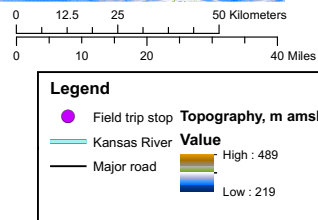
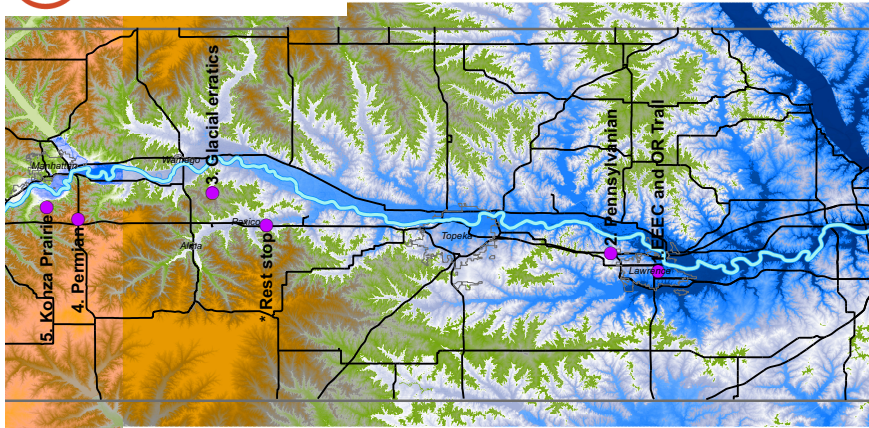




EER 2018 Field Trip 15 July 2018



Generated in ESRI ArcMap, ArcGIS Desktop v. 10.6
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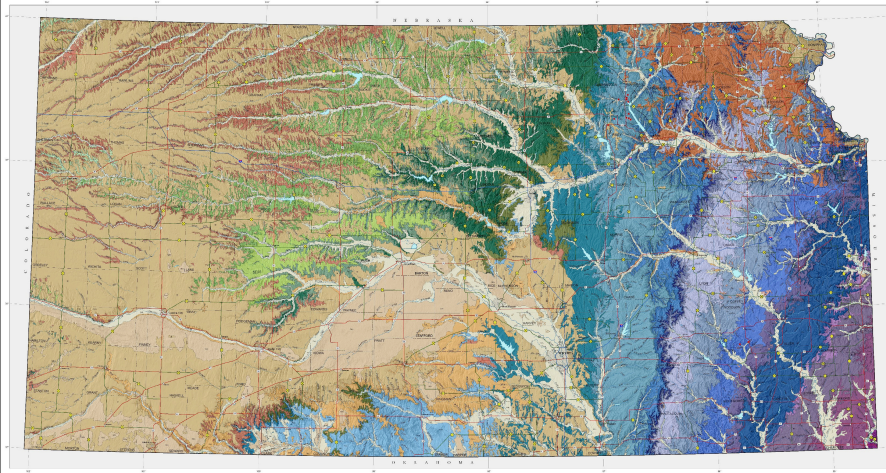
By
Gwendolyn L. Macpherson
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Lawrence, Kansas 66045

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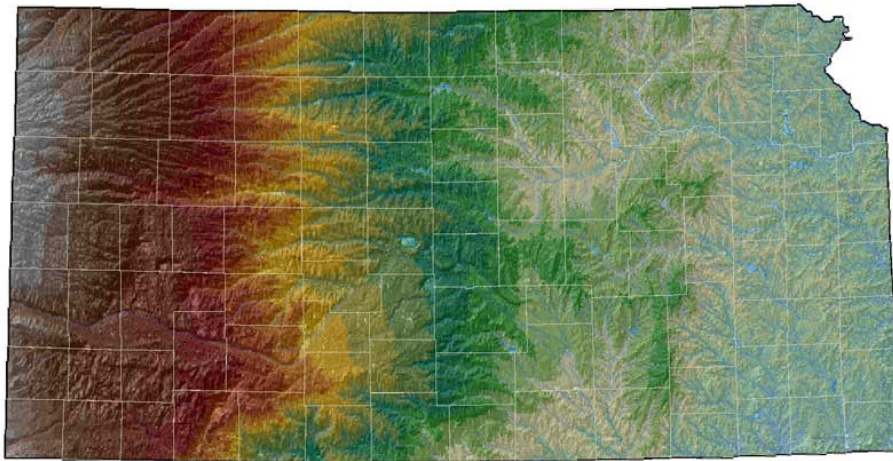


SURFICIAL GEOLOGY OF KANSAS

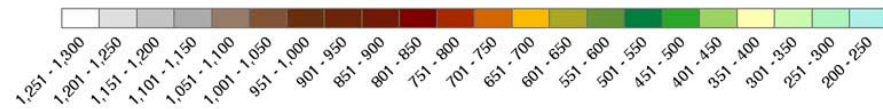
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KANSAS TOPOGRAPHY



Elevation (in meters)



**A cursory look at the geology of northeastern Kansas:
lithology, stratigraphy, topography, and influence on culture**

**4th Earth Educators Rendezvous
July 15, 2018**

**The University of Kansas
Lawrence, Kansas**

Gwendolyn L. Macpherson, Anthony W. Walton, & J. Douglas Walker
Department of Geology
The University of Kansas
Lawrence, Kansas 66045

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Preface

Plan for This Field Trip

This trip has two objectives. One is to give participants a cursory view of the geology of northeastern Kansas and to convey something about its broader significance. This area has been studied and restudied for nearly a century and a half. Geology has shaped the human history of the area and studies of it have helped to shape the understanding of sedimentary rocks. The second objective of the trip is to give participants the opportunity to use some geologic software that has been developed with support from the National Science Foundation and is available free from app providers. These applications will be useful in education as well as their particular intended audience. As our students enter the data-rich environment of the modern professional world, having experience using various kinds of software will help prepare them for challenges they might face. To use such software effectively in classes and research, educators need to be fluent in its use. While fluency is not possible to achieve in a 7-hour field trip, at least some degree of experience will begin the learning process to progress p the software learning curve.

The trip will include 5 stops beginning on the KU campus in Lawrence and ending at the Konza Tallgrass Prairie Research Area near Manhattan, Kansas (Table 1). Along the way we will discuss the geology of Pennsylvanian cyclothems, limits to pre-Illinoian ice sheets, a little about tectonic history, chert as a control of topography and agricultural development, and how ground water moves through and reacts with carbonate aquifers. As a bonus we will see how geology controlled the route of a major branch of the Oregon Trail. The trip will leave and return early to avoid as much of the Kansas summer heat and humidity as possible.

What to bring

Hammer and hand lens. Sunscreen and hat. Your smartphone or other device (Android or iOS), a USB charger cord, and a back-up battery. Trip participants may choose to use their own devices for the demonstration project or may use iPads that leaders will provide. The trip will stop along roadsides, rather than requiring extensive hikes. The weather is likely to be hot and humid (afternoon temperatures above 90° to over 100°F and dew points of 70 to 75°), so dress accordingly. Ticks and chiggers are likely; insect repellent will be provided. Water and soft drinks and cooler space for special needs will be available.

Before the trip: download the applications and do some simple steps.

Download the Flyover Country and StraboSpot apps to your tablet (preferable) or smart phone (works for me--AWW). You can find these at the Apple App Store or at Google Play for Android. Also upload Stereonet Mobile for iOS from the App Store, if you have an iPhone or iPad. StraboSpot has a nice instruction help guide at the website, <https://www.strabospot.org/>. The Stereonet Mobile for iOS manual is available at

<http://www.geo.cornell.edu/geology/faculty/RWA/programs/stereonet-mobile-manual.pdf>. These apps have distinctly different purposes.

- Flyover Country  provides access to geologic maps, geologic information, field-trip guides, and descriptions of certain kinds of sample sites (fossil collections, cores). Available information can be downloaded to a device to be accessed where Internet service is non-existent or too expensive. It is useful during travel by air, car, train, bicycle, or shank's mare. Its developers at the University of Minnesota viewed it first as a form of outreach to the non-specialist community, but envision research applications as well.
- StraboSpot  is a means of gathering and recording field or lab measurements, images, sample lists, and all other kinds of geological data at spots on the Earth's surface using default maps or those designed by the user. Data so recorded, be it from fieldwork or laboratory investigation, can be private or accessible to the broader community. . The Principal Investigators for the project, from KU, Univ. Wisconsin, and TAMU, initially saw StraboSpot as a tool for field research; however, it is now widely used in our classes as well.
- Stereonet Mobile  allows measurement of strike, trend, dip, plunge, rake and other such quantities either by contact with surfaces or by sighting and recording the location of the measurement and making plots of the data on stereonet. It works on iOS devices and is highly compatible with StraboSpot. It is the mobile outreach of a desktop application. One can plug an iOS device into a video projector (with a lightning-VGA connector from Apple) and do classroom demonstrations.

Pre-Trip Activity: In the spirit of the flipped classroom, leaders suspect, and hope, that participants will experiment with the software before the trip. We will be using StraboSpot and Stereonet Mobile (for iOS users) during this trip to record images and measurements made in the field as well as information about each stop. A version of the guidebook will be available on Flyover Country.

- Load the trip route, described below, into Flyover Country.
- Take some time to familiarize yourself with the *StraboSpot manual*, especially the first 15 pages, which talk about the organization of the application and how to set up projects, databases and spots. Trip leaders will set up a trip project and assign each participant a dataset. Those will be available before departure.
- For *Stereonet Mobile*, download the application and the manual (from the website) and experiment with it, as well.

This guidebook contains helpful instructions on how to do simple operations with both Stereonet Mobile and StraboSpot.

Flyover Country (FOC) Help: Getting Started

This guidebook will be available on FOC.

After downloading the application and opening it, you should see a satellite map of the world. Tap the menu icon in the upper right to choose which kind of map to display. In FOC, expand the map to cover the area along I-70 from Lawrence, Kansas (between Topeka and Kansas City) to Fort Riley, west of Manhattan, Kansas. The trip will be in that area. Press the *Start Path* button at the base of the screen and choose the car icon on the resulting dialog, not the airplane one. Of course landscape features and geologic maps are of interest so be sure those choices are highlighted. No dinosaur fossils, lake cores, or ocean core samples are known from along the trip route. While Quaternary mammal fossils have been collected from sand bars along the Kansas River, none of those localities appear have been recorded on FOC.

Tap the map at Lawrence and at a point about 15 miles southwest of Manhattan to indicate the trip route. The map will show links to features along the route and a few miles on either side. Choose *save offline* to gather the data for use where no internet is available.

StraboSpot Help: Getting Started

The first thing to do is to register an account at the StraboSpot website, <https://www.strabospot.org/>. After downloading the application, open it. Define a *Project* (p.14 in the manual) and set its dates and other features. StraboSpot will display the main menu on the left of the screen and a base map on the right. You can use the map layer icon



on the map to choose what kind of map to display (OSM Sheets, Matchbox Topo, Matchbox Satellite, or one of your own devising) as well as which *Datasets* (within the project) and types of *Spots* (which are within a database) you wish to display. As StraboSpot is hierarchal, there can be spots within spots. Once the project has been established, and a database is available under it (either the default database or one the user has defined), the user is ready to define spots and associate data, background information, or images with them.

