—combined

annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages. *Chemical Geology, 20*, 47-66.

Trujillo, K. C., Carrano, M. T., & Chamberlain, K. R. (2015). A U-Pb zircon age for Reed's Quarry 9, Upper Jurassic Morrison Formation, Albany County, WY. *Journal of Vertebrate Paleontology, Program and Abstracts, 2015*, 226.

Trujillo, K. C., & Kowallis, B. J. (2015). Recalibrated Legacy $^{40}Ar/^{39}Ar$ Ages for the Upper Jurassic Morrison Formation, Western Interior, USA. *Geology of the Intermountain West, 2*, 1-8.

Trujillo, K. C., Foster, J. R., Hunt-Foster, R. K., & Chamberlain, K. R. (2014). A U/Pb age for the Mygatt-Moore Quarry, Upper Jurassic Morrison Formation, Mesa County, Colorado. *Volumina Jurassica, 12*, 107-114.

Turner, C. E., & Peterson, F. (1999). Biostratigraphy of dinosaurs in the Upper Jurassic MorrisonFormation of the Western Interior, USA. In D. D. Gillette (Ed.), *Vertebrate paleontology in Utah. Utah Geological Survey Miscellaneous Publications, 99-1* (pp. 77-114).

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 11:30 AM)

THE OLDEST PACHYCEPHALOSAUR (ORNITHISCHIA: MARGINOCEPHALIA) FROM THE EARLY CRETACEOUS KHUKHTEEG FORMATION AT KHUREN DUKH LOCALITY OF MONGOLIA

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Pachycephalosaurians are small- to medium-bodied, bipedal, ornithischian dinosaurs that inhabited Late Cretaceous ecosystems of Asia and North America. Morphologically, they are characterized by a thickened skull roof formed by an inflated frontoparietal and enlarged peripheral elements, and reduced forelimbs relative to the hindlimbs. Despite an increasing fossil record, our knowledge of pachycephalosaurian dinosaurs largely stems from preserved cranial elements, especially the frontoparietal bones, whereas to date, only seven taxa

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preserve portions of the postcranial skeleton (*Goyocephale*, *Homalocephale*, *Pachycephalosaurus*, *Prenocephale*, *Stegoceras*, *Stygimoloch*, and *Wannanosaurus*). Moreover, definitive pachycephalosaurian fossil occurrences are restricted to Upper Cretaceous formations, most commonly those of Campano-Maastrichtian ages (Evans et al., 2013). Presently, spatiotemporal and taphonomic biases are obfuscating the origin, early evolution, and paleobiology of this unique clade.

Here we present the oldest, definitive pachycephalosaurian skeleton from the Lower Cretaceous Albian-aged Khukhteeg Formation at the Khuren Dukh locality in southeastern Mongolia (Hasegawa et al., 2018; Ito et al., 2006; Jerzykiewicz & Russell, 1991; Matsukawa et al., 2006). This formation also yields the iguanodontian dinosaurs *Altirhinus* and *Choyrodon* (Gates et al., 2018; Norman, 1998), a primitive ornithomimosaur *Harpymimus* (Barsbold & Perle, 1984), as well as fish, choristodiran, and turtle fossils (Watabe et al., 2010). The new pachycephalosaurian skeleton is approximately one meter long from the tip of the rostral to the end of the tail. As in the other pachycephalosaurians, the premaxilla bears three teeth, with the posteriormost one being the largest and "canine-like." Despite its geologically old occurrence, the new pachycephalosaurian specimen exhibits a fully developed dome as in the derived pachycephalosaurians. The dorsal surface of the dome is devoid of minute tubercles and is slightly pitted, consistent with relative maturity (Evans et al., 2011). However, it also exhibits immature features (e.g., externally evident frontoparietal suture and open neurocentral suture), suggesting the new specimen was a juvenile or subadult at the time of death. The frontal is gently convex throughout its dorsal surface, unlike in *Stegoceras*, *Colepiocephale*, and *Foraminacephale*, in which the frontal is depressed between the frontonasal boss and the supraorbital lobe. The posterior end of the dome is composed of the interfrontal wedge of the parietal. Posteriorly, the parietal forms a posterolateral process that contacts the squamosal, unlike any other pachycephalosaurians in which the posterior end of the parietal wedges in between the squamosals. The squamosal does not participate in the dome as in *Stegoceras*. While the lateral surface of the posterior process of the squamosal is heavily ornamented with nodes, the posterior surface is entirely devoid of nodes, unlike other pachycephalosaurians. The parietosquamosal shelf is weakly developed and barely covers the occipital condyle in dorsal view. The parietosquamosal shelf is anteroposteriorly compressed unlike pachycephalosaurians, rather resembling those of ceratopsians. The jugal-postorbital contact forms a scarf joint unlike other pachycephalosaurians which exhibit a butt joint. The forelimbs are significantly reduced as in the other pachycephalosaurians, with the humerus being approximately 46% of the femur length. The preacetabular process of the ilium tapers distally, unlike those of the short and transversely expanded preacetabular process of other pachycephalosaurians. The proximal caudal ribs of the new specimen are longer than the corresponding neural spine as in the other pachycephalosaurians.

We performed a phylogenetic analysis using a newly compiled data matrix based on recent ornithischian and pachycephalosaurian matrices (Dieudonné et al., 2021; Schott & Evans, 2016). The analysis recovered the new pachycephalosaur as the most basal member of Pachycephalosauria, which is congruent with its earliest geological occurrence. The result demonstrates that pachycephalosaurian dinosaurs evolved a frontoparietal dome in their early evolution and that the flat-headed condition was a secondarily acquired feature. Our result also recovers a sister-relationship between Pachycephalosauria and Ceratopsia, which is not universally accepted (Dieudonné et al., 2021; Dodson, 1990). The new Early Cretaceous pachycephalosaurian specimen shares common features with basal ceratopsians (e.g., anteroposteriorly compressed parietosquamosal shelf) and fills the gap between the two clades. As such, the new pachycephalosaur from the Early Cretaceous of Mongolia contributes not only to Pachycephalosauria systematics, it also provides key insight into broader ornithischian phylogenetic relationships.

References

Barsbold, R., & Perle, A. (1984). On first new find of a primitive ornithomimosaur from the Cretaceous of the MPR. *Paleontologicheskiy Zhurnal, 2*, 121-123.

Dieudonné, P.-E., Cruzado-Caballero, P., Godefroit, P., & Tortosa, T. (2021). A new phylogeny of cerapodan dinosaurs. *Historical Biology, 33*, 2335-2355. DOI: 10.1080/08912963.2020.1793979.

Dodson, P. (1990). Marginocephalia. In D. Weishampel, P. Dodson, & H. Osmólska (Eds.) *The Dinosauria* (pp. 562-563). University of California Press.

Evans, D. C., Brown, C. M., Ryan, M. J., & Tsogtbaatar, K. (2011). Cranial ornamentation and ontogenetic status of Homalocephale calathocercos (Ornithischia: Pachycephalosauria) from the Nemegt Formation, Mongolia. *Journal of Vertebrate Paleontology, 31*, 84-92. DOI: 10.1080/02724634.2011.546287.

Evans, D. C., Schott, R. K., Larson, D. W., Brown, C. M., & Ryan, M. J. (2013). The oldest North American pachycephalosaurid and the hidden diversity of small-bodied ornithischian dinosaurs. *Nature Communications, 4*, 1828. DOI: 10.1038/ncomms2749.

Gates, T. A., Tsogtbaatar, K., Zanno, L. E., Chinzorig, T., & Watabe, M. (2018). A new iguanodontian

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

(Dinosauria: Ornithopoda) from the Early Cretaceous of Mongolia. *PeerJ, 6*, e5300. DOI: 10.7717/peerj.5300.

Hasegawa, H., Ando, H., Hasebe, N., Ichinnorov, N., Ohta, T., Hasegawa, T., Yamamoto, M., Li, G., Erdenetsogt, B.-O., Heimhofer, U., Murata, T., Shinya, H., Enerel, G., Oyunjargal, G., Munkhtsetseg, O., Suzuki, N., Irino, T., & Yamamoto, K. (2018). Depositional ages and characteristics of Middle-Upper Jurassic and Lower Cretaceous lacustrine deposits in southeastern Mongolia. *Island Arc, 27*, e12243. DOI: 10.1111/iar.12243.

Ito, M., Matsukawa, M., Saito, T., & Nichols, D. J. (2006). Facies architecture and paleohydrology of a synrift succession in the Early Cretaceous Choyr Basin, southeastern Mongolia. *Cretaceous Research, 27*, 226-240. DOI: 10.1016/j.cretres.2005.11.005.

Jerzykiewicz, T., & Russell, D. A (1991). Late Mesozoic stratigraphy and vertebrates of the Gobi Basin. *Cretaceous Research, 12*, 345-377

Matsukawa, M., Lockley, M., & Jianjun, L. (2006). Cretaceous terrestrial biotas of East Asia, with special reference to dinosaur-dominated ichnofaunas: towards a synthesis. *Cretaceous Research, 27*, 3-21. DOI: 10.1016/j.cretres.2005.10.009.

Norman, D. (1998). On Asian ornithopods (Dinosauria: Ornithischia). 3. A new species of iguanodontid dinosaur. *Zoological Journal of the Linnean Society, 122*, 291-348. DOI: 10.1006/zjls.1997.0122.

Schott, R. K., & Evans, D. C. (2016). Cranial variation and systematics of Foraminacephale brevis gen. nov. and the diversity of pachycephalosaurid dinosaurs (Ornithischia: Cerapoda) in the Belly River Group of Alberta, Canada. *Zoological Journal of the Linnean Society, 179*, 865-906. DOI: 10.1111/zoj.12465.

Watabe, M., Tsogtbaatar, K., Suzuki, S., & Saneyoshi, M. (2010). Geology of dinosaur fossil-bearing locations (Jurassic and Cretaceous, Mesozoic) in the Gobi Desert: Results of the HMNS − MPC Joint Paleontological Expedition. *Hayashibara Museum of Natural Sciences Research Bulletin, 3*, 41-118.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 10:00 AM)

GEOLOGICAL REVISION OF THE EARLY CENOMANIAN MUSSENTUCHIT MEMBER, CEDAR MOUNTAIN FORMATION, CENTRAL UTAH (USA)

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An ongoing exploration of sedimentary successions within the uppermost Cedar Mountain Formation, namely the Mussentuchit Member, is providing unprecedented refinement for addressing questions of biotic responses to tectonism, landscape modification, and climate change before the Cretaceous Thermal Maximum (CTM). Here, we present results of combined facies and chronostratigraphic analyses for exposures of the Mussentuchit Member between Willow Springs and Emery North, north of the Fish Lake Plateau and southeast of the Wasatch Plateau along the western San Rafael Swell. We present a novel paleoenvironmental model for the emplacement of volcaniclastic and volcanilithic-rich sediment into this depocenter. Utilizing facies analysis and architectural reconstruction, we conclude that the Mussentuchit Member was a landward paralic depocenter, forming a sink for suspension settling fines enriched with volcaniclastics and volcanic detritus, with a vast majority undergoing pedogenic alteration, analogous to the modern coastal plain of French Guiana (Anthony et al., 2010, 2014; Augustinus et al., 2002; Tucker et al., 2022).

Previously, we theorized that varied sedimentary processes and entombment of fossil assemblages in the Mussentuchit Member were influenced by volcanilithic-rich detritus. We corroborate this pattern by identifying four regionally extensive, stratigraphically separable ash fall horizons. Our analysis coupled LA-ICPMS (sn=14), which identified the most youthful populations (identified to be autocrystic), with secondary analysis of youthful populations via CA-TIMS (sn=12). Once completed, we combined the resulting grain ages based on stratigraphic correlation and termed these horizons "Mussentuchit Ash Zones" (MAZ 1-4). Our results demonstrate that MAZ1 was emplaced no later than 99.550 ± 0.023 Ma; MAZ2 at 99.537 ± 0.024 Ma; MAZ3 at 99.313 ± 0.026 Ma; and MAZ4 at 98.931 ± 0.054. We also reassessed historically dated ash samples by revisiting and freshly sampling these horizons (WS10 [V695] and WS19 [V826]) (Cifelli et al., 1997, 1999). We determined that both

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displayed sedimentological disturbance and clear detrital histories.

Based on geochemical analysis (XRD and XRF), we interpret these ash fall units as dacitic (borderline tholeiitic to medium-K calc-alkaline). Coupled XRD and XRF analysis diagnosed moderate levels of an amorphous clay fraction (39–53%) and high SiO_2 values, which we interpret as preserved glass. Despite this, we identify each of these four MAZ ash falls as tuffaceous bentonites due to low but meaningful levels of smectite present (13-20%) along with infield observations, including; 1) haystacks weathering with co-occurring popcorn textures; 2) jigsaw puzzle clay fractures; and 3) nodular masses ("eggs"). With closer examination, we note significant amounts of Mg (mixing of brackish waters), mineral content (anhedral biotite and euhedral zircon), whole-rock abundances of Al, Fe, Mg, K, and quantities of Ti inversely proportionate with Si, along with variation in internal layering, layer charge, variable clay ratios, and wet color modification. Thus, we can identify MAZ1–4 as K-bentonites (Huff, 2016). Based on the above geochemical assessment, we can also extrapolate an evolutionary history of the ash falls based on two factors of multivariate correspondence analysis, encompassing 99.9% of all variation between 13 oxides (above detection limits). We recognize MAZ1 and MAZ4 as more primitive than the remarkably similar and evolved MAZ2 and MAZ3. Thus, we link MAZ1 and MAZ4 to magma chambers' rejuvenation and eruption phases, whereas MAZ2 and MAZ3 are successive eruptions coupled with chamber depletion.

Based on our sub-million-year temporal framework (99.550 $\pm$ 0.023 to 98.931 $\pm$ 0.054 Ma), the Mussentuchit correlates to the Mowry Shale and subsequent Greenhorn cycle of the Zuni Sequence (between the SB3.1, TS3, and SB3.2) or between the Kiowa transgression at 104 Ma and the Thatcher Limestone at 95.78 Ma based on Obohl-Ikuenobe et al. (2008) and Haq (2014). Lithostratigraphically to the south, the Mussentuchit Member, correlates to the uppermost Mesa Rica Sandstone and Romeroville Sandstone; and to the north, the Arrow Creek bentonite (Bootlegger Mbr) of the Blackleaf Formation at 99.12 and 100 Ma, the Shell Creek Shale and Mowry Shale of Montana, Wyoming, and the Denver Basin of Colorado to the north and northeast (Rosenblume, 2021; Rosenblume et al., 2022; Singer et al., 2021).

In-field observations noted disparities concerning the concentrations of vertebrate fossils within the Mussentuchit Mbr. Notably, most fossils are closely associated with MAZ1–2, and the middle sandstone. Other macrovertebrate fossil sites are clustered around MAZ3 in the upper Mussentuchit Mbr. In contrast, zones lacking ash fall within the lower and upper Mussentuchit Mbr. are relatively depauperate of well-preserved macrovertebrate fossils. Our findings support the findings of a recent study by Ramenzani et al. (2022), extending their observed relationship between fossil abundance and volcanic sedimentation across >20 Myrs of tectonic evolution of the WIB.

The landward paralic setting of the Mussentuchit Mbr would have simultaneously been a collection point for volcaniclastic ash and volcanilithic detritus and a distributary system to outboard distal shelf and slope depocenters (Lee et al., 2018; Tucker et al., 2022). If correct, the Mussentuchit Mbr played a minor role in the fertilization of nutrients into the WIS, resulting in a carbon sink, reflected in the global cooling trend between OAE1d and OAE2 (Wang et al., 2014). Eventually, this lowered oxygen content resulted in an antecedent trigger for the OAE2 (Barral et al., 2017; Lee et al., 2018; Wang et al., 2014).

References

Anthony, E. J., Gardel, A., Gratiot, N., Proisy, C., Allison, M. A., Dolique, F. & Fromard, F. (2010). The Amazon-influenced muddy coast of South America: A review of mud-bank–shoreline interactions. *Earth-Science Reviews, 103*(3-4), 99-121.

Anthony, E. J., Gardel, A., & Gratiot, N. (2014). Fluvial sediment supply, mud banks, cheniers and the morphodynamics of the coast of South America between the Amazon and Orinoco River mouths. *Geological Society of London Special Publications, 388*(1), 533-560.

Augustinus, P. G. E. F. (1989). Cheniers and chenier plains: A general introduction. *Marine Geology, 90*(4), 219-229.

Augustinus, P., Baba, M., Bao, C., Flemming, B., Fortes, M., Han, M., Marone, E., Mehta, A., Kb, X., Kirby, R., & Kierfve, B. (2002). Definition, properties, and classification of muddy coasts. In T. R. Healy, Y. Wang, & J.-A. Healy (Eds.), *Muddy coasts of the world: Processes, deposits and function* (pp. 9-18). Elsevier.

Barral, A., Gomez, B., Fourel, F., Daviero-Gomez, V., & Lécuyer, C. (2017). CO_2 and temperature decoupling at the million-year scale during the Cretaceous Greenhouse. *Scientific Reports, 7*(1), 8310.

Cifelli, R. L., Kirkland, J. I., Weil, A., Deino, A. L., & Kowallis, B. J. (1997). High-precision 40Ar/39Ar geochronology and the advent of North America's Late Cretaceous terrestrial fauna. *Proceedings of the National Academy of Sciences, 94*, 11163-11167.

Cifelli, R. L., Nydam, R. L., Gardner, J. D., Weil, A., Eaton, J. G., Kirkland, J. I., Madsen, S. K., & Gillette,

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

D. D. (1999). Medial Cretaceous vertebrates from the Cedar Mountain Formation, Emery County, Utah: The Mussentuchit local fauna. *Vertebrate Paleontology in Utah, Miscellaneous Paper, 99-1*, 219-242.

Haq, B. U. (2014). Cretaceous eustasy revisited. *Global and Planetary Change, 113*, 44-58.

Huff, W. D. (2016). K-bentonites: A review. *American Mineralogist, 101*(1), 43-70.

Lee, C. T. A., Jiang, H., Ronay, E., Minisini, D., Stiles, J. & Neal, M. (2018). Volcanic ash as a driver of enhanced organic carbon burial in the Cretaceous. *Scientific Reports, 8*(1), 4197.

Oboh-Ikuenobe, F., Holbrook, J. M., Scott, R. W., Akins, S. L., Evetts, M. J., Benson, D. G., & Pratt, L. M. (2008). Anatomy of epicontinental flooding: Late Albian-Early Cenomanian of the southern US Western Interior Basin. *Geological Association of Canada Special Paper, 48*, 201-227.

Ramezani, J., Beveridge, T. L., Rogers, R. R., Eberth, D. A., & Roberts, E. M. (2022). Calibrating the zenith of dinosaur diversity in the Campanian of the Western Interior Basin by CA-ID-TIMS U–Pb geochronology. *Scientific Reports, 12*(1), 16026.

Rosenblume, J. A., Finzel, E. S., & Pearson, D. M. (2021). Early Cretaceous provenance, sediment dispersal, and foreland basin development in southwestern Montana, North American Cordillera. *Tectonics, 40*, e2020TC006561. https://doi.org/10.1029/2020TC006561

Rosenblume, J. A., Finzel, E. S., Pearson, D. M., & Gardner, C. T. (2022). Middle Albian provenance, sediment dispersal and foreland basin dynamics in southwestern Montana, North American Cordillera. *Basin Research, 34*(2), 913-937.

Singer, B. S., Jicha, B. R., Sawyer, D., Walaszczyk, I., Buchwaldt, R., & Mutterlose, J. (2021). Geochronology of late Albian–Cenomanian strata in the US Western Interior. *Geological Society of America Bulletin, 133*(7-8), 1665-1678.

Tucker, R. T., Suarez, C. A., Makovicky, P. J., & Zanno, L. E. (2022). Paralic sedimentology of the Mussentuchit Member coastal plain, Cedar Mountain Formation, central Utah, USA. *Journal of Sedimentary Research, 92*(6), 546-569.

Tucker, R. T., Crowley, J. L., Renault, R. K., Makovicky, P. J., Cifelli, R. L., Mohr, M. T., & Zanno, L. E. (In Review). Exceptional age constraint on a fossiliferous sedimentary archive preceding the Cretaceous Thermal Maximum. *Geology*.

Wang, Y., Huang, C., Sun, B., Quan, C., Wu, J., & Lin, Z. (2014). Paleo-CO2 variation trends and the Cretaceous greenhouse climate. *Earth-Science Reviews, 129*, 136-147.

Theme Session: Laramidia to Asia: Biota and Biogeography of Interconnected Iconic Late Cretaceous Ecosystems (Saturday, June 10, 2023, 5:20 PM)

VERTEBRATE PALEOFAUNA OF THE CAMPANIAN ALMOND FORMATION OF WYOMING: HISTORY OF STUDY, BIOGEOGRAPHIC SIGNIFICANCE, AND EARLY RESULTS OF AN ONGOING PALEONTOLOGICAL SURVEY.

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The Upper Cretaceous of Western North America includes some of the most well studied terrestrial Mesozoic ecosystems known. Still, significant temporal and geographic gaps remain in this record. Terrestrial vertebrates have been well documented from the Campanian of Alaska, Alberta, Montana, Utah, Colorado, New Mexico, Texas, and Mexico, whereas diagnostic material from the Campanian of Wyoming is limited. The Campanian Almond Formation of Southern Wyoming is located in this biogeographic gap. The Almond Formation constitutes a transgressional sequence of the Western Interior Seaway which is bounded by the Ericson Sandstone below and the Lewis Shale above. Ammonite biozones constrain the unit, with *Baculites reesidei* occurring in the bottom of the deposit and *B. baculus* at the top, suggesting an age of 72.94-70.00 Ma (Cobban et al., 2006; Gates & Farke, 2009; Roehler, 1990), although a recent recalibration has proposed somewhat older dates of ~71.9-73.5 Ma (Fowler, 2017). So far, vertebrates have only been reported from the lower half of the formation,

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suggesting the Almond assemblage is temporally equivalent to dinosaur-bearing deposits such as the Drumheller Member of the Horseshoe Canyon Formation of Alberta, the Hall Lake Formation of New Mexico, and possibly the Cerro Del Pueblo Formation of Mexico.

The earliest report of dinosaur fossils in the Almond Formation was made by Ferdinand Hayden who, in 1868, described the presence of 'bird' tracks in the Rock Springs Uplift. These were later relocated and ascribed to hadrosaurids, proving that the first dinosaur fossils found in Wyoming were not from the well-studied Maastrichtian Lance Formation as previously assumed, but from the obscure Almond Formation (Deibert & Breithaupt, 2006). The first systematic paleontological survey of the Almond Formation was undertaken by a team led by Barnum Brown of the American Museum of Natural History (AMNH) in 1937. The AMNH collected numerous dinosaur specimens including several hadrosaurids and ceratopsids. Brown never described this material in the technical literature, though he did discuss their discoveries in a popular article (Brown, 1938). Some of this material has since been discarded or lost and only a few specimens have been adequately described, though none have yet been assigned to the species level. AMNH 3652 consists of an articulated chasmosaurine skull lacking most of the frill. It was once referred to *Anchiceratops* on the basis of a 'field photograph' (Carpenter, 1992). A subsequent description conducted after its rediscovery in collections found that it could be excluded from all chasmosaurine genera then known except for *Anchiceratops* or *Arrhinoceratops*, though it could not be positively referred to either of those genera (Farke, 2005). Several features suggest that AMNH 3652 is not referable to any known chasmosaurine. Thus, a redescription of this skull and a refined taxonomic diagnosis is currently underway (Warner-Cowgill & Storrs, in progress). A pair of frill fragments (AMNH 3656) have been found to pertain to an indeterminate chasmosaurine (Farke, 2005). Hadrosaurids are represented by AMNH 3651, a partial skeleton including a fragmentary skull and skin impressions. AMNH 3651 was tentatively referred to *Saurolophus* sp. based on jugal morphology, though this element is not identical to that of *S. osborni* (Gates & Farke, 2009). Two surveys of the Almond Formation conducted by the Natural History Museum of Utah in 2004 and 2005 did not locate significant new material. Brown's supposedly exhaustive collecting efforts, the slow rate of erosion, and the limited results of subsequent expeditions likely limited subsequent exploratory interest in the formation.