Stereonet Mobile Help: Getting Started

Stereonet Mobile is only available for iOS devices. Download the app from Apple's App Store and open it. A stereo net screen appears. The app will measure, record and display linear and planar data depending upon the selections made by the user on this screen. Data can be input by tying values into the labeled boxes, by dragging and dropping on the stereo net image, or by measurement. Additional instructions are below.

Acknowledgements. This field trip has been partially supported by the Department of Geology of the University of Kansas, the Geology Associates Program, and the Strabo Project. Jen Roberts, Department Chair has offered resources, encouragement, and personal participation. Ramia Whitecotton and Ally Smith have provided administrative support. Krista Herbstrith assisted with arrangements. Jude Kastens, Kansas Biological Survey, provided a LiDAR-sourced DEM of the Konza Prairie stop. Figures from publications and website of the Kansas Geological Survey are reproduced with permission.

Road Log

Stop #	KTA or I-70 MM	Travel distance, increment (miles)	Driving distance between stops (miles)	Cumulative mile	Description
1				0	Oregon Trail Crossing, Lindley Hall. Device check.
		0	0	0	Slawson Hall, load into vans.
		0.06		0.06	Slawson Hall to 15th St.; turn right (west) on 15th St.
		0.05		0.11	Travel west on 15th St. to Iowa St., turn right (north) on Iowa St.
		0.96		1.07	On Iowa St., bear right to KTA/I-70.
		1.49		2.56	Go west (Topeka) on KTA/I-70.
2	196.6	5.4	8.56	7.96	Lecompton Limestone (oldest to youngest: Big Springs Limestone Mbr., Queen Hill Shale Mbr., Biel Limestone Mbr.
		7.3		15.26	Big Spring (OR Trail wagon ruts on south side of road).
	183	4.9		20.16	Bear right to I-70 off of KTA, 0.45 miles before toll booth.
		26.2		46.36	Entering Flint Hills physiographic province.
	337	2.8	41.2	49.16	Left exit, Wabaunsee Rest Area (Beecher's Bibles).
	330	7.0		56.16	Take McFarland Rd exit (K-185). Turn left (north) onto McFarland Rd.
		3.5		59.66	Turn left (west) onto Homestead Rd.
3		0.9	11.4	60.56	Travel 0.9 miles to glacial erratics field.
		1.6		62.16	Continue on Homestead Rd. to K-99. Turn left (south) onto K-99 (Homestead Custom Cabinets on SE corner).
	328	3.5		65.66	Enter I-70 at K-99 exit.
4	313	15	20.1	80.66	Exit I-70 to K-177. Turn left (south) onto K-177. Cross under overpass and park. Florence Limestone Member of Barneston Limestone (and Blue Springs Shale). Return to I-70 west after activity.
	307	7		87.66	Exit, McDowell Creek Rd (#307). Turn right (north) on McDowell Creek Rd.
		5		92.66	Turn right on Konza Prairie Lane (after Ashland Cemetery on right and transmission lines).
5		0.5	13	93.16	Arrive at Konza Meeting Hall.
					Loop tour, lunch, activity (not necessarily in that order).
					Depart Konza Meeting Hall.
Return		86.1	86.1	179.26	Return to KU campus, Slawson Hall.

Introduction

The Pennsylvanian and Permian rocks of eastern Kansas dip slightly to the west, at a rate of about 4-8 m/km (20-40 ft/mile), and the topography from east to west Kansas rises gradually from a low point of 207 m amsl (679 ft.) in the southeast corner of the state to a high point of 1231 m amsl (4039 ft.) at Mount Sunflower on the western border. This combination of stratigraphic and topographic gradients results in first, a long travel distance to move from Pennsylvanian into Permian rocks, and second, younging of the rocks as we move westward (Figure XXX). The erosion of the Rocky Mountains left expansive alluvial fans that blanket western Kansas (and eastern Colorado), making up the High Plains Aquifer. This occurred in the late Miocene to early Pliocene, around 2-6 million years ago. A relatively thin belt of Cretaceous rocks lies between the Permian outcrops and the High Plains Aquifer. Finally, pre-Illinoian glaciation left tills and glacial erratics covering parts of the northeast corner of Kansas.

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This field trip will start at the Earth Energy and Environment Center (EEEC) on the KU campus and travel west, more or less following the Kansas River (Table XXX, cover page) and I-70. The five stops include a brief introduction to geologic impacts on history by talking about the Oregon Trail, one outcrop of Pennsylvanian and one of Permian rocks, a field of Pleistocene glacial erratics, and lunch and activities at the Konza Tallgrass Prairie research area (Konza Prairie Biological Station; Konza). The geology and paleontology are, of course, interesting, but the field trip will also focus on exercises using some relatively new apps that are useful in education, so that trip participants will be able to incorporate some new teaching tools into their own field trips and teaching.

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Table 2. Field trip stops and activities.

Stop #	Subject	Activity
1	EEEC-Lindley Hall, Oregon Trail marker and geologic impact on history.	StraboSpot, establish a new spot, upload a digital image
2	Pennsylvanian cyclothems	StraboSpot, same as Stop 1 but also add joint measurements.
*	Rest stop	
3	Pleistocene glacial erratics	Strabospot, establish a new spot, upload images, measure erratics and upload data
4	Permian cyclothem	Same as 2 but also use Steronet Mobile to sight joint orientations; transfer Steronet data to Strabospot
5	Konza Prairie Biological Station	Compare measurement results, use remote sensing to find joint orientations, establish another spot and upload results.

A Glimpse Into Geology of Northeastern Kansas

Kansas lies in a tectonically stable area where a succession of Phanerozoic sedimentary rocks overlies Proterozoic basement. The city of Lawrence, including The University of Kansas (KU) campus, is underlain by the Lawrence Shale of the Douglas Group and several members of the Oread Limestone of the overlying Shawnee Group (Jewett et al., 1968). These rocks are assigned to the Virgilian Stage of the Pennsylvanian Subsystem. Pre-Illinoian glaciation reached across the Kansas River from near Wamego (Near Stop 3 of this trip) and eastward into Missouri, including the site of Lawrence and the valley of the Wakarusa River to the south. Illinoian and Wisconsinan glaciation did not reach the area (Dort, 2007; Lyle, 2009). Of course, alluvium and terrace deposits are present along the Kansas and Wakarusa rivers (O'Connor, 1992). Gentle westward dips and increasing elevation to the west bring younger and younger rocks. West of Topeka, in Wabaunsee County, Permian rocks crop out and the topography rises into the Flint Hills. These simple statements have interesting implications for local topography, cultural history, and stratigraphic theory as well as late Paleozoic paleogeography and paleoclimatology. We will develop these ideas further as the trip progresses.

Let's begin with a description of the local Pennsylvanian rocks of the Missourian and Virgilian succession (and extending lower, into the Desmoinesian). The succession consists of shale and limestone and local sandstone incised-valley fill or coal beds (Jewett, et al., 1968). A surprising feature of the rocks is the lateral extent of certain beds: The Heebner Shale Member of the Oread Formation, a layer about 1 m thick, is a key horizon in the subsurface of eastern Colorado and virtually all of western Kansas as well as extending along the outcrop belt from Iowa through northwestern Missouri and eastern Kansas, including Lawrence, to Oklahoma. As a phosphatic, uranium-rich black shale, it is obvious on gamma-ray logs in oil or gas wells. However, this lateral extent is not even remarkable, let alone unique among beds of the Pennsylvanian succession. Beds do change facies, for example some formations or members pass from oolitic grainstone in west-central Kansas to bioclastic grainstone in north-central Kansas or have build-ups of phylloid algae in their southern extent (Dubois, 1979; Watney, 1980). Some named intervals are not as extensive, and most do vary in thickness from place to place. Nevertheless, thin (m to 10m to a very few tens of meters, rarely), laterally extensive layers are characteristic of the local late Paleozoic succession.

Pre-Illinoian glaciation. Since deposition in the late Paleozoic, eastern Kansas has been rather stable. Uplift of the Ozark Dome may have tilted the rocks to the west-northwest. Cretaceous deposits of the Western Interior Seaway, or its environs, may have accumulated here, but if so, evidence has been erased. At least two advances of glaciation did in fact reach the Kansas River or somewhat beyond (Lyle, 2009). In the past, such deposits might have been referred to the Nebraskan and Kansan glaciations, but currently they are taken as some of the several episodes of pre-Illinoian glaciation (Dort, 2007). Poor preservation of the deposits and difficulty of determining ages prevent precise correlation.

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Field Trip Stops and Travel Directions

This guidebook assumes that the trip will begin on the University of Kansas campus at the Earth Energy and Environment Center.

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Stop I. Oregon Trail Marker on the KU Campus. Nature and Importance of Cuesta Topography; Spots and Photos on StraboSpot.

Walk north from the vehicles along the walkway between Chalmers and Marvin Halls on the right and Lindley Hall on the left. Arrive at the Oregon Trail monument at the northeast corner of Lindley Hall and on Jayhawk Blvd (Figure XXX). After brief comments cross Jayhawk Blvd. to the north to view the relief of Mount Oread. On the return to the vehicles pause at the stone marker recording the gift of the Class of 1947.

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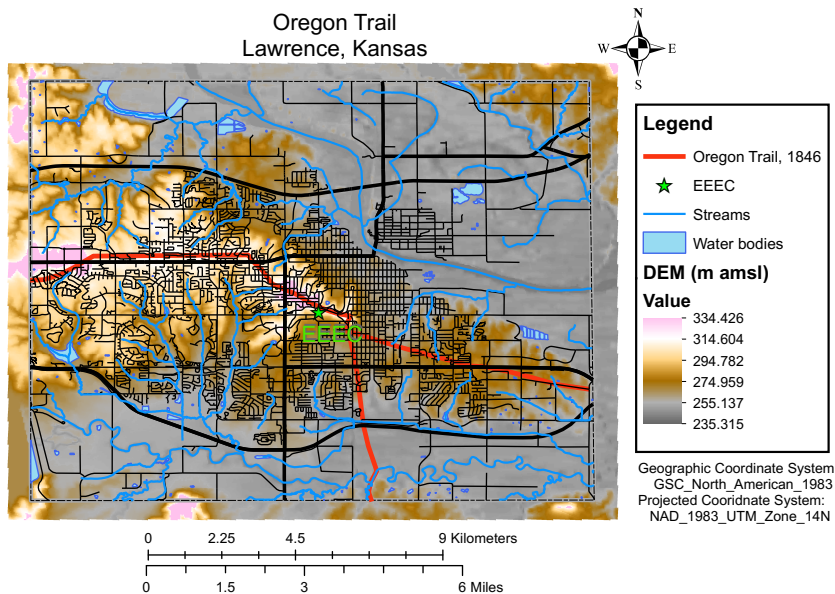


Figure XXX. The route of the Oregon Trail in part of Lawrence, Kansas. Trail location provided by Craig Voorhees, Lawrence historian. The year 1846 was likely the year with the most traffic on the trail. The trail was not a single path, but an area up to a mile wide where wagons chose the best terrain to traverse. The trail split on the eastern side shows two likely paths to climb out of the Wakarusa River bottom (to the south) and climb onto Mount Oread. The Kansas River is the northern river on the map, and location of EEEEC is shown for reference.

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Activity: Define a SPOT on StraboSpot and take a photo or two to illustrate the area. Generate a TAG to record stratigraphic information about the area. Also photograph the Class of 1947 marker. It is a piece of Sioux Quartzite brought here by a Pre-Illinoian glacier. While human hands probably placed this marker, such erratics are common in Lawrence, including in this immediate area. We will see many more such erratics in a few hours.

At this stop, the nature and importance of the local cuesta topography becomes obvious, as does the control that topography exerted on through-going travel in the middle of the 19th century. Jayhawk Boulevard extends along the crest of a distinct ridge to the east southeastward from the fountain and roundabout (Figure XXX). From the top of the ridge to the football stadium to the north there is about 100' of relief. The building site for the new Earth, Energy, and Environment Center had a relief of 66' on the south slope of the ridge. The crest of the ridge at this point is only about 100 yards wide.

StraboSpot Help: Defining a Spot

First, be sure that your assigned dataset is open in the project. To define a spot, choose *Spot* on the main menu. [To get to the main menu, press the stack of three lines  in the upper left of the screen.] In the *Spot dialog*, give the spot a name, set its location from the GPS ( "Set to My Location") or the map and set its radius, and *Tag* the *rock unit* with an existing tag or name a new one. If you make a tag for a new rock unit, you can enter age and other features on a new dialog.

Spotting Us

The Toronto Limestone Member of the Oread Limestone (Shawnee Group) underlies the ridge where we are standing (O'Conner, 1992). The KGS assigns this unit to the Virgilian Stage, which is Late Pennsylvanian (Jewett et al., 1968). In a larger scheme, the Toronto Limestone is likely Kasimovian and between 307 and 304 MA (Age of Kasimovian from Walker et al., 2012). Local declension is about 3.5°.

StraboSpot Help: Capturing Images

Pressing MORE at the top of the dialog for a particular spot will open the BASIC SPOT PAGE CONTROL dialog, where one can choose to record images, orientations (e.g. strike and dip), and other features at each spot. To record images, move the *Images* slider to the right. Note that you can define a prefix label for each spot and sample and indicate a starting number for each. You can also make the spots public [accessible to all users] or not, after uploading to StraboSpot.org. You might have already chosen to activate *Images* or *Orientations* (etc.) under *Preferences* in the Project Menu.

Once the option to record images is available, simply choose the camera icon for the active spot and take the picture. Users are then given the choice to use the picture or not. The picture will be placed in the project database

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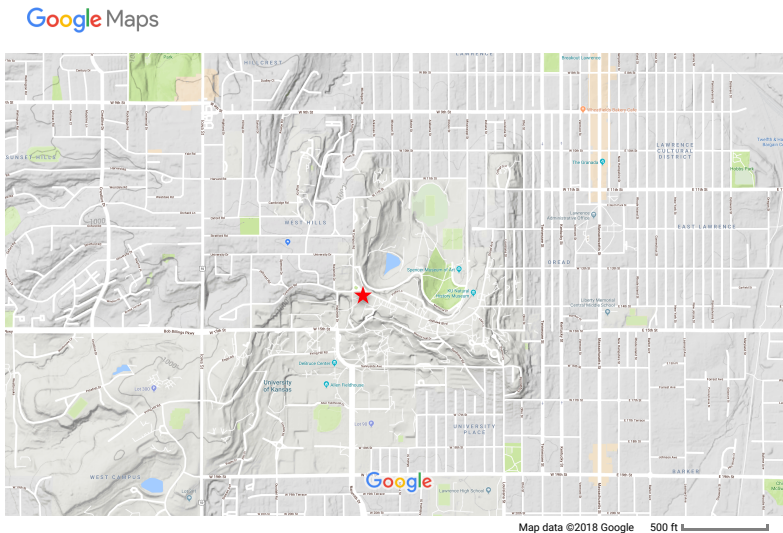


Figure XXX. GoogleMaps topographic map of Lawrence, Kansas, showing the Oread cuesta, underlain by the Oread Limestone, in the vicinity of the University of Kansas Campus. Mount Oread is the eastern extension of the cuesta, although the term is applied to the general location of KU. Star shows the location of Stop 1 of this field trip. Map downloaded May 24, 2018.

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The Toronto Limestone Member of the Oread Limestone underlies the crest of the ridge (Figure XXX, Appendix 1, O'Conner, 1992). This layer is tan to brown, fossiliferous, packstone or wackestone with evidence of soil development in its upper part. It is about 3 m (10 ft) thick locally. Other members of the Oread Limestone are present along the ridge above the Toronto Limestone and also up the incline to the west. The best place to view the Toronto here at this stop is in the walls of Marvin Hall, just to the southeast. Abundant fossils of marine invertebrates (stalked echinoderm fragments, brachiopods, and bryozoans) and foraminifera (probably *Triticites*) are present as are root marks and other pedogenic features in the browner blocks. The vertical slab of limestone at the Oregon Trail marker appears to be made of Leavenworth Limestone Member, also part of the Oread Limestone and considered to be a middle or transgressive limestone (see Stop 2 discussion). Note the large burrows on the back (bottom) of the slab.

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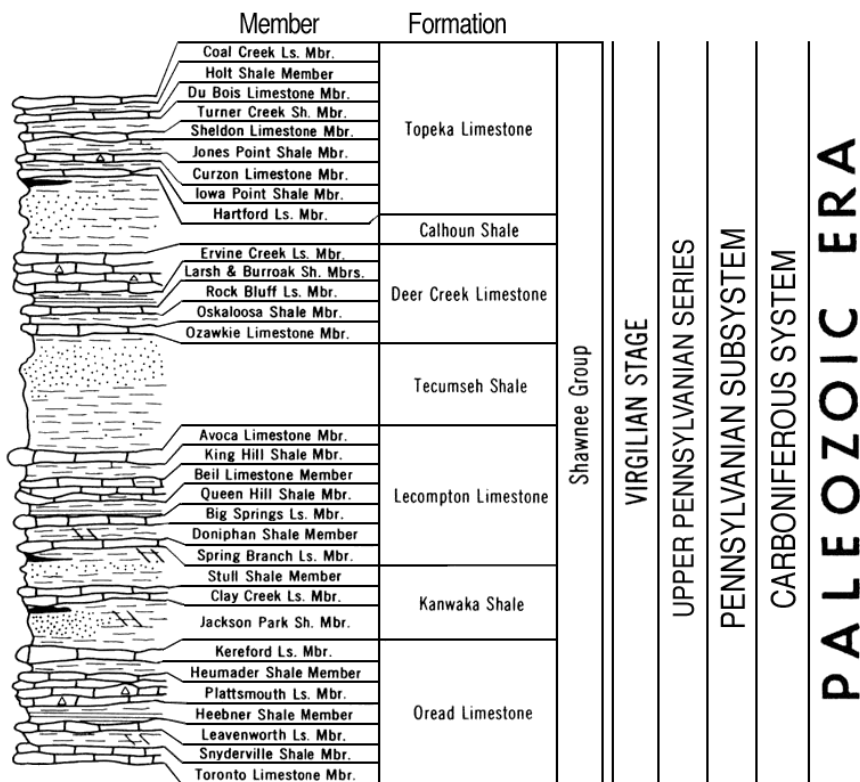


Figure XXX. Stratigraphy of the Shawnee Group, Virgilian Stage, Upper Pennsylvanian. Stop 1 is on Oread Limestone, specifically the Toronto Limestone Member with Lawrence Shale (of the underlying Douglas Group, not shown) beneath. Stop 2 is in the Big Springs limestone, Queen Hill shale, and Biel Limestone members of the Lecompton Limestone (Zeller 1968). http://www.kgs.ku.edu/General/Strat/Chart/paleozoic_8.html, downloaded 6/18/2018.

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The Lawrence Shale forms the slopes below the Toronto Limestone and underlies the downtown area of Lawrence to the east and northeast. The Lawrence Shale contains some paleosols that are unstable in areas of steep relief, and tongues of deposits of various mass movements are visible along the west side of the valley where Potter's Pond sits, hidden among trees. Memorial Drive, which lies part way down the slope to the north, has recently been rebuilt, partially to improve parking, but also because it was breaking up at the head of the several mass-movement areas.

Lithology, Weathering, and Dip. How does the stratigraphic succession affect the local landforms? The alternation of limestone, which in this climate is somewhat resistant to erosion, and shale, which erodes relatively easily, together with the gentle westward dip (20 to 40 feet per mile (3.7 to 7.4 m/km); Aber, 2017), creates a series of cuestas with steep faces to the east and gentle slopes to the west. Of

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course, at such low dips, the eastern, up-dip faces of the cuestas are very irregular in plan, as drainages have cut into them. And the more gently dipping western slopes are more or less dissected by drainages that trend northward or southward, generally, into the Kansas River or, locally, into the Wakarusa River (Figure XXX).

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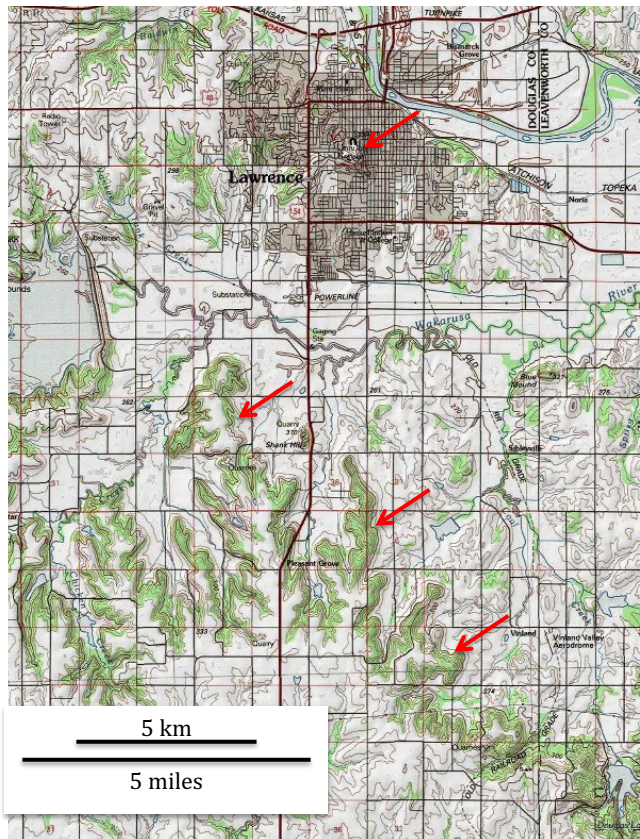


Figure XXX. The Oread cuesta south of Lawrence, Kansas (red arrows). The cuesta appears as the forested slope running diagonally from the SE corner of the map to a point in the west center and then SW south of the dam of Clinton Lake. The cuesta continues on the north side of the Wakarusa River. (Map downloaded from Kansas Geological Survey website <http://maps.kgs.ku.edu/oilgas/index.cfm?extenttype=field&extentvalue=1000147602>, on May 24, 2018.)