Preliminary prospecting in 2021 and 2022 resulted in the discovery of numerous new vertebrate localities on Bureau of Land Management lands. So far this survey has discovered the first turtles, fish, and crocodylomorphs from the formation as well as a growing number of partial dinosaur skeletons. Most of this material is currently referable only to the family level, representatives of which are commonly found throughout the Upper Cretaceous of Western North America. No partial skeletons have yet been exhaustively collected. All collections have been surface collected or removed with only limited ground disturbance. Turtles are represented by carapace fragments referable to the adocid genus *Adocus* and the nanshiungchelyid genus *Basilemys*. Amiid fish are represented by a series of vertebrae (Cf. *Melvius* sp.) from one locality and a mandible from another. Lepisosteid fish are represented at several localities by rhombic ganoid scales. Two isolated partial crocodylomorph mandibles have been collected. Due to their small size these likely pertain to immature individuals. Dinosaurs located include the first example of an ankylosaur from the formation represented by at least three large osteoderms found in close association. A small ornithischian dentary, vertebra and associated pieces may pertain to a thescelosaurid. Hadrosaurids appear to dominate the dinosaur fauna, as at least six individuals ranging in completeness from isolated bones to partial skeletons have been identified thus far. One specimen is represented by an unprepared partial skull including a maxilla, dentary, and numerous pieces. A large hadrosaurid femur collected in 2022 is ~1200 mm long which is comparable in length to the holotype of *Saurolophus osborni* (AMNH 5220) but 25% longer than AMNH 3651.

It has been suggested that distinct northern and southern 'faunal zones' were present on the island continent of Laramidia during the Campanian (Lehman, 2001). Subsequent studies took this further, claiming that there were several co-occurring dinosaur faunas present in latitudinally arrayed basins for at least parts of the Campanian (e.g., Sampson et al., 2010). Some work has claimed that perceived endemism is merely an artifact of a temporal disjunction (e.g., Fowler, 2017). It has been suggested that the area of the geographic separation between northern and southern faunal zones was located east of Northern Utah's Rocky Mountains, as this area was likely physically impassible at times during the Late Cretaceous (Lehman, 2001; Sampson et al., 2010). Lying near this supposed geographic barrier, the exposures of the Almond Formation offer a unique sampling opportunity that may inform future interpretations of Laramidian biogeography. Sustained systematic excavation and preparation of new material is necessary before the Almond faunal assemblage can be accurately characterized.

References

Brown, B. (1938). The mystery dinosaur. *Natural History, 41*, 190-202, 235.

Carpenter, K. (1992). Behavior of hadrosaurs as interpreted from footprints in the "Mesaverde"

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Group (Campanian) of Colorado, Utah, and Wyoming. *Contributions to Geology, University of Wyoming, 29* (2), 81-96.

Cobban, W. A., Walaszczyk, I., Obradovich, J. D., & McKinney, K. C. (2006). A USGS zonal table for the Upper Cretaceous middle Cenomanian-Maastrichtian of the Western Interior of the United States based on ammonites, inoceramids, and radiometric ages. *U.S. Geological Survey Open-File Report, 2006-1250*, 1-45.

Deibert, J. E., & Breithaupt, B. H. (2006). Ferdinand V. Hayden's 1868 "huge bird" tracks in the

Upper Cretaceous Almond formation: field evidence for the first dinosaur fossil discovered in Wyoming. *New Mexico Museum of Natural History and Science Bulletin, 35*, 69-78.

Farke, A. A. (2005). Ceratopsid dinosaurs from the Upper Cretaceous Almond Formation of

Southwestern Wyoming. *Rocky Mountain Geology, 39* (1), 1-5.

Fowler, D. W. (2017). Revised geochronology, correlation, and dinosaur stratigraphic ranges of the Santonian-Maastrichtian (Late Cretaceous) formations of the western interior of North America. *PLoS ONE, 12*(11), e0188426.

Gates, T. A., & Farke, A. A. (2009). Biostratigraphic and biogeographic implications of a hadrosaurid (Ornithopoda: Dinosauria) from the Upper Cretaceous Almond Formation of Wyoming, USA. *Cretaceous Research, 30*(5), 1157-1163.

Lehman, T. M. (2001). Late Cretaceous dinosaur provinciality. In D. H. Tanke & K. Carpenter (Eds.), *Mesozoic vertebrate life* (pp. 310-328). Indiana University Press.

Roehler, H. W. (1990). Stratigraphy of the Mesaverde Group in the Central and Eastern Greater

Green River Basin, Wyoming, Colorado, and Utah. *United States Geological Survey, Professional Paper, 1508*, 1-52.

Sampson, S. D., Loewen, M. A., Farke, A. A., Roberts, E. M., Forster, C. A., Smith, J. A., & Titus, A. L. (2010). New horned dinosaurs from Utah provide evidence for intracontinental dinosaur endemism. *PLoS ONE, 5*(9), e12292

Poster Session 3 (Saturday, June 10, 2023)

REASESSMENT OF *TOROSAURUS UTAHENSIS* WITH A FOCUS ON MATERIAL FROM THE MAASTRICHTIAN NORTH HORN FORMATION OF CENTRAL UTAH

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Centrosaurines and chamosaurines were two clades of ceratopsid dinosaurs that evolved and flourished on the North American island continent of Laramida. After the extinction of the centrosaurines, the final Maastrichtian representatives of Chasmosaurinae included *Triceratops* and *Torosaurus*, ranging from Alberta and Saskatchewan in the north to Colorado in the south. *Torosaurus* has received renewed attention since it was proposed to be a mature growth stage of *Triceratops* rather than its own taxon (Scannella & Horner, 2010). While further study is necessary to test the validity of this hypothesis, including strict stratigraphic and ontogenetic comparisons, most subsequent morphologic comparisons have cast doubt on this idea (Longrich & Field, 2012; Maiorino et al., 2013). *Torosaurus* is comparatively rare while *Triceratops* is known from hundreds of specimens. The scarcity of *Torosaurus* has led to renewed interest in the composition of the genus (Farke, 2006; Hunt & Lehman, 2008; Sullivan et al., 2005; Wiersma et al., 2012). Currently, *Torosaurus latus* is recognized from the Hell Creek Formation and its laterally equivalent formations. A second species, *Torosaurus utahensis*, is known from the Maastrichtian North Horn Formation of Central Utah, collected by Smithsonian crews in the late 1930's. Since 2000, more material was collected by the Natural History Museum of Utah (UMNH) and The Prehistoric Museum, Utah State University Eastern (CEUM). UMNH VP 13674 includes much of the posterior transverse parietal bar, a complete jugal, and a cervical rib. CEUM 13895 consists of a predentary. CEUM 35299 includes the left quadratojugal, right quadrate; the anterior left squamosal; and part of the posterior transverse parietal bar. The holotype USNM 15583 consists of a partial skull and several other referred USNM specimens have diagnostic features. These materials remain poorly figured or studied.

Reassessment of all *T. utahensis* material from the North Horn Formation reveals several features that distinguish it from *T. latus* (Fig 1). The supraorbital horns are distally "waisted" and located on the anterior part of the orbit (USNM 15583; 16169). The squamosal of *T. utahensis* (USNM 15583; 15875) is relatively broad and short with a distinct kink or change in lateral blade angle in the posteriormost 20% of its length. A midline epiparietal (ep0) is present in *T. utahensis* (USNM 15587; UMNH VP 13674). Characters shared with *T. latus* include a distinct right angle (USNM 15583; 15875; 16169) between the posterior portion of the otic notch and the lateral blade of the squamosal (discounting the anteriormost

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episquamosal); the presence of 5-6 epiparietals (rather than 3 on all other known chasmosaurines) on each side of the parietal (USNM 15583; 15875; 16573); a dorsoventrally thin, anteroposteriorly broad transverse parietal bar (USNM 15583; 15875; 16573; UMNH VP 13674; CEUM 35299); small, subcircular parietal fenestrae (USNM 15875; 16573); and a midline parietal that is unthickened ventrally, producing a "C" or "V" shaped cross-section (USNM unnumbered; 2146; 16573).

Frill material recovered from the North Horn Formation is of similar size except for a single large specimen (USNM 16169), suggesting most specimens are not fully mature. The type skull (USMN 15583) includes 13 unfused episossifications, further suggesting sub-adult status. Regardless, *T. utahensis* is one of the largest chasmosaurines with a constructed composite frill width of 1.7 meters (using all known squamosals and parietals except USNM 16169) and overall skull length (based

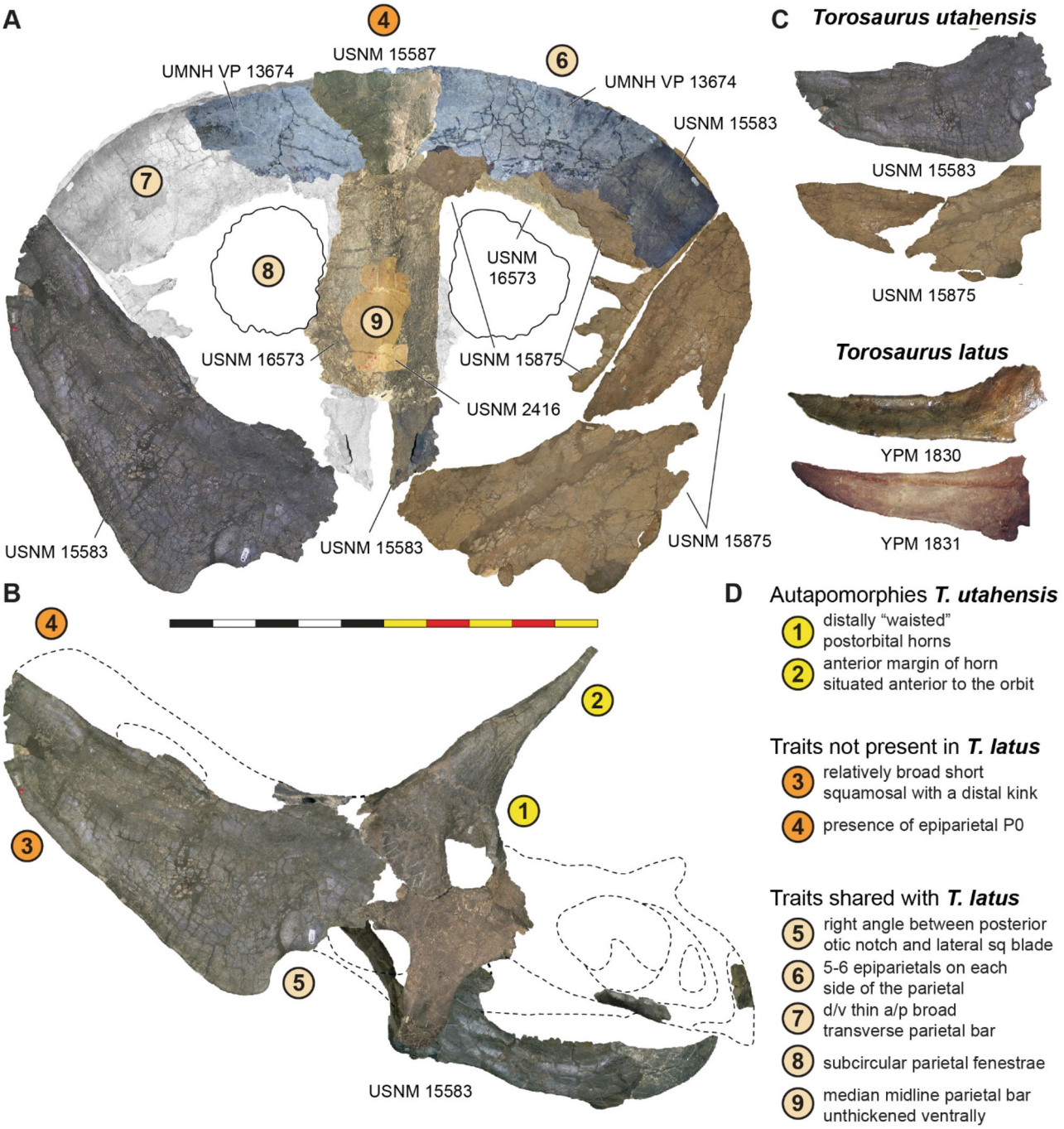


Figure 1. A. Composite frill of *Torosaurus utahensis* based on known frill elements from the North Horn Formation. B. Right lateral view of the holotype skull USNM 15583. C. Comparisons of the squamosals of *T. utahensis* and *T. latus*. D. Characters diagnosing *T. utahensis* (modified after Wiersma et al. (2012).