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The Oread Limestone, named for Mount Oread where The University of Kansas largely sits, forms one such cuesta (Figure XXX) and illustrates how topography influences culture. The location of early trails, such as the Oregon and Santa Fe trails depended upon water sources and topography. In eastern Kansas, topography was a dominant control. The river floodplains, where water was plentiful, were heavily vegetated and impassible, unless a road had been built. The slopes above them were

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both treacherous, because of the danger of tipping wagons over, and intricately dissected, so that draft animals would have to drag wagons up many hills. Hence the trails ran along divides, where the track was fairly smooth and prairie grasses offered little resistance as well as fodder for the animals. Slopes also offered springs, as ground water accumulated in fractured limestone forming perched aquifers with underlying aquitards of shale beds. Springs might occur on hillsides where such westerly dipping contacts met the north-south valleys.

The particular branch of the Oregon Trail that passed through the site of Lawrence was constrained to this ridge top to avoid the steep slopes on either side and the riparian vegetation of the valley bottoms. The trail generally followed this same ridgetop to the northwest and west to the site of Topeka, avoiding the steep gullies on either side and roughly along the route of US 40. Along the route, the trail climbed stratigraphically across the cuestas of the Lecompton Limestone, Deer Creek Limestone and Topeka Limestone and the intervening shale formations.

At the KU campus, the topographic constraint limited passage to a path only about 100 yards wide atop the Oread cuesta at Stop 1. Lawrence, founded in 1854, was built here between an Oregon Trail route and the Kansas River at a site recommended by Dr. Charles Robinson partly because of the magnificent vista from the top of what became known as Mount Oread (Cordley, 1895).

After completing the discussions and StraboSpot activity, return to the vehicles.

Continuing the trip.

Exit parking area to the Hoch Auditoria Drive (extension of 15th Street) and turn right. Continue to the west along 15th Street to Iowa Street.

Turn right (north) on Iowa Street.

After passing the traffic light at 9th and Iowa Street, bear right to McDonald Drive, the access road for the Kansas Turnpike.

Enter the Kansas Turnpike (I-70 at this point) at the West Lawrence Toll Plaza.

Continue along the Kansas Turnpike to Stop 2 at KTA Mile MARKER 196.6, Field Trip mile 8.

Stop 2. The Lecompton Limestone, a Kansas Cyclothem; record this outcrop as a spot on StraboSpot, including measurements of the orientation of some joints.

Note: Wear the provided highway safety vest at this locality.

Important: It is illegal to stop on the Kansas Turnpike and get out of one's vehicle. The KU Dept. of Geology has written permission from the Kansas Turnpike Authority to do this, but individuals should not try this on their own.

The rocks exposed here are assigned to the Big Spring Limestone, Queen Hill Shale, and Beil Limestone members of the Lecompton Limestone (Figure XXX). The succession of a thin (~1m) limestone, a fissile black shale also about 1 m thick (including the overlying gray shale) and a thicker (~3m) limestone is a leitmotif of local stratigraphy. More about that just below.

Activity: Measuring and recording joints on StraboSpot. *Procedure:* Establish a new spot on StraboSpot. Enter appropriate text about the site. Use the compass in your device to measure the orientation of a few joints, especially in the Big Springs Limestone. Photograph the joints you measure. We may assemble the results of all of the participants into a single project or data set. Then we will do the same at a later station and compare the results.

At this stop, establish a new spot on StraboSpot, and measure the orientation of some of the joints in limestone. Stresses are generally anisotropic, with a greater and lesser horizontal stress. The joints perpendicular to the maximum stress might be less open than those parallel to it.

Joints in these thin limestone beds generally run NE-SW and NW-SE, but vary somewhat from place to place. Some surface outcrops in this area appear to have been cut with pinkish shears, because joint surfaces of that strike at about 45° to the N-S and E-W roads dictated by the Jeffersonian land grid of sections, townships, and ranges.

It is a valid question to see whether joint orientations differ from place to place, which probably reflects refraction of the stress field by some geological feature, or the orientation varies from stratigraphic unit to unit.

StraboSpot Help: Recording Orientations

Define a *Spot* for this location and indicate that it is stratigraphically in the Lecompton Limestone. The actual measurements will occur in the Big Springs Limestone Member, Plb. These units are Virgilian or Kasimovian, or in the range of 307 to 304 Ma. Declension remains about positive 3.5°. If the Orientations tab does not appear at the top of the dialog for this Spot, press MORE to open the BASIC SPOT PAGE CONTROL and move the Orientations slider to the right.

To make a measurement, choose ORIENTATIONS from the Spot dialog for the spot in question. Complete the information on the dialog as to whether the measurement a plane or a line (plane in this case) and whether the plane is a joint, a bed, or whatever (here a joint). Use the compass in your device to measure the strike and dip of the joints. Press the *Compass* icon and place the device on the joint surface. Orient the device with the home button down dip. The values of strike and dip will appear in the dialog. Rotate the compass on the plane to bring it to the maximum dip and *Save* (blue button in the upper left).

Samples

If you collect samples at this site or at Stop 3 or 4, you can curate them at the given *Spot*. Choose MORE to open the BASIC SPOT PAGE CONTROL and activate the Sample choice. On the Spot dialog, choose SAMPLE at the top and enter your data on the resulting dialog. If *implaceness* is actually an English word, it should not be. You can photograph any samples now or later to help remember which is which.

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Cyclothem and the Lecompton Limestone (Figure XXX) is a Kansas Megacyclothem (Moore, 1935) comprising seven members (Figure XXX, Appendix 2). Three of these members are particularly remarkable. The Spring Branch Limestone is a fusulinid packstone or grainstone, more or less densely packed with fossil foraminifera about the same size and shape of grains of wheat. The black, uraniferous and phosphatic part of the Queen Hill Shale Member is easily traceable across Kansas as a marker in oil or gas wells. The Beil Limestone Member is both rather clay rich and fossil rich; it is a favorite collecting horizon for field trips and little kids. Moore (1964) defined a Beil-type (*Pulchratia*) faunal assemblage that includes 8 genera each of fusulinids and of corals, 15 genera of bryozoans, 35 genera of brachiopods, 28 genera of molluscs, 3 genera of trilobites, not to mention ostracodes ("inconspicuous, but common"), miscellaneous echinoderms (crinoid fragments and spines and plates of echinoids), and rare fish teeth. It is not clear that specimens of all 100-odd genera will be available at this site.

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The Lecompton Limestone, as shown in Figure XXX, is strikingly similar to three other successions of Missourian and Virgilian limestone formations. Each succession displays both fossiliferous marine deposits and indicators of continental sedimentation, such as paleosols and coal beds, suggesting that sea level and land level shifted relatively during the deposition. Considering only the Big Spring-Queen Hill-Beil portion of the succession, almost exact replicas exist in the older Kansas City and Marmaton Groups and may exist in the Atokan Gray Group in the subsurface of western Kansas. In the Lecompton Limestone, for example, the Big Springs Limestone can be taken as representing a rise of relative sea level. The fissile and black part of the Queen Hill Shale might represent the deepest water. The overlying Beil Limestone here at Stop 2 and elsewhere is taken to represent either declining sea level or filling of the available accommodation (Heckel and Baesemann, 1975).

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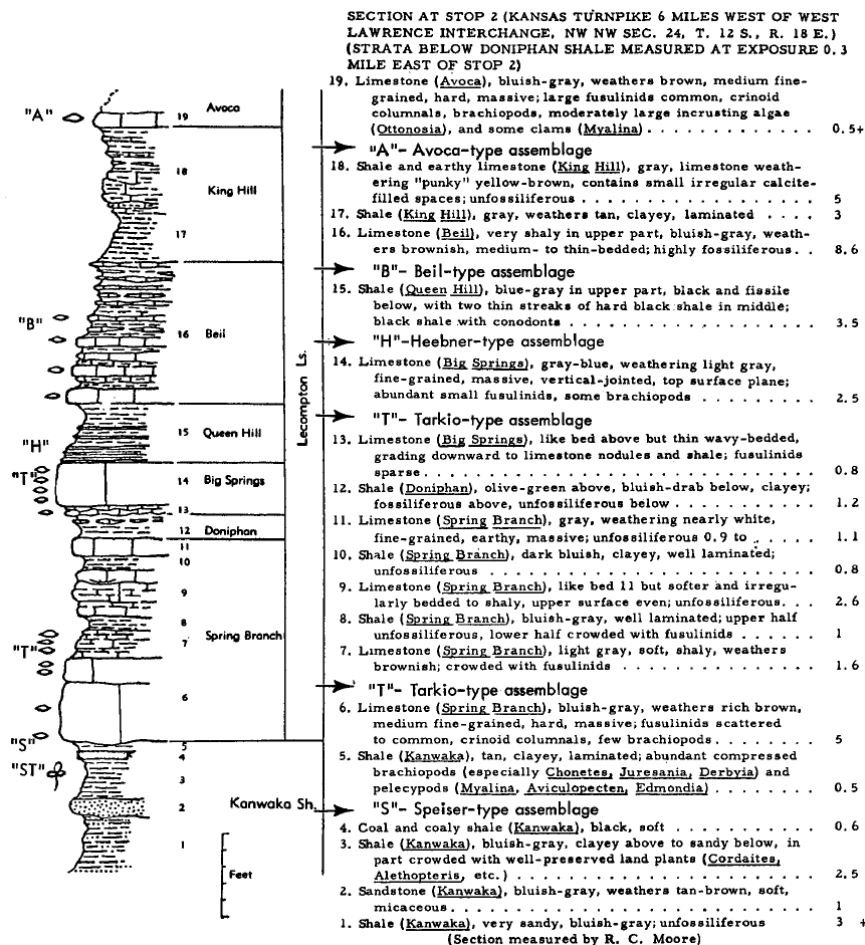


Figure XXX. Measured section of the Lecompton Limestone at Stop 2 (Moore, 1964, modified from Moore and Merriam, 1959). Stop 2 in the title refers to the earlier field trip guidebook. Reproduced by permission of the Kansas Geological Survey. Only the top of the Doniphan Shale, the Big Springs Limestone, Queen Hill Shale, and Beil Limestone are exposed; other parts of the formation are exposed at outcrops to the east and west and across the highway. The Beil, Queen Hill, and Big Springs have different faunal assemblages.

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Moore (1964) points out that not only are the correlative beds in Figure XXX similar in lithology, but also in weathering character and faunal content. These lithologic repetitions, especially in the Middle and Upper Pennsylvanian are *cyclothems*. Shortly after Wanless and Weller (1932) described cyclothems in the Pennsylvanian coal measures of Illinois, Moore (1935) defined various types of cyclothems here in Kansas, with the Lecompton Limestone being one of several examples of Moore's limestone-shale Kansas megacyclothem (Figure XXX; see also Heckel and Baesemann, 1975).

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The thin (~1 m) limestone bed at the base is generally a wackestone or possibly a lime mudstone that displays few sedimentary structures or gradations of character. Such beds may be so intensely burrowed that no trace of original bedding remains. In Moore's scheme, this bed is referred to as the middle limestone, because another bed of limestone lies beneath (Figure XXX), e.g. the Toronto Limestone of the Oread Formation (Stop 1) and the Spring Branch Limestone Member of the Lecompton Limestone (Stop 2).

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The thin beds (~1m) of fissile black shale in such successions, with their abundant conodonts, apatite concretions, and uranium, are good subsurface markers on gamma-ray logs. During much of the time of deposition of a black shale, dysoxia or anoxia likely prevailed at the sediment-water interface, or even above it, so that no benthic megafauna was present, and organic matter and fossils of pelagic organisms accumulated in addition to the argillaceous and silt fractions. Many such shale beds are microbioturbated or even marked by small-scale ripples where the constituent floccules and pellets have been reworked by bottom currents (Aplin and Macquaker, 2011). The obvious fissility is a result of weathering that emphasizes any subtle lamination or foliation of the deposit, features that may not be visible in core samples (Lazar et al., 2015). Many such beds, including the Queen Hill Shale, have an upper portion that is more normal marine in character. Rader (personal communication, 2015) found paleosol features in the upper part of the Larsh and Burr Oak Shale Member of the Deer Creek Formation.

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The overlying Beil Limestone here at Stop 2 and elsewhere is taken to represent either declining sea level or filling of the available accommodation (Heckel and Baesemann, 1975). It contains a normal marine fauna (Moore, 1964). Such limestone beds may display progression from shelf deposition to supratidal over an interval of a few meters. Several of these upper limestone beds are oolitic grainstones, in part. Others are highly nodular, with irregular clay-rich seams defining the margins of calcite-cemented volumes. The Beil Limestone Member is relatively enriched in argillaceous material, unlike most of the other upper limestone beds. Such regressive limestone beds are the ones with the faunas of 100 genera (taken collectively), and have been designated as the *upper limestone* at times in the past. There is also a super limestone in full megacyclothems. Interpretations of cyclothems of the Desmoinesian, Missourian, and Virgilian (upper Middle and Upper Pennsylvanian) have evolved over the years (e.g. Heckel and Baesemann, 1975, Rader, personal communication, 2015), but the lithologic similarity remains.

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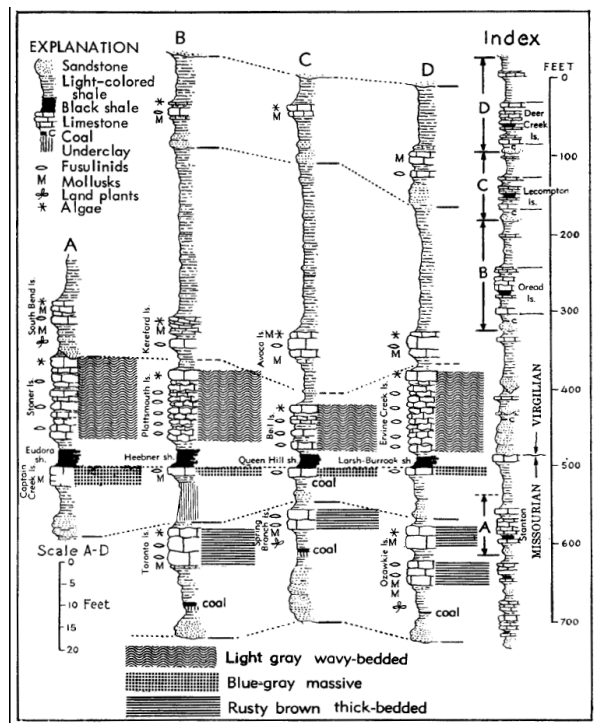


Figure XXX. Stratigraphic sections of four upper Missourian and lower Virgilian cyclothems at sites roughly along I-70 (Kansas Turnpike) in northeastern Kansas (Moore, 1964). Column A centers on the Missourian Stanton Limestone, B on the Virgilian Oread Formation (on which the KU campus centers), C is the Lecompton Limestone, site of Stop 2 on this field trip, and D is the Deer Creek Limestone, which crops out along I-70 on the rising slope just west of outcrops of the Lecompton Limestone. Note the striking similarity of the central part of each column and the strong, but not perfect, similarity of the underlying and overlying successions.

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Most authors recognize that various beds of the cyclothems represent changes of sea level relative to the land, perhaps owing to eustatic causes. The time period of the cycles lies within the Milankovitch band, and Pennsylvanian was a time of glaciation in the southern hemisphere, so a connection to rising and falling sea levels related to glacial advances in Gondwana provides an attractive hypothesis explaining the development of the cyclic repetitions.

Cycles related to relative change of sea level lie at the heart of *sequence stratigraphy*. This form of analysis of sedimentary successions divides them at boundaries—either unconformities, conformable surfaces correlative with the unconformities or flooding surfaces—defining synchronous units between such boundaries. Recognition of cycles, such as these here nearly a century ago has been one of the steppingstones to sequence stratigraphy and modern forms of analysis of sedimentary successions.

Continuing the trip.

After completing the observations and grabbing a couple of brachiopods, or whatever, return to the vans.

Continue westward on I-70.

Pass an outcrop of Deer Creek Limestone on the right. Note the transgressive ("middle") limestone, the fissile black shale, and the nodular upper or regressive limestone.

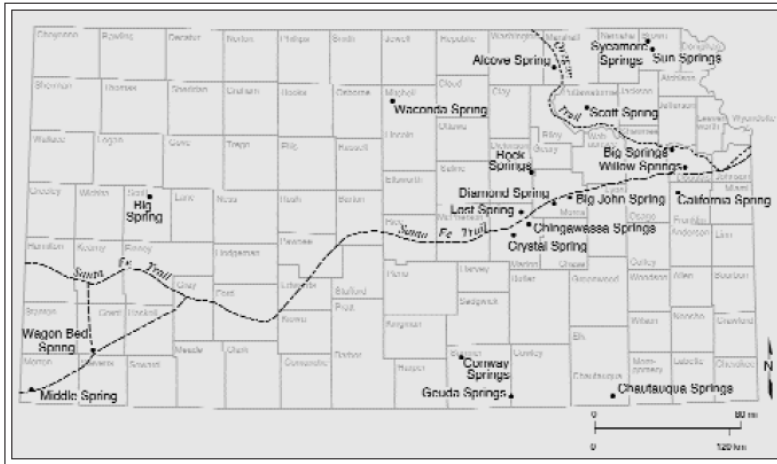
Road cuts between Stop 2 and Topeka expose Deer Creek Limestone, Calhoun Shale, and Topeka Limestone. The Topeka limestone is less developed than the older cyclothems, consisting of several dm- to m-thick beds and no black shale. The Deer Creek is marked especially by the highly nodular character of the regressive upper limestone, the Ervine Creek Limestone Member, along with the fissile, black Larsh and Burr Oak Shale Member.

Oregon Trail Wagon Ruts: Around KTA Mile Marker 186, on the south side of the road (left) in the pasture, are Oregon Trail wagon ruts following a road that passes under the Turnpike. They are a little hard to spot with summer vegetation, but they mark where pioneers came down a little from high ground to get water at Big Springs, which used to be on the north (right) side of the highway at this location. The nearby town of Big Springs, settled in 1854 with post office opening in 1855, is named after the springs. The town was the site of the first Free-State convention in the state of Kansas and the post office is operating even today (http://www.kancoll.org/books/cutler/douglas/douglas-co-p31.html#BIG_SPRINGS, accessed 7 June 2018). Construction of the Kansas Turnpike in 1955 interrupted the spring flow, however, and only a few seeps mark the location of the formerly reliable water supply. Wagons could travel 16-32 km (10-20 miles) daily, depending on the terrain, weather, and accidents, and springs were an important source of water along the trail, being clean (the Kansas River is quite muddy) and without strong currents that could sweep one away (Figure XXX).

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B.



Figure XXX: A. The major springs of Kansas, and their proximity to the Oregon and Santa Fe Trails (Buchanan *et al.*, 2000). Willow Springs is in southern Douglas County; Lawrence, KS, and KU are in northern Douglas County. Alcove Spring, one of the 8 Wonders of Kansas, was a popular stopping place Native Americans, fur traders, and Oregon Trail emigrants. B. One notable group was the Donner-Reed party who visited in 1846, as evidenced by a carving in a rock at the spring (Pinterest, accessed 6-7-2018), accomplished as the pioneers waited for spring-swollen rivers to lower enough to be forded safely. James F. Reed's mother-in-law, Sarah Keyes, died there at age 70, on 29 May 1846. Alcove Springs also had a "message center", which consisted of a stick driven into the ground, the top of which was notched to hold letters. One of these letters was found and described in 1849, and it read: "A letter in this post office was found addressed to Captain Pyle. It was from Captain Paul, giving information that at this place his driver, John Fuller, had accidentally shot and killed himself whilst removing a gun from the wagon." (https://www.kansassampler.org/8wonders/geographyresults.php?id=252, accessed 6-7-2018).

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At Mile 183 bear right to follow I-70 (Mile 367).

The larger road cuts just east of the East Topeka interchange expose the Calhoun Shale. Bearing left at this point would remain on the Kansas Turnpike and soon lead us to Wichita and Oklahoma.

Pass through Topeka.

The Native American atop the Capitol dome is pointing his arrow at the North Star. The famous John Steuart Curry picture of John Brown with the rifle and bible is outside the Governor's office in the Capitol. Topeka is also home of the Brown vs. Board of Education National Historical Site, the Evel Knievel Museum, and the Kansas Historical Museum, with a blood-spattered program from Fords Theater, April 14, 1865.

West of Topeka, *look for the sign* noting the first section of the Interstate Highway System to be completed.

And *look for the sign* denoting the beginning of the Flint Hills physiographic province (Figure XXX). Permian rocks underlie the Flint Hills, limestone-shale cyclothem to be discussed more at Stops 4 and 5. The Flint Hills are named for the chert found in the limestones, used by Native Americans to make tools and arrowheads. In the heart of these Hills, a little further west, the topography becomes highly dissected and the soils thin and rocky. For this reason, the Hills have never been plowed, but instead were used for cattle ranching, making the Flint Hills the largest remaining tract of the tallgrass prairie biome. This biome once stretched from Canada to Texas (Figure XXX) but now occupies less than 1% of its original extent. Tallgrass prairie in recent history covered approximately 60 million hectares (600,000 km² or 230,000 mi² or 150 million acres—which unit do you like?). All North American prairie once covered something like 3.6 million km² (1.4 million mi²; <http://www.blueplanetbiomes.org/prairie.htm>, accessed 6-4-2018).

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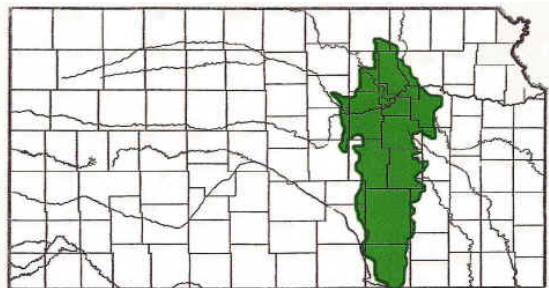


Figure XXX: Extent of the Flint Hills (<http://www.gpnc.org/meadow.htm>, accessed 6-4-2018).

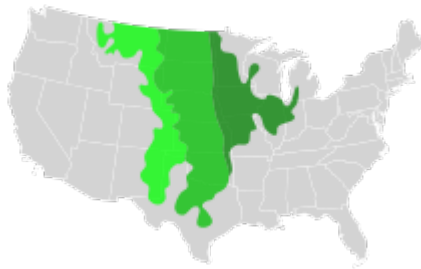


Figure XXX: Tallgrass prairie, dark green; mixed grass, medium green; shortgrass neon green. (Wikipedia, accessed 6-4-2018)

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Enter rest area at I-70 Mile 337 (left exit). Field Trip mile 49 Rest Stop.