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solely on the type) of 1.8 meters (Figure 1). USNM 16169 includes a proximal squamosal that is significantly (1.6X) larger, revealing a possible maximum skull length of ~ 2.9 meters.

Other specimens from the southwest have been attributed to *T. utahensis* but none of these can be currently attributed to *T. utahensis* including: TMM 41835-1 (placement of the supraorbital horn); TMM 41480-1 (presence of a distinct midline parietal embayment, and midline parietal with a triangular cross-section); and UNM B-628 (squamosal shape). TMM 41361 is too incomplete to definitively assign to *T. utahensis*.

The dinosaur-bearing sediments of the North Horn Formation near North Horn Mountain were deposited in a perched intermontane basin with north trending paleocurrents. It is depositionally distinct from outcrops both higher in section and laterally in Price Canyon and in the San Pitch Mountains. No radiometric dates of the lower part of the North Horn Formation have been published, but the presence of *Tyrannosaurus rex* (UMNH VP 11000 [Sampson & Loewen, 2005]) and the titanosaurian sauropod *Alamosaurus* (USNM 15660 [Gilmore, 1946]) have generally led researchers to consider it temporally equivalent to the Hell Creek Formation and lateral equivalents in the North or to the Ojo Alamo and Javelina formations in the south. The presence of a giant tyrannosaurine in the Hall Lake Formation of New Mexico recently dated to ~ 73 Ma (Amato et al., 2017) has led to questions regarding the status of UMNH VP11000, but the postorbital and squamosal of NMMNH P-3698 are distinct from *T. rex* (Dalman et al. in review). Previous workers have suggested an earlier Maastrichtian age of ~ 69-68 Ma for the North Horn Formation, tying it to *Alamosaurus* in the San Juan Basin of New Mexico and Javelina Formation of Texas (Fowler, 2017; Sullivan & Lucas, 2005). Recent studies establish a latest Maastrichtian age of ~66.5 Ma for these occurrences of *Alamosaurus* in both formations (Green et al., 2013; Heisler et al., 2018; Leslie et al., 2018). The occurrence of *Alamosaurus* in the North Horn Formation is consistent with a latest Maastrichtian age. Further discoveries from the south may also improve our understanding of the temporal and evolutionary relationships of *T. utahensis*.

References

Amato, J. M., Mack, G. H., Jonell, T. N., Seager, W. R., & Upchurch, G. R. (2017). Onset of the Laramide orogeny and associated magmatism in southern New Mexico based on U-Pb geochronology. *Geological Society of America Bulletin, 129*, 1209-1226.

Dalman, S. G., Loewen, M. A., Jasinski, S. E., Malinzak, D. E., Lucas, S. G., Fiorillo, A.F., Currie, P. C., & Longrich, N. L. (In review). A giant tyrannosaur from the Campanian-Maastrichtian of southern North America and the origins of *Tyrannosaurus*. *Nature*.

Gilmore, C. W. (1946). Reptilian fauna of the North Horn Formation of central Utah. *U.S. Geological Survey Professional Paper, 210-C*, 29-51.

Greene, S., Heaman, L. M., DuFrane, S. A., Williamson, T., & Currie, P. J. (2018). Introducing a geochemical screen to identify geologically meaningful U-Pb dates in fossil teeth. *Chemical Geology, 493*, 1-15.

Heizler, M. T., Mason, A., Williamson, T. E., Peppe, D. J., Ramezani, J., & Bowring, S. A. (2013). $^{40}Ar/^{39}Ar$ Chronostratigraphy of Cretaceous and Paleocene strata in the San Juan Basin, New Mexico: Accuracy limitations of high precision measurements. *Geological Society of America Abstracts with Programs*, 2013.

Hunt, R. K., & Lehman, T. M. (2008). Attributes of the ceratopsian dinosaur *Torosaurus*, and new material from the Javelina Formation (Maastrichtian) of Texas. *Journal of Paleontology, 82*(6), 1127-1138.

Leslie, C. E., Peppe, D. J., Williamson, T. E., Heizler, M., Jackson, M., Atchley, S. C., Nordt, L., & Standhardt, B. (2018). Revised age constraints for Late Cretaceous to early Paleocene terrestrial strata from the Dawson Creek section, Big Bend National Park, west Texas. *Geological Society of America Bulletin, 130*(7-8), 1143-1163.

Longrich, N., & Field, D. (2012). *Torosaurus* is not *Triceratops*: Ontogeny in chasmosaurine ceratopsids as a case study in dinosaur taxonomy *PLoS ONE, 7*(2), e32623.

Maiorino, L., Farke, A. A., Kotsakis, T., & Piras, P. (2013). Is *Torosaurus Triceratops*? Geometric morphometric evidence of late Maastrichtian ceratopsid dinosaurs. *PLoS ONE, 8*(11), e81608.

Sampson, S. D., & Loewen, M. A. (2005). *Tyrannosaurus rex* from the Upper Cretaceous (Maastrichtian) North Horn Formation of Utah: biogeographic and paleoecologic implications. *Journal of Vertebrate Paleontology, 25*(2), 469-472.

Scannella, J. B., & Horner, J. R. (2010). *Torosaurus* Marsh, 1891, is *Triceratops* Marsh, 1889 (Ceratopsidae: Chasmosaurinae): Synonymy through ontogeny. *Journal of Vertebrate Paleontology, 30*(4), 1157-1168.

Sullivan, R. M., Boere, A. C., & Lucas, S. G. (2005). Redescription of the ceratopsid dinosaur *Torosaurus utahensis* (Gilmore, 1946) and a revision of the genus. *Journal of Paleontology, 79*(30), 564-582.

Wiersma, J. P., Loewen, M. A., & Irmis, R. B. (2012). A re-evaluation of *Torosaurus utahensis*: implications for Maastrichtian ceratopsian diversity in western North America. *Journal of Vertebrate Paleontology SVP Program and Abstracts Book, 2012*, 193.

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Poster Session 2 (Friday, June 9, 2023)

EXPANDED NEUROCENTRAL JOINTS IN THE VERTEBRAE OF SAUROPOD DINOSAURS

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In most vertebrates, the paired neural arch elements attach to the centrum at cartilaginous joints (synchondroses), which usually co-ossify and fuse during ontogeny. Typically, the neural elements enclose the spinal cord dorsally and laterally, hence the term 'neural arch'. But in some cases the neurocentral joints may be shifted ventrally or dorsally relative to the neural canal by varying the relative contributions to the pedicles from the neural and central elements. As a result, the canal may end up mostly or entirely enclosed by either the neural arch or the centrum. Shifts in both directions happened in sauropod dinosaurs, sometimes in the same individual (Figure 1).

In all cases, the neural canal remains immediately dorsal to the articular surfaces of the centrum, so it makes more sense to talk about the neurocentral joint shifting relative to the neural canal, rather than the canal shifting relative to the joint. Ventral shifts in the neurocentral joints appear to be phylogenetically more common. In the embryos and young of many vertebrates, including mammals, each unfused neural arch pedicle is ventrally expanded to form a 'bouton' (French for "button"), which creates a broad contact surface for the neurocentral joint (Schaefer et al., 2009). An unfused neural arch of a juvenile *Alamosaurus*, BIBE 45885, has enlarged boutons that almost meet at the midline, but are still separated by a very narrow (~1 mm) gap. Caudal vertebrae 3-7 of a subadult *Haplocanthosaurus*, CM 879, illustrate an even more extreme condition, in which the paired boutons are so large that they meet on the midline, ventrally enclosing the neural canal in a complete ring of bone. The neural arch in such a vertebra is really a tunnel rather than an arch, and the centrum does not contribute to the neural canal at all.

Dorsal shifts in the neurocentral joints occurred in the dorsal vertebrae of some sauropods. In *Haplocanthosaurus*, CM 879, and *Giraffatitan*, MB.R. 3823, dorsals have pedicles that extend from the dorsal surface of the centrum to the top of the neural canal but do not meet at the midline, leaving a tiny gap. In *Camarasaurus*, YPM 1901, the centrum pedicles project dorsally in a similar manner, and meet to form the roof of the neural canal (Ostrom & McIntosh, 1966: plates 23-25). As in the *Haplocanthosaurus* caudals discussed above, the neural canal is entirely enclosed in a ring of bone, but in the *Camarasaurus* dorsals the neural canal lies in what is developmentally the centrum rather than the arch. In such vertebrae, the neural arch doesn't contribute to the neural canal, so technically it is neither neural nor an arch.

Both ventral and dorsal shifts in the position of the neurocentral joints can be present in a single individual, as illustrated by *Haplocanthosaurus*. In CM 879, the neurocentral joints lie entirely below the neural canals in the proximal caudal vertebrae, but the joints are almost entirely above the neural canals in the dorsal vertebrae, and the vertebrae exhibiting these different conditions are only separated by the five sacral vertebrae.

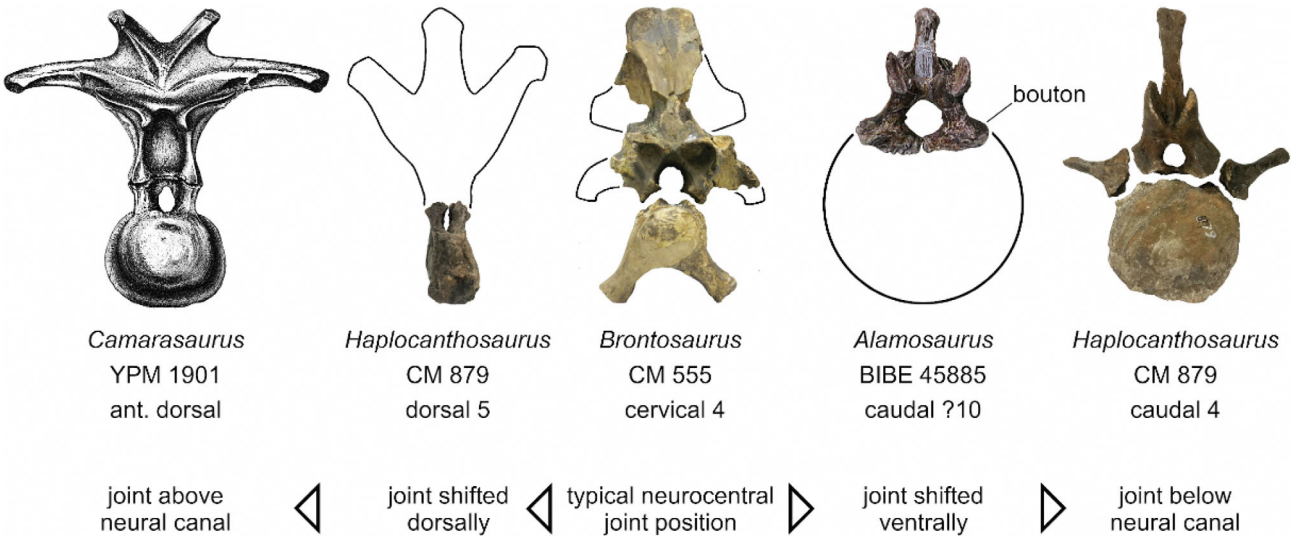


Figure 1. Sauropod vertebrae in anterior view exhibiting a spectrum of variation in the dorsoventral positions of the neurocentral joints.

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Fronimos and Wilson (2017) suggested that the complex interdigitations of the neurocentral joints in sauropods were an adaptation for resisting biomechanical stresses associated with large body size and long necks. Shifting the position of the neurocentral joint dorsal or ventral to the neural canal may have served a similar function, by essentially merging the left and right halves of each joint into one and thereby increasing the surface area of the joint. Even if some other adaptive or developmental cause provided the impetus for such change, these shifts would at least have had the exaptive effect of increasing the surface area available for the joints.

Sauropods therefore increased the surface area of the neurocentral joints in all available directions: cranio-caudally and dorso-ventrally by increasing the height and complexity of the interdigitations, and medio-laterally by shifting the joints dorsally or ventrally to eliminate the gap created by the neural canal.

This leaves the question of why neurocentral joints are shifted dorsally in some vertebrae and ventrally in others. To date, all examples we have found of dorsally-shifted neurocentral joints occur in dorsal vertebrae, and all ventrally-shifted joints occur in caudal vertebrae. The dorsal centra of most sauropods are deeply excavated by lateral pneumatic fossae or foramina, even in very young individuals (Wedel et al., 2000: Figure 14), and shifting the joint ventrally might have either reduced the surface area available for the joint, or interfered with the process of pneumatization. In sauropod caudal vertebrae, the neural arches become narrower dorsally, so shifting the neurocentral joint dorsally would have expanded the surface area of the joint little, if at all. Shifting the joint ventrally not only widened the contact between the neural arch and the centrum, but also allowed the arch to be partially morticed between the caudal ribs, which probably strengthened the joint even further.

Alternatively, the direction of the shift in the position of the joint may have been influenced more by a need to protect the spinal cord from trauma. Perhaps the caudal centra of sauropods were more susceptible to injury than the neural arches, although this is neither obvious *a priori* nor backed up by data. A global survey of vertebral pathologies in sauropods is outside the scope of this work, but it could provide useful insights. Furthermore, as we have only described herein a handful of examples of shifted neurocentral joints, a more comprehensive survey in other sauropods, in basal sauropodomorphs, and indeed in other dinosaurs would also be most welcome.

In conclusion, dorsal and ventral shifts in the positions of the neurocentral joints in many sauropods could plausibly have strengthened the vertebrae, improved protection for the spinal cord, or both. These hypotheses await testing by further paleontological discoveries, and by biomechanical modeling.

Institutional Abbreviations: BIBE, Big Bend National Park, Texas; CM, Carnegie Museum, Pittsburgh, Pennsylvania; MB.R., Museum für Naturkunde Berlin, Berlin, Germany; YPM, Yale Peabody Museum, New Haven, Connecticut.

We thank Matt Lamanna and Amy Henrici at the Carnegie Museum of Natural History and Ron Tykoski of the Perot Museum of Nature and Science for access to specimens in their care.

References

Fronimos, J. A., & Wilson, J. A. (2017). Neurocentral suture complexity and stress distribution in the vertebral column of a sauropod dinosaur. *Ameghiniana, 54*, 36-49.

Ostrom, J. H., & McIntosh, J. S. (1966). *Marsh's dinosaurs*. Yale University Press.

Schaefer, M., Black, S. M., Schaefer, M. C., & Scheuer, L. (2009). *Juvenile osteology: A laboratory and field manual*. Academic Press.

Wedel, M. J., Cifelli, R. L., & Sanders, R. K. (2000). Osteology, paleobiology, and relationships of the sauropod dinosaur Sauroposeidon. *Acta Palaeontologica Polonica, 45*, 343-388.

Technical Session 3: Terrestrial Ecosystems – Late Jurassic (Friday, June 9, 2023, 2:15 PM)

MICROVERTEBRATE EXPANSION OF KNOWN FAUNA OF THE MORRISON FORMATION OF OKLAHOMA WILL ENABLE MORE MEANINGFUL COMPARISONS WITH OTHER REGIONS

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The vertebrate fauna of the Jurassic Morrison Formation as it crops out in the valley of the Cimarron River near Kenton, Oklahoma, USA was discovered in 1931 and worked 1935 - 1942 under the direction of Dr. Willis Stovall. The fossil-bearing exposures lie near the eastern edge of the Upper Jurassic Morrison Basin, where the formation is about 60m thick and thins to the East (Richmond et al., 2020). Analysis of pedogenic calcite

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suggests that there was not significant rainfall seasonality (Myers et al., 2018), which may differentiate the region from the more intensively studied central basin (Turner & Peterson, 2004).

In 2012 a new site, OMNH V1694, was discovered. In the interim some collections had been made in adjacent Union County, New Mexico, but no further extensive collection in Oklahoma had been done and a comprehensive faunal study of the Stovall localities is lacking, although some individual taxa have been published. V1694 is being worked with the advantage of more advanced techniques of quarrying and preparation. Significantly, this includes underwater screening, and one result has been the recovery of many small elements of the Jurassic paleocommunity.

The new site has thus far produced fruiting bodies of charophyte algae, ostracods, several types of snails, teeth and vertebrae of actinopterygian fish, an anuran distal humerus, and mammalian teeth, in addition to small crocodilian teeth and fragments of large animals. Larger elements of the community include the turtle *Glyptops*, crocodylians, teeth of an allosaurid, and diplodocid sauropod skeletal elements, some of which are attributable to *Barosaurus*. *Glyptops* is the most common vertebrate from the site on the basis of MNI, although crocodylian teeth are common. There are probably both strong environmental and taphonomic signals in the composition of the assemblage; the richest parts of the site were deposited in a high-energy current.

Faunal comparisons across the Morrison Formation have tended to focus on dinosaurs (e.g., Whitlock et al., 2018) in part because of historical collecting bias. Increasing recovery and recognition of small-bodied vertebrates allows more nuanced ecological comparisons (e.g., Foster, 2020) and will likely facilitate more exact biogeographic divisions and characterizations of habitats. Whitlock et al. (2018) found low endemicity of the southern dinosaur assemblage, but this could change with the inclusion of microvertebrates if smaller animals have smaller or habitat-specific ranges. While microvertebrates from V1694 will be useful, age constraint is currently lacking in the Oklahoma outcrops, making temporal correlation to sites in other regions difficult. V1694 has been interpreted as lower in the section than Stovall's sites (Richmond et al., 2020) although nothing identified from the macrofauna is not also present in those sites. It is not easy to compare V1694 to Stovall's sites; even factoring out collecting bias, sedimentary facies indicate somewhat different taphonomy. Future work should include both ostracod biostratigraphy from the vertebrate-bearing sites themselves, if possible, and magnetostratigraphy.

Funding from the Whitten-Newman Foundation and Oklahoma State University Center for Health Sciences is gratefully acknowledged.

References

Foster, J. (2020). *Jurassic West* (2nd ed.). Indiana University Press.

Myers, T. S., Tabor, N. J., Eagle, R., Bateman, J. B., May, S., Jacobs, L. L., & Weil, A. (2018). Paleoclimate of the Upper Jurassic Morrison Formation in Oklahoma and Texas. *Geological Society of America Abstracts with Programs, 50*, 162.

Richmond, D. R., Hunt, T. C., & Cifelli, R. L. (2020). Stratigraphy and sedimentology of the Morrison Formation in the western panhandle of Oklahoma with reference to the historical Stovall dinosaur quarries. *Journal of Geology, 128*, 477-515.

Turner, C. E., & Peterson, F. (2004). Reconstruction of the Upper Jurassic Morrison Formation extinct ecosystem—a synthesis. *Sedimentary Geology, 167*, 309-355.

Whitlock, J. A., Trujillo, K. C., & Hanik, G. M. (2018). Assemblage-level structure in Morrison Formation dinosaurs, Western Interior, USA. *Geology of the Intermountain West, 5*, 9-22. https://giw.utahgeology.org/giw/index.php/GIW/article/view/25

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 11:45 AM)

HIGH DIVERSITY MIDDLE JURASSIC DINOSAUR FAUNAS REVEALED THROUGH MICROVERTEBRATE ANALYSIS

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INTRODUCTION

In the Middle Jurassic, Great Britain was situated at ~30° north and east of what would eventually become the North Atlantic rift. The area was dominated by a series of structural highs and rifted basins forming areas of low-lying land surrounded by shallow seas with a mixture of fully marine, shelf and lagoonal sedimentation. Fluctuations in relative sea level during the Bathonian resulted in a series of regressive units and locally emergent areas on the carbonate shelves surrounding the landmasses. These periods of emergence preserved snapshots of the terrestrial fauna in several microvertebrate sites throughout southern England, with a mixture of marine (possibly reworked), aquatic / semi-aquatic and terrestrial taxa, including mammaliaforms, dinosaurs, pterosaurs, frogs, turtles, albanerpetontids, salamanders, lizards, choristoderes, crocodiles, bony fish, sharks and rays. Recent analysis of the dinosaur material from these sites, historical specimens and newly collected material, using a combination of novel machine learning methods and morphological comparisons, has resulted in a much more granular view of the dinosaur taxa present which includes clades previously unknown or unconfirmed from this period, including troodontids and therizinosaurs.

GEOLOGICAL SETTING

The microvertebrate sites of Hornsleasow Quarry, Kirtlington Quarry, Woodeaton Quarry and Watton Cliff, are stratigraphically located in the Bathonian Great Oolite Group and have been described in some detail (e.g., Evans & Milner, 1994; Metcalf et al., 1992; Wills et al., In Press, 2019). The sites range from the basal Bathonian Chipping Norton Limestone Formation (Hornsleasow Quarry) through to the uppermost Bathonian Forest Marble Formation (Watton Cliff) exposing terrestrial sediments developed in ponds, marshes and freshwater lagoons, within an otherwise marine or marginal-marine succession.

MATERIAL AND METHODS

We examined 149 isolated theropod teeth, 577 ornithischian teeth and several hundred fragments of eggshell. All specimens were imaged with a combination of optical imaging using a Dino-Lite AM 7915 MZTL microscope and SEM on a LEO 1455VP microscope. We also CT-scanned each

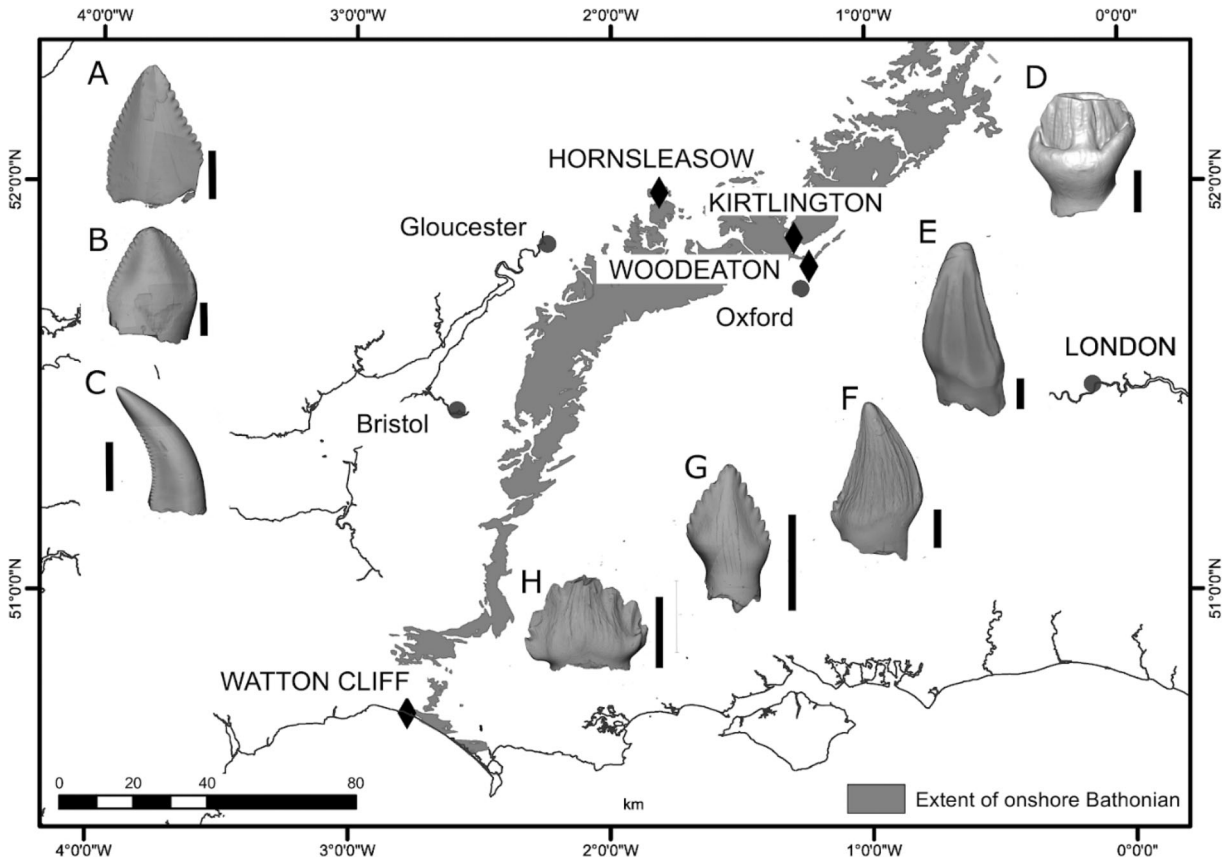


Figure 1. Site localities and examples of dinosaur tooth morphotypes. (A) Indeterminate troodontid (Hornsleasow quarry). (B) Indeterminate therizinosauroid (Hornsleasow quarry). (C) Indeterminate dromaeosaur (all sites). (D) Indeterminate stegosaur (Hornsleasow quarry). (E) Indeterminate ornithischian (Kirtlington quarry). (F) Indeterminate thyreophoran (Kirtlington and Woodeaton quarries). (G) Indeterminate thyreophoran (Woodeaton quarry). (H) Indeterminate ankylosaur (all sites). Scale bars 2 mm apart from (H) 1 mm.