This rest area is on the southern (right) bluff of Mill Creek, a tributary of the Kansas River, which is about 8 miles to the north. Mill Creek joins the Kansas River about 8 miles to the ENE. On-line geologic maps at the Kansas Geologic Survey show that the parking lot lies in the Admire Group of Pennsylvanian rocks and the hilltop is underlain by Foraker Limestone and Johnson Shale of the Council Grove Group, also Pennsylvanian (Mudge and Barton, 1959; Sawin et al., 2006). One or more periglacial lakes have occupied the valley of Mill Creek because pre-Illinoian ice sheets blocked the valley downstream. The rather wide valley may reflect sedimentation during the existence of the lake (or lakes; Dort, 2007). If there is time, you might be interested in reading the historical marker about Beecher's Bibles.

Continuing the Trip

Continue west on I-70.

At Exit 330 (Field Trip mile 56), turn north on McFarland Road (dirt).

Observe the color and character of the rocks in the pastures on either side of the road.

Continue north 3.5 miles to Homestead Road and turn left. A binary tower marks the SW quadrant defined by the two roads.

Continue west 0.9 miles and stop at a small creek with some trees on the left of the road.

Stop 3. Multiple pre-Illinoian glaciation events identified at the margin.

Spotting size distribution of clasts. (Field Trip mile 61; Appendix 3)

The Wabaunsee County geologic map (Mudge and Burton, 1959) from the Kansas Geological Survey shows this area to be underlain by Permian bedrock. Permian beds do not crop out well at this locality, but many cream-colored float blocks limestone of the Permian Council Grove Group are visible on hillsides. Commonly such accumulations of blocks follow contours, as they have shifted downslope from the level of outcrop of certain more resistant beds. Limestone blocks in the small creek at Stop 3 are from the Beattie Limestone.

Along the road and scattered in the adjacent pastures are numerous hard, rounded pink boulders, very greatly in contrast with the cream-colored and blocky chunks of limestone. These boulders can easily be traced to the Sioux Quartzite, which crops out in SW Minnesota, SE South Dakota and adjacent Nebraska and just a little into NW Iowa. In fact, the hilltops in the area of Stop 3 are mapped as Qtg, Quaternary glacial till. The stream exposes a small area of that till.

Activity. Establish a new spot on StraboSpot, write a brief description, and record the location with a photo or two. Measure the diameter of some of the Sioux Quartzite boulders, not repeating the measurements of other trip participants. Question: do the diameters represent a normal or log normal distribution?

StraboSpot Help: Recording Measurements of Boulders

Glacial Advances into Kansas. The large Sioux Quartzite boulder in the patio area of the EEEEC came from this site. These pink rocks are erratics recording the previous presence of an ice sheet. They are scattered widely in NE Kansas and adjacent Missouri, but well south and west of the margin of Wisconsinan or Illinoian glaciation. The biggest concentration in Kansas is along a line from Lawrence through Topeka to the area around Stop 3 near Wamego, Kansas, then to the NW or NNW toward Nebraska (Lyle, 2009).

Wakefield Dort (2007), a geomorphologist and emeritus professor at KU, found not only the exposed layer of till, but an older layer exposed in the creek a short distance upstream. "The area of this stop comprises the most important single, presently available, source of information about the Pleistocene glacial history of Kansas" (Dort, 2007, p. 19). He continues (p.19)

"At the point where the small creek turns to pass under the road there is a relatively spectacular (for Kansas!) exposure of glacial debris resting on limestone bedrock. Although this material is unsorted, containing fragments ranging from boulders to gravel and sand, and therefore can be called till, the high percentage of rounded clasts suggests considerable meltwater activity."

Dort reports that nearly 100% of the observed clasts are Sioux Quartzite with less than 1% mafic rocks and a minor scattering of granite boulders. The quartzite boulders, the sandy matrix, and even the mafic fragments are remarkably fresh (Dort, 2007).

Flash floods in 2007 exposed creek banks upstream, and Dort (2007) found a stratigraphy there:

"[I]t was instantly apparent...that the material exposed here just above water level is markedly different from that seen in the steep face by the road. The

constituent clasts appear to be large, but are so intensely weathered as to be strongly discolored and rotten. And Sioux Quartzite is absent. This looks like a deposit that is much older than the unit by the road" (p.21).

At nearby creek bank exposures an additional unit appeared:

"Just above water level are other exposures of the bouldery diamicton comprised entirely of far-travelled igneous rocks. Surely these are more of the intensely weathered till seen downstream.

"At the top of the section, reaching to the grassroots of the general land surface, is fresh appearing material which closely resembles that in the steep face by the road. It is comprised overwhelmingly of Sioux Quartzite clasts.... A third stratigraphic unit lies between the till at the top and the weathered unit at water level. It is unconformably separated from each by a sharp contact. Sioux Quartzite is present, though in smaller and fewer clasts. There is evidence of moderate weathering" (p. 21).

Hence there are three distinct stratigraphic Pleistocene units at Stop 3; two are clearly tills and the third one may be till, as well. The three units are successively less weathered, with the oldest one, which contains no Sioux Quartzite, most heavily weathered. Dort (2007) points out that the line of Sioux Quartzite boulders has long been taken as the southwestern extent of Pleistocene glaciation in the US midcontinent. He notes, however, that glacial deposits actually extend somewhat farther to the SW; perhaps those deposits are from one of the older stages of glaciation.

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John Gosse (personal communication, 2018) used cosmogenic isotopes to date the duration of exposure of about 5 of the Sioux Quartzite boulders from this area. He reports dates over a large range, 0.6 to 1.1 Ma. He suspects that the youngest ages are most reliable for the age of the younger till; the older ages may reflect exposure of the boulders in the original outcrop in South Dakota before the ice sheet dragged them to Kansas. Gosse agrees with the un-weathered nature of the boulders; he reports using a jackhammer to collect the samples!

Dort (2007) then engaged some speculation. He noted that some tills in Missouri had recently been dated at approximately 1.8 and 2.4 Ma, respectively. He speculated that the older, highly weathered deposit here at Stop 3 is correlative with the 1.8 Ma till from Missouri, partially because of its high degree of weathering, compared to the younger, well-known till. That makes the older deposit far older than the one previously recognized. He accounted for the lack of Sioux Quartzite boulders in the older deposit by suggesting that the Sioux Quartzite was still covered by younger sediments at the time of advance of the older ice sheet.

Kaw Lake. Stop three is south of the Kansas River, which heads in Colorado and, with tributaries, drains a large area of NW Kansas and SW Nebraska. The most recent ice sheet to reach Stop 3, and likely any earlier ice sheets, blocked the river, forming a lake, Kaw Lake, that extended at least 70 miles upstream from the ice margin. The surprising feature of this lake is that while there is a clear sill at an elevation of 1165', there is no evidence of a real drainage route with extensive

channeling. Furthermore, ice sheets of pre-Illinoian glaciations blocked drainage from the northern Rocky Mountains and the northern, unglaciated Great Plains. And the ice sheets and mountain glaciers had to melt. A large fraction of the melt water and stream flow from precipitation had to flow southward. How did all of that water get to the Gulf of Mexico (Dort, 2007)?

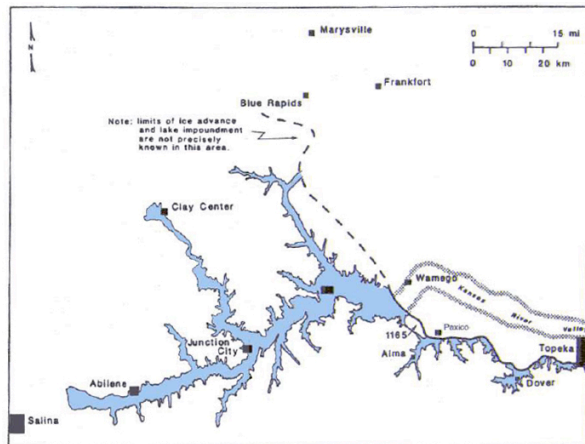


Figure XXX. Extent of periglacial Kaw Lake, based upon a spillway at an elevation of 1165 feet (355 m) and at the time of maximum advance of the most recent glacial advance. Several smaller lakes were trapped in other drainages to the east, notably Mill Creek, the lake bottom of which was visible from the recent rest stop (After Dort, 2007). The boundary of the ice sheet, as estimated from the distribution of Sioux Quartzite boulders, is shown by the heavy solid and dashed line.

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Continuing the trip.

Return to the vans and continue 1.6 miles west to the intersection of Homestead Road with K-99.

Turn Left on K-99 and continue 3.5 miles to I-70.

Enter I-70 westbound at Exit 328.

Mile 310 to 315: **Humboldt fault and Nemaha uplift** extend from Nebraska across eastern Kansas to central Oklahoma; it generally lies west of Topeka, east of Wichita, and under Oklahoma City. The fault has a history of significant motion ranging from Ordovician to Pennsylvanian (McBee, 2003) and has been the locus of earthquakes up to the present, including the Manhattan earthquake in 1867 with an estimated Modified Mercalli Intensity of VIII at a point 3 miles south of Wamego (Dubois & Wilson, 1978), which is just up K-99 from where we turned onto it. The Nemaha uplift lies west of the fault zone, the Forest City basin and Cherokee basin or shelf lie to the east (Figure XXX).

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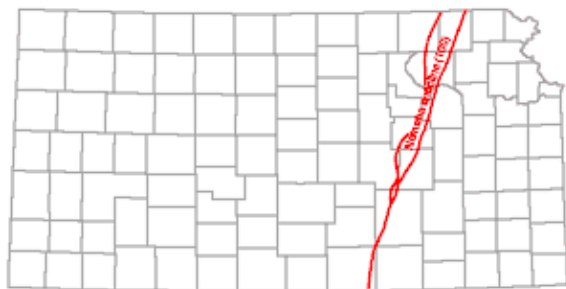


Figure XXX: Location of the Nemaha Anticline and parallel Humboldt fault. (http://www.kgs.ku.edu/Publications/Bulletins/90_6/page2.html, accessed 6-7-2018).

Apparent relative motion on the fault zone is close to vertical, but varies from normal to reverse along the trend of the zone. McBee (2003) argues that the fault zone has dominantly strike-slip motion, but notes that vertical offset of pre-Pennsylvanian strata ranges up to about 2500 feet or ~750m. The multiple branches of the fault, and its apparent reversals from normal motion suggest that it is a flower structure of transpressional character. The fault zone geologically separates eastern and western Kansas. The Oklahoma City and El Dorado oil fields, and many others, especially in southern Kansas and in Oklahoma, are along the eastern margin of the Nemaha uplift.