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(complete) tooth and representative eggshell fragments on a Nikon Metrology HMX ST 225 μCT and a Zeiss Versa μCT and created 3D models from the CT volumes. Ten polished eggshell samples mounted on glass thin sections were additionally analysed by electron backscatter diffraction (EBSD) using a Tescan MIRA3 field emission gun SEM with rare earth element (REE) geochemistry captured along a series of transects using LAICPMS. We used a combination of machine learning on morphometric data and standard morphological comparisons to classify the dinosaur assemblage (Wills et al., In Press, 2021).

THE DINOSAUR ASSEMBLAGE

- Dinosauria
  - Theropoda
    - Maniraptora
      - Dromaeosauridae
        - Gen. et sp. indet. Morphotype A
        - Gen. et sp. indet. Morphotype B
        - Gen. et sp. indet. Morphotype C
      - Troodontidae
        - Gen. et sp. indet.
      - Therizinosauroidea
        - Gen. et sp. indet.
  - Ornithischia
    - Gen. et sp. indet.
      - Heterodontosauridae
        - Gen. et sp. indet.
      - Thyreophora
        - Gen. et sp. indet. Morphotype A
        - Gen. et sp. indet. Morphotype B
          - Stegosauria
            - Gen. et sp. indet.
          - Ankylosauria
            - Gen. et sp. indet.

DISCUSSION

Dinosaurs are represented by abundant isolated teeth and fragments of eggshell, with ornithischians making up the bulk of the identifiable teeth. The application of machine learning techniques, combined with morphological-based approaches, to the isolated teeth confirms the presence of at least three maniraptoran taxa in the assemblage: three dromaeosaur morphotypes (which might indicate multiple dromaeosaur taxa); a troodontid; and a therizinosaur. These results provide the first quantitative support for the presence of maniraptoran theropods, including the oldest occurrences of troodontids and therizinosaurs worldwide, in the Middle Jurassic and are consistent with predictions made by phylogenetic analyses, whose ghost lineages posited the likely presence of these clades at this time (e.g., Carrano et al., 2012; Holtz, 2000; Rauhut & Foth, 2020). There are at least six ornithischian taxa in the assemblage; a distinctive and rare (only found at Kirtlington Quarry), highly-ridged morphotype that, although sharing morphological similarities with the premaxillary teeth of the basal thyreophoran *Laquintasaura*, cannot be referred with certainty to any known ornithischian taxa and therefore represents a new taxon; a number of small teeth with denticles restricted to the upper third of the crown which represent a hitherto unknown occurrence of heterodontosaurids in the Middle Jurassic of the UK; at least one morphotype of a basal thyreophoran with similarities to the cheek teeth of *Scutellosaurus*; an indeterminate thyreophoran from Kirtlington Quarry with morphological similarities to the Lower Jurassic basal thyreophoran *Laquintasaura venezuelae* from Rio La Grita, Venezuela; a stegosaur, which along with *Adratiklit boulahfa* from the Middle Jurassic of Morocco (Maidment et al., 2020), represents one of the oldest stegosaurs worldwide; and a number of ankylosaur morphotypes which make up the vast majority of the isolated ornithischian teeth seen from these sites. Analysis of the eggshell fragments confirms, in a broad sense, some of these taxonomic referrals. The EBSD visual microstructure morphological comparisons combined with grain shape morphometric analysis indicates the presence of maniraptorans, ornithischians and, additionally, probable sauropods at these sites.

CONCLUSIONS

The applications of new technologies, such as machine learning, when combined with traditional morphological comparisons provides a powerful tool for the qualitative assessment of isolated teeth. This analysis, together with consideration of eggshell fragments, substantially increases the known diversity of Middle Jurassic dinosaur taxa in the UK. The confirmation of the presence of early maniraptorans, heterodontosaurids and stegosaurs highlights the importance of incorporating microvertebrate remains into faunal and evolutionary analyses.

References

Carrano, M. T., Benson, R. B. J., & Sampson, S. D. (2012). The phylogeny of Tetanurae (Dinosauria: Theropoda). *Journal of Systematic Palaeontology, 10*, 211-300.

Evans, S. E., & Milner, A. R. (1994). Middle Jurassic microvertebrate assemblages from the British Isles. In N. C. Fraser & H.-D Sues (Eds.), *In the shadow of the dinosaurs. Early Mesozoic tetrapods* (pp. 303-321). Cambridge University Press.

Holtz, T. R. (2000). A new phylogeny of the carnivorous dinosaurs. *Gaia, 15*, 5-61.

Maidment, S. C. R., Raven, T. J., Ouarhache, D., & Barrett, P. M. (2020). North Africa's first stegosaur: Implications for Gondwanan thyreophoran dinosaur diversity. *Gondwana Research, 77*, 82-97.

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Metcalf, S. J., Vaughan, R. F., Benton, M. J., Cole, J., Simms, M. J., & Dartnell, D. L. (1992). A new Bathonian (Middle Jurassic) microvertebrate site, within the Chipping Norton Limestone Formation at Hornsleasow Quarry, Gloucestershire. *Proceedings of the Geologists Association, 103*, 321-342.

Rauhut, O. W. M., & Foth, C. (2020). The origin of birds: Current consensus, controversy, and the occurrence of feathers. In O. W. M. Rauhut, & C. Foth (Eds.), *The evolution of feathers. Fascinating life sciences* (pp. 27-45). Springer.

Wills, S., Bernard, E. L., Brewer, P., Underwood, C. J., & Ward, D. J. (2019). Palaeontology, stratigraphy and sedimentology of Woodeaton Quarry (Oxfordshire) and a new microvertebrate site from the White Limestone Formation (Bathonian, Jurassic). *Proceedings of the Geologists Association, 130*, 170-186.

Wills, S., Underwood, C. J., & Barrett, P. M. (2021). Learning to see the wood for the trees: machine learning, decision trees, and the classification of isolated theropod teeth. *Palaeontology, 64*, 75-99.

Wills, S., Underwood, C. J., & Barrett, P. M. (In Press). Machine learning confirms new records of maniraptoran theropods in Middle Jurassic UK microvertebrate faunas.

Technical Session 1: Paleoclimatology & Paleogeography (Thursday, June 8, 2023, 10:00 AM)

A NEW ANKYLOSAUR FROM CHINA AND ITS SIGNIFICANCE TO ASIAN PALEOBIOGEOGRAPHY

Xing, Lida[1,2], Niu, Kechun[3], Mallon, Jordan C.[4,5], Miyashita, Tetsuto[4,5,6]

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Some 2,500 km southeast of the unusually fossiliferous Nemegt Basin, the Upper Cretaceous red beds from Guangdong to Jiangxi provinces of China – known collectively as the Nanxiong Group – have yielded a terrestrial fauna curiously reminiscent of their well-studied Mongolian counterparts. Capped by the K-Pg boundary at the top, the Nanxiong fossil assemblage hints at possible evidence for the elusive faunal linkage that characterizes (and constrains) the vertebrate fauna of the post-Cenomanian of Asia, which includes numerous oviraptorids with their eggs and embryos, a long-snouted tyrannosaurine, and nanhsiungchelyid turtles. What has been historically missing in this fauna in comparison to the Nemegt are large herbivores, such as ankylosaurines. Here, we report the first definitive ankylosaurine from the Nanxiong strata, representing a new genus and species. Despite the immature ontogenetic status of the type materials, the new taxon can be diagnosed with autapomorphic traits in the cranial caputegulae (such as double horns on the quadratojugal) and extensive gular osteoderms. Morphologically, it falls intermediate between the chronologically older ankylosaurids from Asia (e.g., *Crichtonpelta*, *Jinyunpelta*, shamosaurines) and derived post-Cenomanian ankylosaurines (e.g., *Pinacosaurus*). Phylogenetic analysis supports this assessment by recovering the Asian grade of ankylosaurids across the ankylosaurine node. A closer inspection of the character matrix and phylogenetic trees suggests that the consistently low clade support in ankylosaurian phylogeny is not so much due to homoplasies and missing data as to character correlation and insufficient/uneven sampling of morphological variation. Biogeographical comparison finds that the members of the Nanxiong fauna are closely related to their counterparts from the Djadokhta, Nemegt, and Qiupa localities. The faunal linkage highlights the potential for a further study of Nanxiong biostratigraphy to test and constrain chronological relationships among these poorly dated localities, particularly whether the Djadokhta fauna (conventionally considered Campanian) truly precedes the Nemegt fauna (conventionally considered Maastrichtian).

Technical Session 3: Terrestrial Ecosystems – Triassic – Middle Jurassic (Friday, June 9, 2023, 11:30 AM)

A NEW PARTIAL SKELETON INCLUDING DERMAL ARMOR OF A THYREOPHORAN (ORNITHISCHIA) DINOSAUR FROM MIDDLE JURASSIC OF NORTH AFRICA (MOROCCO)

Zafaty, Omar[1], Oukassou, M.[1], Pereda-Suberbiola, X.[2], Riguetti, F.[3], Company, J.[4], Bendrioua, S.[5], Tabuce, R.[6], Charrière, A.[7]

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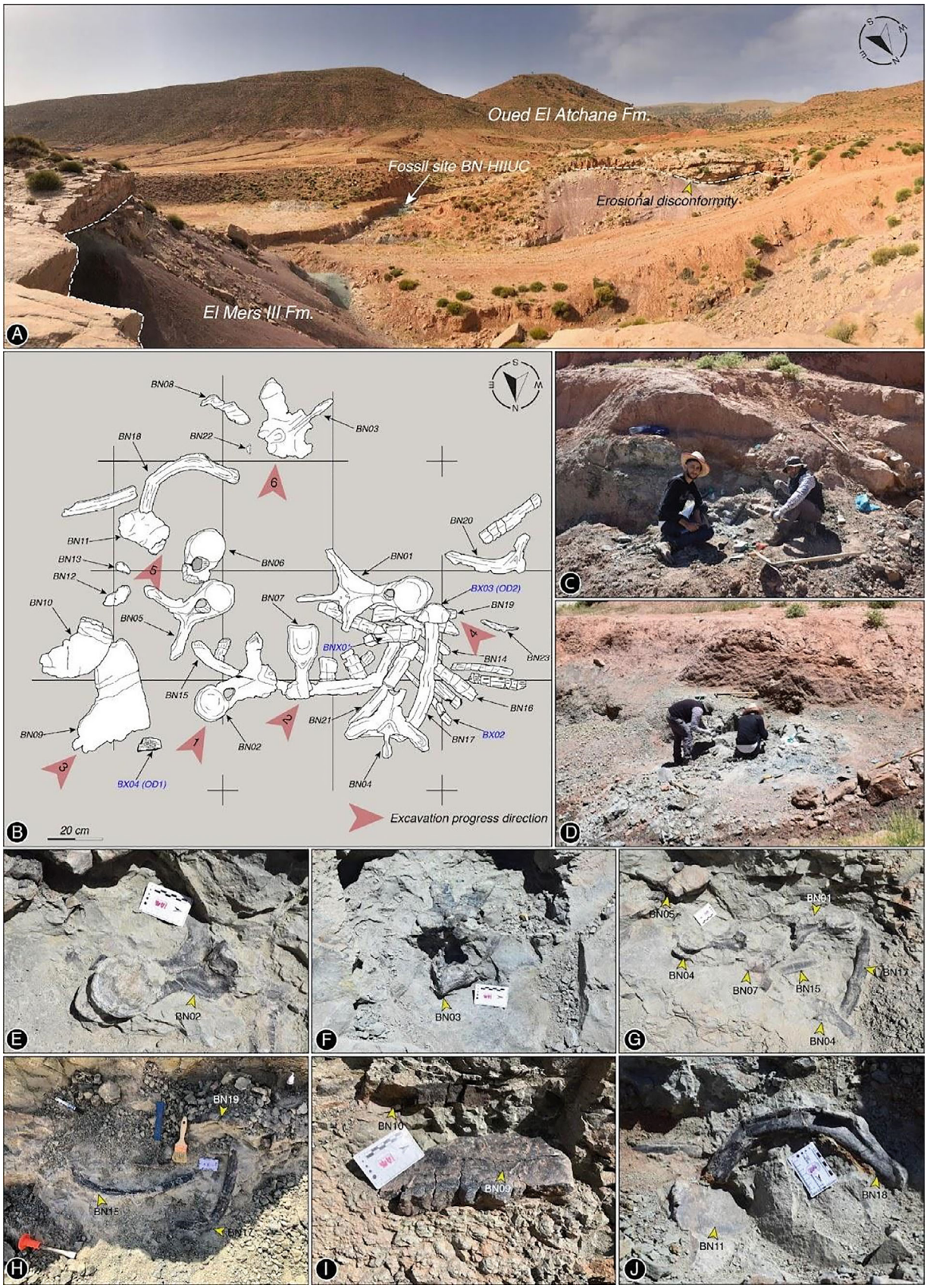


Figure 1. A. Panoramic view on the BN-HIIUC fossil site; **B.** Quarry map drawn during excavation of BN-HIIUC; **C and D.** Excavation process and site evolution; **E, F, G, H, I and J.** Photos of various specimens in-situ taken at different times during excavation.

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In the last decades, the Middle Atlas region has become an important area for the study of Moroccan's Mesozoic vertebrates, especially the Boulemane-El Mers region, rich in diverse dinosaur bones and tracks.

The first dinosaur skeletal fossils have been found in Middle Jurassic (El Mers I Formation) sites of this area (du Dresnay, 1963; Lapparent, 1955; Termier et al., 1940) were attributed to sauropods: i.e., '*Cetiosaurus*' *moghrebiensis* (Lapparent, 1955; Monbaron et al., 1999).

In the Bathonian-?Callovian continental deposits (Charrière & Haddoumi, 2016) of this area (El Mers Group), new genera and species of thyreophoran dinosaurs have been described recently, include the stegosaur *Adratiklit boulahfa* (Maidment et al., 2020), the first eurypodan thyreophoran from North Africa, and the ankylosaur *Spicomellus afer* (Maidment et al., 2021), a bizarre armored dinosaur with spiked osteoderms fused to dorsal surface of the one preserved T-shaped rib. Additionally, an isolated well-preserved stegosaur footprint has also been described in the basal sandstone beds of the ?Upper Jurassic-?Lower Cretaceous Oued El Atchane Formation (Oukassou et al., 2023).

The El Mers III Formation, in which our new site (BN-HIIUC) was discovered, is represented by a series of many tens of meters of fine friable marls and green pinkish siltstones interbedded with relatively hard calcareous marls. At the base of the series, siltstones are organized in irregular pinkish and greenish laminae where sauropod footprints (a manus-pes set) have been identified. This bioturbated level laterally changes to greenish grey marls rich in fossil wood, dinosaur bones, and pyrite concretions, indicating a continental sedimentary environment with reducing conditions. At the top of the series, the marls are locally interbedded with small lenses of poorly-graded sandstones, and covered unconformably by sandstone paleochannels of the Oued El Atchane Formation, and by pink siltstones with root traces indicating the development of a paleosol.

Herein, we describe a new specimen discovered in 2021 and collected over several consecutive field trips. The preserved material is composed by a partial, disarticulated skeleton found in the grey siltstones of the El Mers III Formation. The specimen consists of postcranial remains: dorsal vertebrae and ribs, osteoderms, and other incomplete elements. All the fossils were found associated in a small area, so it is likely that they belong to a single individual. The new thyreophoran remains shows stegosaurian features, such as moderately elongated pedicels of the dorsal neural arches, and osteoderms are reminiscent of that of ankylosaurs.

Osteoderms show a quite asymmetrical structure. The internal surface shows a homogeneously ornamented surface, with a cross-hatched pattern of longitudinal ridges at angles between 90° and 110° representing collagen fibers. Two different osteoderms have been sampled for histological analyses. Both osteoderms are very thick and show a massive and compact structure. The microstructure of these osteoderms consists of two outer coarse cortices composed of compact, primary woven bone, with simple vascular canals, enclosing a thick trabecular core composed of coarse cancellous secondary bone, resulting from a heavily remodelation of the primary tissues by secondary osteons. There is no evidence of the interwoven arranged structural fiber bundles and large resorption cavities that constitutes the general pattern observed in ankylosaurs dermal ossifications (Burns et al., 2014; Scheyer & Sander, 2004).

In general, the morphological features of the vertebrae are very similar to those of the stegosaurian dinosaurs, notably *Adratiklit boulahfa*. The osteoderms are very particular and their structure resembles at first glance the sacropelvic armor described in certain nodosaurid ankylosaurs (e.g., *Polacanthus*).

Therefore, preliminary observations of the new material argue for the occurrence in the Middle Jurassic of North Africa of a stegosaur with osteoderms that look externally like those of 'polacanthid' ankylosaurs. Additional work is needed for clarifying the phylogenetic position of this new specimen. These new data represent an extremely important point to understand the diversity of thyreophoran (i.e., armored) dinosaurs, their paleobiogeography, and evolutionary relationships.

References

Burns, M. E., & Currie, P. J. (2014). External and internal structure of ankylosaur (Dinosauria; Ornithischia)

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

osteoderms and their systematic relevance. *Journal of Vertebrate Paleontology, 34*, 835-851.
Charrière, A., & Haddoumi, H. (2016). Les « Couches rouges » continentales jurassico-crétacées des Atlas marocains (Moyen Atlas, Haut Atlas central et oriental): bilan stratigraphique, paléogéographies successives et cadre géodynamique. *Boletin Geológico y Minero, 127* (2-3), 407-430.
Dresnay du, R. (1963). Données stratigraphiques complémentaires sur le Jurassique moyen des
synclinaux d'El Mers et de Skoura (Moyen Atlas, Maroc). *Bulletin de la Société Géologique de France, 7*(6), 883-900.
Garcia, G., Tabuce, R., Cappetta, H., Marandat, B., Bentaleb, I., Benabdallah, A., & Vianey-Liaud, M. (2003). First record of dinosaur eggshells and teeth from the North-West African
Maastrichtian (Morocco). *Paleovertebrata, 32*, 59-69.
Lapparent de, A. F. (1955). Etude paléontologique des vertébrés du Jurassique d'El Mers (Moyen Atlas). *Notes et Mémoires du Service Géologique du Maroc, 124*, 1-36.
Maidment, S. C., Raven, T. J., Ouarhache, D., & Barrett, P. M. (2020). North Africa's first stegosaur: Implications for Gondwanan thyreophoran dinosaur diversity. *Gondwana Research, 77*, 82-97.
Maidment, S. C., Strachan, S. J., Ouarhache, D., Scheyer, T. M., Brown, E. E., Fernandez, V., Johanson, Z., Raven, T. J., & Barrett, P. M. (2021). Bizarre dermal armour suggests the first African ankylosaur. *Nature Ecology & Evolution, 5*, 1576-1581.
Monbaron, M., Russell, D. A., & Taquet, P. (1999). *Atlasaurus imakelai* n. gen., n. sp., a brachiosaurid-like sauropod from the Middle Jurassic of Morocco. *Comptes Rendus de l'Académie des Sciences Paris, Sciences de la Terre et des Planets, 329*, 519-526.
Oukassou, M., Zafaty, O., Gierliński, G. D., Klein, H., Saber, H., Amzil, M., & Charrière, A. (2023). First record of a small stegosaur footprint (cf. *Stegopodus)* from ? Upper Jurassic-?Lower Cretaceous red beds of the Middle Atlas, Morocco. *Ichnos*, (submitted)
Scheyer, T., & Sander, P. M. (2004). Histology of ankylosaur osteoderms: implications for systematics and function. *Journal of Vertebrate Paleontology, 24*, 874-893.
Termier, H., Gubler, J., & de Lapparent, A. F. (1940). Le Bathonien de la région d'El Mers: Reptiles et poisons due Bathonien d'El Mers. *Paris, Compte Rendus del'Académie des Sciences, 210*, 768-770.
Vianey-Liaud, M., & Garcia, G. (2003). Diversity among North Africa dinosaur eggshell. *Palaeovertebrata, 32*, 171-188.

Technical Session 3: Terrestrial Ecosystems – Early Cretaceous (Saturday, June 10, 2023, 9:45 AM)

PALEOBIODIVERSITY OF THE MUSSENTUCHIT MEMBER, CEDAR MOUNTAIN FORMATION (UTAH): NEW DISCOVERIES ENHANCE AND CONTEXTUALIZE AN EXCEPTIONAL WINDOW INTO MID-CRETACEOUS TERRESTRIAL ECOSYSTEMS

Zanno, Lindsay E.[1,2], Tucker, Ryan T.[3], Suarez, Celina[4], Avrahami, Haviv M.[1,2], Herzog, Lisa[1], Hedge, Josh[1,2], Gates, Terry[1,2], Lund, Eric[1], Freimuth, William J.[1,2], Beguesse, Kyla[1,2], King, M. Ryan[5], Cifelli, Richard L.[6], Makovicky, Peter J.[7]
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The Cedar Mountain Formation (CMF) of Utah is an exceptional fossil archive, entombing terrestrial biodiversity data for western North America (NA) throughout ~45 million years of Earth's history. Documentation of paleobiodiversity patterns in the CMF stems from intensive, multi-institutional, collection efforts spanning decades. From these collective labors came early recognition that the gross composition of CMF vertebrate communities was shaped, in part, by changing paleobiogeographic influences. Specifically, the CMF is hypothesized to preserve a shift from pre-Albian communities with European ties, to assemblages resembling coeval Asian faunas in its uppermost members, although the initiation and duration of this turnover are unresolved.
Perhaps more germane, the uppermost CMF records climate and environmental changes leading up to a global

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temperature spike dubbed the Cretaceous Thermal Maximum (CTM) that mimic (albeit at a profoundly different rate) some aspects of our current climate crisis. The CTM, together with ongoing foreland basin evolution (Phillips et al., 2021), are linked to corollary effects across the Western Interior (WI) such as eurybatic changes (Haq, 2014), increasing humidity and precipitation rates (Suarez et al., 2012), and the eventual commandeering of landscapes by angiosperms (Davis et al., 2005); all of which are suspected of having shaped regional patterns of vertebrate extinction and evolution.

Ultimately, we should expect that the drivers of faunal transformations within the CMF were multifarious, and perhaps in some instances, inextricable. Nonetheless, parsing broadly between the impacts of Laurasian paleobiogeographic exchange (EKLInE) and habitat evolution on Aptian-Cenonamian assemblages in western NA is a tractable and relevant problem. Addressing it requires granular and coupled paleobiodiversity, paleoclimatic, and spatiotemporal data across multiple scales, and relies on broad collaborative efforts. Here we present updated assemblage data for the uppermost CMF strata–the Cenomanian age Mussentuchit Member (MM)–based on our efforts over the past 15 years.