The Nemaha uplift and its eastern marginal fault zone have little topographic expression, if any. However, it is evident in the configuration of Pennsylvanian

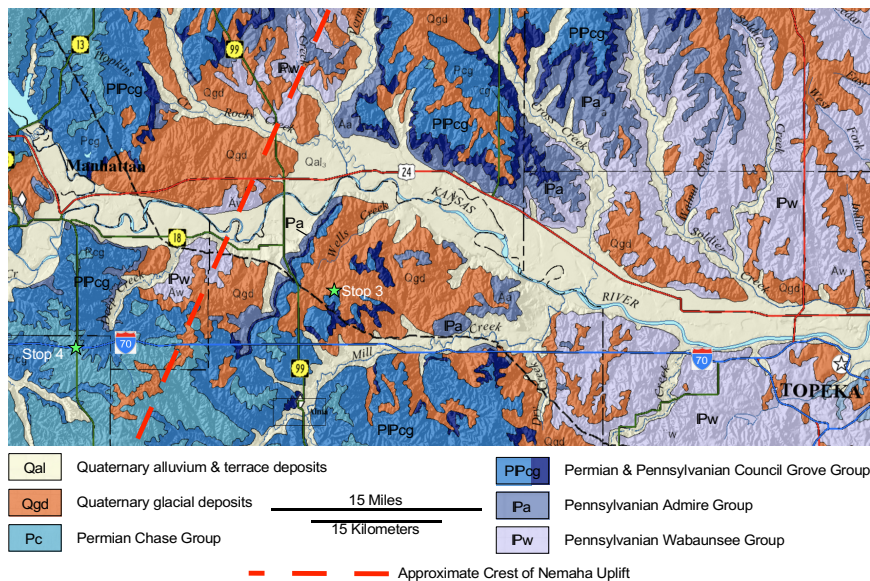


Figure XXX. Geologic map of portions of Wabaunsee, Shawnee, Riley, Geary, and Pottawatomie counties, Kansas. The Wabaunsee Group (pale purple) is at or above the level of the Kansas River in the eastern 1/3 of the map, but dips below the river alluvium and younger Pennsylvanian and Permian strata in eastern Wabaunsee and Pottawatomie counties. In western Wabaunsee and southeastern Riley counties, the group rises above the river level, despite the fact that the river level is higher. These exposures of the Wabaunsee Group lie close to the crest of the Nemaha uplift, as suggested by the red dashed line. The Humboldt Fault zone is east of the Nemaha uplift, and Stop 3 is located in the Forest City Basin. Map is a section of the Interactive Geologic Map available on the Kansas Geological Survey website at http://maps.kgs.ku.edu/state_geology/. Downloaded June 7, 2018.

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stratigraphic units on the state geologic map. In Figure XXX, the Pennsylvanian Wabaunsee Group underlies much of the topography for about 20 miles west of Topeka along I-70. That succession dips below the level of the Kansas River beneath the Admire and Council Grove groups, but then reappears above river level up stream around Kansas Highway 99, defining a syncline, as the elevation of the Wabaunsee-Admire contact drops and then rises farther to the west. Similar subtle arrangements can be found associated with some of the other drainages to the south. Stop 3 lies in the highly asymmetric syncline east of the fault zone and Stop 4 lies west of it. The red dashed line in Figure XXX approximates the crest of the Nemaha Uplift.

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The Nemaha Uplift underlies the Flint Hills (See below, Stop 4). Its core of Proterozoic igneous and metamorphic rocks plunges southward so that the base of the Paleozoic is at 180m near the Nebraska border and at about 1220 m or 4000 feet (375 to 1220 m) at the southern border of Kansas (Merriam, 1998). The uplift is asymmetrical with a locally faulted steeper east flank (Figure XXX). Rocks older than Pennsylvanian off-lap from it (Figure XXX) while Middle and Upper Pennsylvanian strata progressively lap on to it. The uplift apparently became a topographically positive feature before the late Middle Pennsylvanian (Desmoinesian) but post-Mississippian during deformation related to the formation of the Ouachita and Arbuckle mountains far to the south. The Central Kansas uplift as well as the Nemaha uplift were activated or re-activated at that time.

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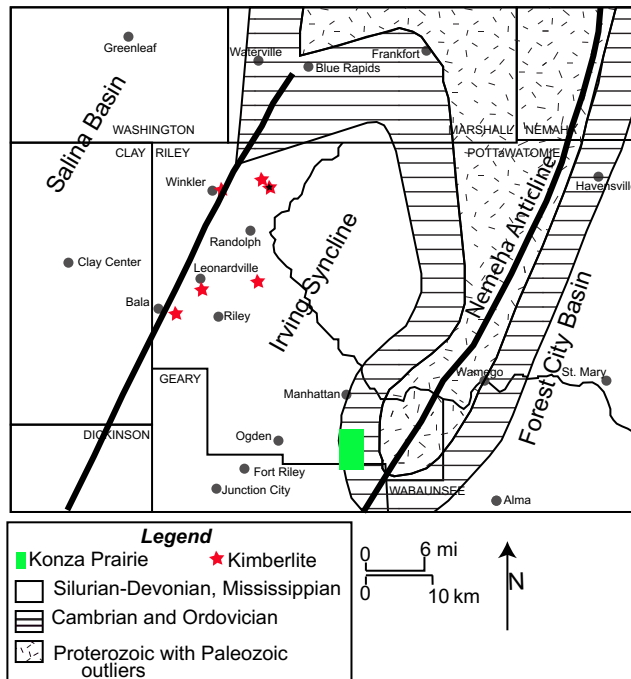


Figure XXX: The crest of the Nemaha Uplift trends north-northeastward just west of Wamego and East of Manhattan and the Konza Prairie, stop 5. Pre-Pennsylvanian strata off lap the structure. Modified from Chelikowsky (1972). Note the kimberlite occurrences in northern Riley County.

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Look for the Yaege Oil Field. Several pump jacks are visible from I-70, especially south of the highway. This small field (currently 29 active wells, maximum of 40 producing wells from 1985 to 1994, has produced about 3.9 million bbls of oil since discovery in 1959) lies atop the Nemaha uplift in a small, down-faulted block. The major reservoirs are the Silurian to Devonian Hunton Group and the transgressive conglomerate at the base of the Pennsylvanian succession, called (bear with me here) the Pennsylvanian basal conglomerate. In 2017, 31 wells produced 15146 bbls of oil, about 1.33 bbls of oil per day per well (<http://chasm.kgs.ku.edu/ords/oil.ogf4.ProdQuery>, accessed 6/11/2018).

Exit I-70 at Exit 313. Turn south on US 177, pass under I-70, and park as directed.

Stop 4. Permian Limestone of the Flint Hills and More StraboSpot joints. (Field Trip mile 65.7 XXX, Appendix 4)

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Note: Wear the provided highway safety vest at this locality.

The Flint Hills of Kansas are (mis)named for the abundant white, gray, pale blue, or brown chert (McCauley et al., 2001) that abounds in some of the limestone beds.

The chert is much less soluble than the limestone, leaving the thin loess-based soils peppered with hard pieces of plow-destroying cobbles and pebbles. The Flint Hills are the cuesta of the early Permian strata, occupying a north-northeast trending belt from the Oklahoma border to just south of the Nebraska border (Figure XXX). The outcrop of Florence Limestone at Stop 4 has abundant chert plus nice fossils of marine organisms.

Activity: Characterizing joints in the Florence Limestone Member. Upload images and make measurements of the joints in the Florence. The seesaw nature of the outcrop will allow you to measure in almost all orientations. Measure the widths of the joints, as well. Try sighting along a joint face with the app Stereonet Mobile (iOS only) and comparing the orientations you get with sighting with those you get with placing your device on the outcrop. Upload the images and measurements into StraboSpot as a new spot. At Stop 5 we will compare the results of the joint measurements in Stops 2 and 4. Also look for silicified gypsum rosettes.

Joints are the main avenues of permeability in limestone aquifers, and thus of great interest to one of us (GLM), who is studying the hydrogeology of the nearby Konza Prairie Biological Station. She would like information on the orientation of joints here at Stop 4 (and at Stop 2, as well) to compare with actual measurements on the Konza.

Note on sampling: Because the final stop, the Konza Prairie Biological Station, is protected, and one must have a permit to bang on rocks or collect specimens, use the opportunity here at Stop 4 to hammer all you want and collect whatever you want. You will not be allowed to do this on Konza.

Permian Geology of the Konza Area.

Stratigraphy: *What is Permian and What is Pennsylvanian?* The location of the boundary between the Pennsylvanian and Permian in Kansas has been debated for many years (Figure XXX). Mudge and Yochelson (1962) placed it at the top of the

Brownville Limestone Member of the Wood Siding Formation based on the first occurrence of *Pseudofusulina* in the overlying Five Point Limestone Member of the Janesville Shale and the next older fusulinid faunal in the Brownsville, as was generally accepted at that time. This is also the boundary in O'Conner et al. (1968),

StereoNet Mobile Help: Saving Data Files and Uploading StereoNet Mobile Data to StraboSpot

Save often! *Select the data you want to save.* Then, decide how you want your data saved: text file, as a file Stereonet Mobile can read, as a Stereonet 10.0 native (binary file), or in a format that can be uploaded to StraboSpot. Here we will only describe text file and StraboSpot upload. The others are described in the manual.

For text file: choose between two formats for saving. 1) *Text file* with 2-line header. In this format, line properties saved are TP (trend, plunge) and plane property is AD (Azimuth Dip, i.e., right hand rule). (There is a Stereonet3D application, as well, that we are not covering. Text file format is the better one to use in Stereonet3D or older versions of Stereonet.) 2) *Table format*. This has a 1-line header with column labels. All location information is saved (longitude, latitude, elevation, notes) in addition to orientation data.

To export data for upload into StraboSpot: Select File>Upload to StraboSpot. Enter your StraboSpot login credentials when prompted (required only the first time in a session). Choose your StraboSpot project (or start a new project). This process can be slow, depending on the Internet connection.

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although the stratigraphic chart accompanying the publication was updated in 2013. Baars et al. (1994) put the boundary much higher in the section, at the base of the Neva Limestone Member of the Grenola Limestone. Possibly the final word, Sawin et al. (2006) shifted the location again, this time between the previous boundaries, at the base of the Bennett Shale Member of the Red Eagle Limestone, using the first occurrence of the conodont *Streptognathodus isolatus* to mark the boundary. Figure XXX shows that the bedrock at Stops 3, 4, and 5 is all Permian.

StraboSpot Help: Transferring Data to Stereonet Mobile

In StraboSpot, on the map, [go to the three dot icon on the upper right and choose Lasso Spots for Stereonet to](#) draw a polygon around the spots with interesting data, which place them on the clipboard of your device. In Stereonet Mobile, go to *Open selection* and find a dialog to access data from a file or clipboard. Choose clipboard and data should transfer. Then use features of Stereonet Mobile to display the data (Allmendinger, 2018).