Historical paleobiodiversity data for the MM was compiled almost exclusively from abundant microvertebrate bonebeds, producing an extraordinary record of >100 taxa and one of the most diverse Cenomanian terrestrial assemblages documented worldwide (Cifelli et al., 1997, 1999; Kirkland et al., 2016). With few exceptions, macrofaunal (dinosaur) taxonomy was initially assessed via isolated teeth, useful at coarse taxonomic scales. Among theropods, these records included tyrannosaurids (cf. *Alectrosaurus* sp.); dromaeosaurines, velociraptorines, troodontids, and avialans; therizinosaurs; a large-bodied indet. theropod; and the tooth morphotypes cf. *Paranychodon* and cf. *Richardoestia*. Ornithischian assemblages were noted to contain "hypsilophodontids" (cf. *Zephyrosaurus* sp.), pachycephalosaurids, neoceratopsians, nodosaurids (cf. *Pawpawsaurus* sp.), hadrosaurids, and iguanodontians (cf. *Tenontosaurus* sp.), as well as rare records of diminutive, sauropod teeth (titanosaurimorphs, cf. *Astrodon* sp.). The collection of select macrovertebrate remains by prior teams produced key taxonomic resolutions early on, including updating "hadrosaurid indet." to the hadrosauromorph *Eolambia caroljonesa* (Kirkland et al. 1998) and nodosaurid indet. to *Animantarx ramaljonesi* (Carpenter et al., 1999). However, much of the macrofauna remained tenuously identified and/or coarsely resolved.

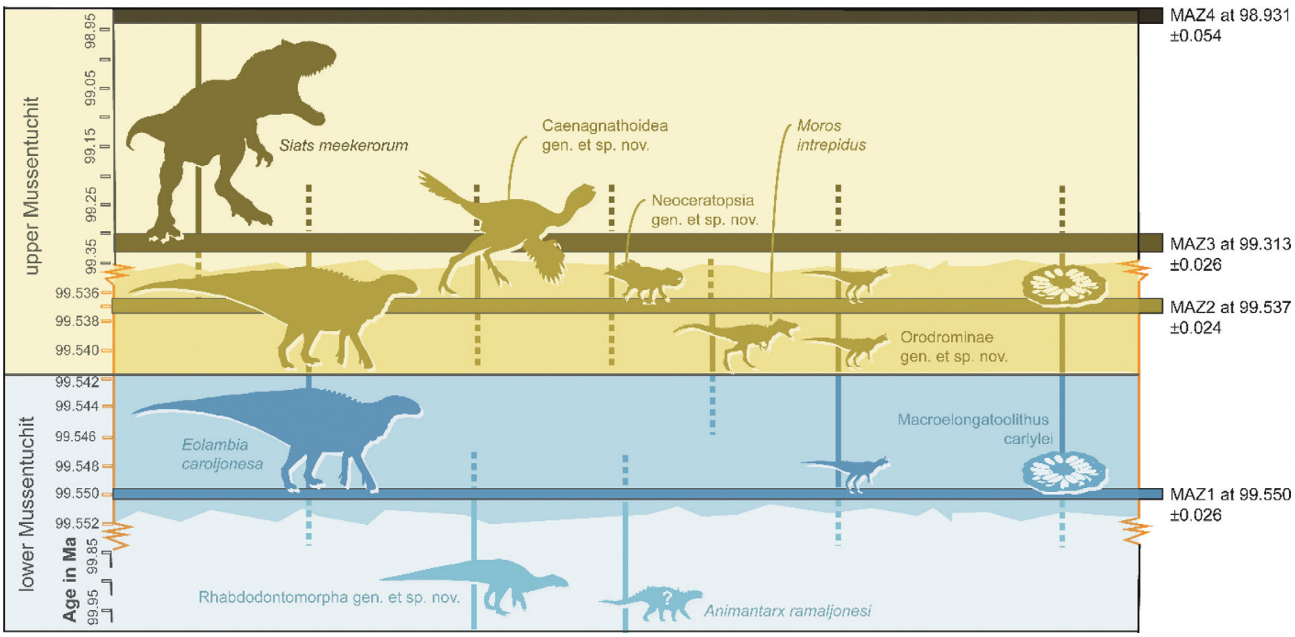


Figure 1. Known chronostratigraphic distributions of named dinosaurian taxa, definitive new species in review or prep, and ootaxa from the Mussentuchit Member of the Cedar Mountain Formation, Utah. Based on our direct stratigraphic assessments, we agree with recent publications stating that ankylosaurs from PR-2 and equivalent quarries (*Peloroplites* and *Cedarpelta*, Carpenter et al., 2008) derive from the underlying Ruby Ranch Mbr. Solid bars represent known distributions between established boundaries (MAZs [Mussentuchit Ash Zones 1–4, *sensu* Tucker et al., in press] and the upper and lower submember boundary). Taxon silhouettes are placed on the lowermost boundary strata; their position does not reflect meters above or below those boundaries; they are not to scale. Orange ticks represent a change in temporal scale along the y-axis. Taxon silhouettes by Jorge Gonzales (*Siats*, *Moros*), Zachary Lukas (*Eolambia*, Orodrominae, Rhabdodontomorpha), Myra Doughty (nest). The remainder are derived from phylopic.org under license Public Domain Dedication 1.0.

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Since then, our teams have made significant advances in MM biodiversity and spatiotemporal data, and have begun the long process of testing for intramember assemblages. We have reclassified the "indet. large-bodied theropod" as the enigmatic allosauroid/megaraptoran *Siats meekerorum* (Zanno & Makovicky, 2013) and reidentified the tyrannosaurid cf. *Alectrosaurus* as the tyrannosauroid *Moros intrepidus* (documenting cohabitation of these clades into the early Late Cretaceous; Zanno et al., 2019), and discovered a new record, a species of toothless caenagnathoid representing the largest of its kind in NA. The latter two taxa are also key for temporally constraining Laurasian interchange, as their closest relatives inhabited Asian landmasses. Additionally, we can now reclassify the "hypsilophodontid" to a new species of orodromine (sister-taxon to *Oryctodromeus*), and the "iguanodontian" or cf. *Tenontosaurus*, as a North American rhabdodontomorph, extending the record of the latter clade (and that of early-diverging ornithopods generally) into the Late Cretaceous. Moreover, we can definitively confirm the presence of an early-diverging neoceratopsian based on ongoing excavations of a partial skeleton, representing an elusive record and one of the oldest ceratopsians from the continent. Other key discoveries include a new species of lungfish (*Ceratodus molossus*, Frederickson & Cifelli, 2019), the earliest record of NA adocid remains (Avrahami et al., 2018), well-preserved helochelydrid turtles, mesoeucrocodylians, and the only clutches (>2 eggs) of elongatoolithid eggs from NA.

Our taxonomic work is coupled with ongoing chronostratigraphic, facies, and paleoclimate reassessments. We have identified four, regionally continuous bedded dacitic ashes, temporally constraining the MM fossil assemblage to ~600 kyrs, with resolution between markers (and fossil localities) as high as ~13 kyrs—the tightest yet produced for Late Cretaceous strata of the WI (Tucker et al., in press). Altered base levels permit us to informally divide the MM into lower/upper submembers. The emplacement of historic localities in our new stratigraphic framework alters the temporal sequence of existing MM climate proxies (Suarez et al., 2012), yet does not contradict a trend of > relative humidity (~60% ± 10%), precipitation rates (616 ± 160 mm/yr), and mean annual temperatures of freshwater of 20 ± 2.5°C within the uppermost CMF (Hatzell, 2015; Suarez et al., 2011).

References

Avrahami, H. M., Gates, T. A., Heckert, A. B., Makovicky, P. J., & Zanno, L. E. (2018). A new microvertebrate assemblage from the Mussentuchit Member, Cedar Mountain Formation: insights into the palaeobiodiversity and paleobiogeography of early Late Cretaceous ecosystems in western North America. *PeerJ, 6*, e5883.

Carpenter, K., Kirkland, J. I., Burge, D., & Bird, J. (1999). Ankylosaurs (Dinosauria: Ornithischia) of the Cedar Mountain Formation, Utah, and their stratigraphic distribution. In D. D. Gillette (Ed.), *Vertebrate paleontology in Utah* (pp. 243-251). Utah Department Natural Resources.

Carpenter, K., Bartlett, J., Bird, J., & Barrick, R. (2008). Ankylosaurs from the Price River Quarries, Cedar Mountain Formation (Lower Cretaceous), east-central Utah. *Journal of Vertebrate Paleontology, 28*, 1089-1101.

Cifelli, R. L., Kirkland, J. I., Weil, A., Deino, A. L., & Kowallis, B. J. (1996). High-precision 40Ar/39Ar geochronology and the advent of North America's Late Cretaceous terrestrial fauna. *Proceedings of the National Academy of Sciences, 94*, 11163-11167.

Cifelli, R. L., Nydam, R. L., Gardner, J. D., Weil, A., Eaton, J. G., Kirkland, J. I., Madsen, S. K., & Gillette, D. D. (1999). Medial Cretaceous vertebrates from the Cedar Mountain Formation, Emery County, Utah: The Mussentuchit local fauna. In D. D. Gillette (Ed.), *Vertebrate paleontology in Utah* (pp. 219-242). Utah Department Natural Resources.

Davis, C. C., Webb, C. O., Wurdack, K. J., Jaramillo, C. A., & Donoghue, M. J. (2005). Explosive radiation of *Malpighiales* supports a mid-Cretaceous origin of modern tropical rain forests. *American Naturalist, 165*, E36-65.

Frederickson, J. A., & Cifelli, R. L. (2017). New Cretaceous lungfishes (Dipnoi, Ceratodontidae) from western North America. *Journal of Paleontology, 91*, 146-161.

Haq, B. U. (2014). Cretaceous eustasy revisited. *Global and Planetary Change, 113*, 44-58.

Hatzell, G. A. (2015). *Paleoclimate implications from stable isotope analysis of sedimentary organic carbon and vertebrate fossils from the Cedar Mountain Formation, UT, USA* [Master's thesis, University of Arkansas].

Kirkland, J. I. (1998). A new hadrosaurid from the upper Cedar Mountain Formation (Albian-Cenomanian: Cretaceous) of eastern Utah - the oldest known hadrosaurid (lambeosaurine?). In S. G. Lucas, J. I. Kirkland, & J. W. Estep (Eds.), *Lower and Middle Cretaceous terrestrial Ecosystems. New Mexico Museum of Natural History and Science Bulletin, 14*, 283-295.

Kirkland, J., Suarez, M., Suarez, C., & Hunt-Foster, R. (2016). The Lower Cretaceous in east-central Utah—the Cedar Mountain Formation and its bounding strata. *Geology of the Intermountain West, 3*, 101-228.

Makovicky, P. J., Zanno, L. E, & Gates, T. A. (2015). The advent of North America's Late Cretaceous fauna revisited: Insights from new discoveries and improved phylogenies. *Journal of Vertebrate Paleontology Program Abstracts, 2015*, 172-173

Phillips, S. P., Howell, J. A., Hartley, A. J., Chmielewska, M., & Hudson, S. M. (2021). Evolution of foreland basin fluvial systems in the mid-Cretaceous of Utah, USA

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

(upper Cedar Mountain and Naturita formations). *Sedimentology, 68*, 2097-2124.

Suarez, C. A., Gonzáalez, L. A., Ludvigson, G. A., Cifelli, R. L., & Tremain, E. (2012). Water utilization of the Cretaceous Mussentuchit Member local vertebrate fauna, Cedar Mountain Formation, Utah, USA: using oxygen isotopic composition of phosphate. *Palaeogeography, Palaeoclimatology, Palaeoecology, 313*, 78-92.

Suarez, M. B., González, L. A., & Ludvigson, G. A. (2011). Quantification of a greenhouse hydrologic cycle from equatorial to polar latitudes: the mid-Cretaceous water bearer revisited. *Palaeogeography, Palaeoclimatology, Palaeoecology, 307*, 301-312.

Tucker, R. T., Crowley, J. I., Renault, R. K., Makovicky, P. J., Cifelli, R. L., & Zanno, L. E. (In Press). Exceptional age constraint on a fossiliferous sedimentary archive preceding the Cretaceous Thermal Maximum. *Geology*

Zanno, L. E., & Makovicky, P. J. (2013). Neovenatorid theropods are apex predators in the Late

Cretaceous of North America. *Nature Communications, 4*, 2827.

Zanno, L. E., Tucker, R. T., Canoville, A., Avrahami, H. M., Gates, T. A., & Makovicky, P. J. (2019). Diminutive fleet-footed tyrannosauroid narrows the 70-million-year gap in the North American fossil record. *Communications Biology, 2*, 64.

19328494, 2023, S1, Downloaded from https://anatomypubs.onlinelibrary.wiley.com/doi/10.1002/ar.25219, Wiley Online Library on [08/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License