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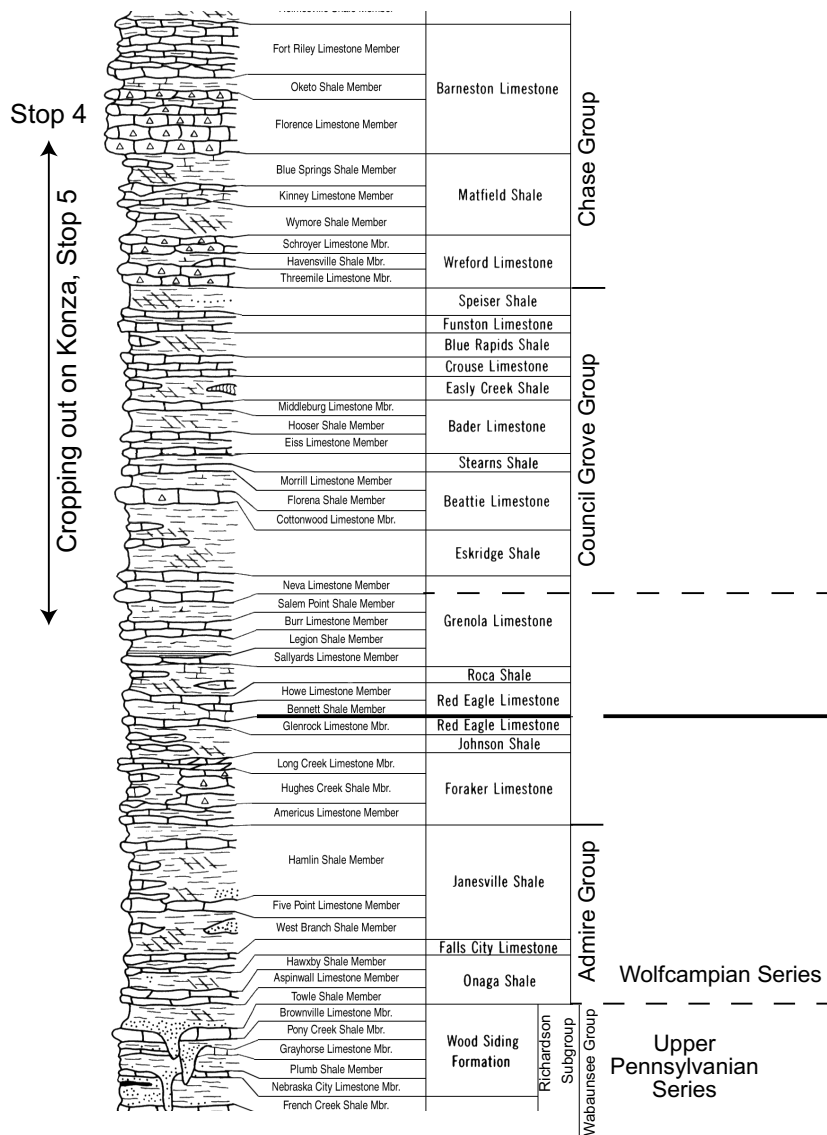


Figure XXX: Stratigraphy at Stops 4 and 5 and history of the Pennsylvanian-Permian boundary location: 1, Mudge and Yochelson (1962); 2, Baars et al. (1994); 3, Sawin et al. (2006).

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The Florence Limestone Member cropping out at Stop 4 represents shallow water, warm-sea deposition. About 10 km north of this stop it is described as a skeletal wackestone to packstone with closely spaced nodular chert layers. The fauna is dominated by productid brachiopods; fenestrate, ramose, and encrusting bryozoans; crinoids; and echinoids (Miller, 2011). You may also find ostracodes, gastropods, sponge spicules, and lophophyllidid corals (Archer et al., 1995).

In some places, where the bedding planes are exposed, chert **layers** form nearly continuous polygonal networks that may be joined by vertical to inclined chert masses, forming three-dimensional networks that are 20-30 cm thick. These networks may have been burrows that resulted in localized silica replacement because of their higher porosity (Miller, 2011). On the other hand, Twiss (1991) proposed that the chert represents replacement of original anhydrite or gypsum. He reports on core from a well drilled into the Chase Group approximately 43 km (27 miles) north-northeast of Stop 4 that contains extensive anhydrite beds consisting of nodules, rosettes, and irregular masses, some of which are partially replaced by microcrystalline quartz. The irregular masses were identified as burrows. If you stand back and look at the Stop 4 outcrop, you might agree the horizontal chert layers resemble chicken-wire anhydrite.

Miller (2011) identifies five flooding surfaces within the Florence Limestone Member and transgressive surfaces bounding the unit (Figure **XXX**). Twiss and Underwood (1988) found that at I-70 exit 305, 8 miles west of here, the Florence Limestone Member contained 28 nodular chert beds (how many can you count here?). Appendix 5 gives the descriptions of the Florence Limestone Member at that location. Beneath the Florence is the Blue Springs Shale Member of the Matfield Shale. Notice how poorly it crops out here. The contact with the Florence is a pale yellowish brown, ostracode packstone, and rare myalinid bivalves also occur here (Archer et al., 1995).

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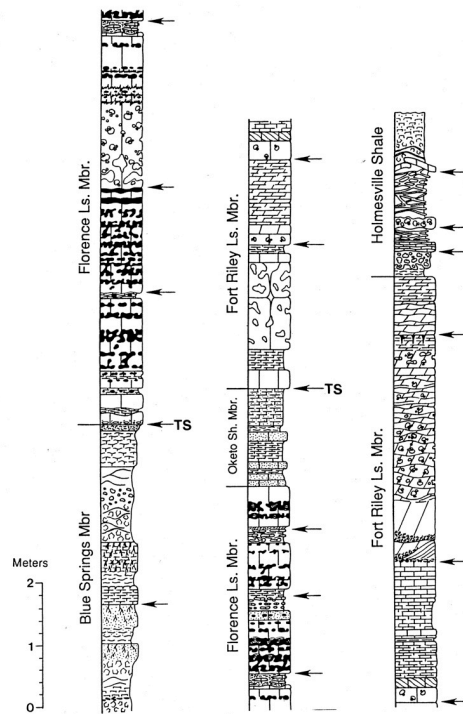


Figure XXX: Barneston Formation members with flooding surfaces (arrows) and transgressive surfaces (TS) marked. Black = chert. From Miller, 2011.

Cyclothems of the Early Permian differ from the Pennsylvanian cyclothems in that they are dominantly shallow-water limestone and shale (paleosols or marine deposits), with only rare “core shale” (deep-water shale) present and no sandstone or coal. The units are **commonly** mapped as shale-limestone couplets, or limestone-shale couplets, because limestone beds crop out reasonably well but the shale beds do not. Mapping units thus extend from either the base or top of a significant limestone to the base or top of the next significant limestone. A typical complete cyclothem consists of (from base to top) red mudstone and siltstone (non-marine), green to grey mudstone, skeletal calcilutite, and, finally, yellowish-gray mudstone (Twiss, 1988), so the significant limestone beds may be in the middle of cyclothems.

Joints in the Area of Stops 4 & 5: Joint orientations in the area trend north-south to northwest-southeast (Figure XXX; Chelikowsky, 1972). Jorgensen et al. (1996) say the regional joint patterns in the midcontinent trend N35°W and N55°E, while Aber (2017) describes two dominant and complementary joint sets, one trending about N50°E and paralleling the Fredonia tectonic zone the second trending parallel to northwest-trending basement faults known as the Neosho and Fall River trends. A third set occurs in places and parallels the Humboldt Fault zone (Figure XXX).

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Solution-enlarged joints are critical for development of the merokarst (i.e. relatively thin limestone beds interlayered with non-limestone beds, and surface drainage that is only partially controlled by karst features) aquifers in this area.

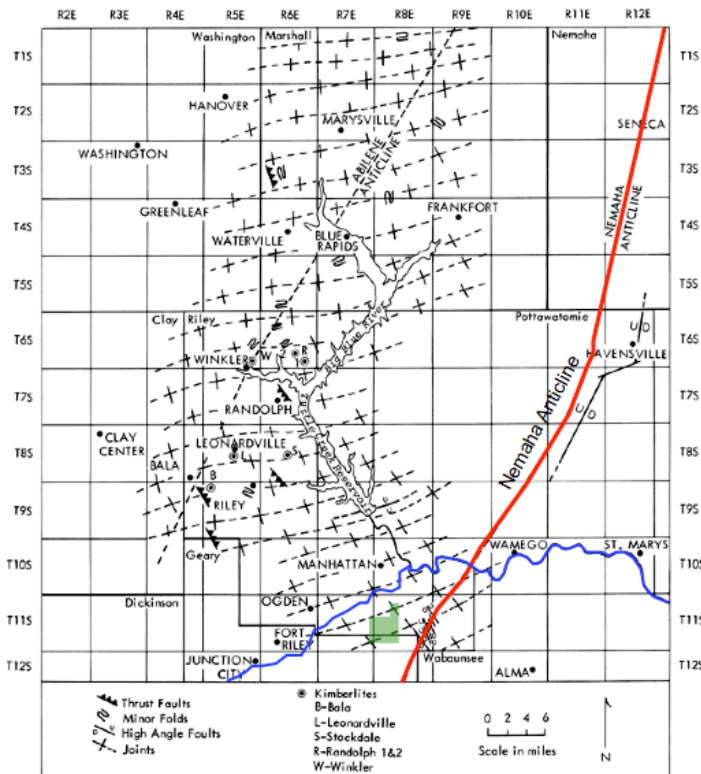


Figure XXX: Structural features in the Manhattan, Kansas, area. Modified from Chelikowsky (1972). Approximate path of the Kansas River is shown in blue, and approximate location of the Konza Prairie is shown in green.

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Economic Impact of Permian Paleoclimate. Permian rocks indicate continuation of a drying trend that began in the Late Pennsylvanian and peaked in the late part of the Early Permian with deposition of the Wellington Formation, which contains the Hutchinson Salt Member. Although the surface expression of the Wellington is mostly shale with small amounts of limestone, dolomite, siltstone, gypsum and anhydrite, the Hutchinson Salt Member is the thickest member of the Wellington in the subsurface. In places it is more than 213 m (700 ft) thick. The other members of the Wellington are only a maximum of about 4 m (13 ft) thick (O'Conner et al., 1968).

Kansas has an extensive salt-mining industry centered near Hutchinson in Reno County. In 2015 the state produced over 2.3 million tons of salt, worth over \$200 million (Bolen, 2017). Mined-out volumes are used as gas storage reservoirs or for secure record storage. A leaky gas storage volume caused explosions in downtown Hutchinson in January 2001, destroying two stores and later, at a trailer park, destroyed a trailer and killed two occupants. The Kansas Geological Survey was extensively involved in tracing the source of the gas and discovering the key failure and the migration route (<https://www.youtube.com/watch?v=4QgCEIPaPxc>, accessed 6/13/2018). An underground museum has been developed in an abandoned mine.

Topographic Development. In this part of the Flint Hills, the hill-topper limestone is the Florence Limestone Member, shown in its glory at this roadcut. The Florence is the lower limestone member of the Barneston Limestone. For whatever reason, formation-level units of the Permian in Kansas are not called formations, but instead named limestone or shale, depending upon the predominant lithology. Members of the formations are formally identified as such (e.g. Florence Limestone Member), so one can usually assume a unit is a formation if it is called a limestone (Barneston Limestone) or shale.

The Florence Member contains abundant chert and a fossil assemblage of brachiopods, bivalves, bryozoans, and fusulinids. It ranges from 3.7 to 13.7 m (12 to 45 ft) thick. Although not present at this stop, the thin overlying shale, the Oketo Shale Member, is generally less than 1.5 m (5 ft) thick, and the uppermost unit of the Barneston, the Fort Riley Limestone Member, is about the same thickness as the Florence.

Fort Riley Limestone. In the lower part of the Fort Riley Limestone Member is a dense limestone that forms a prominent rim rock throughout the Flint Hills (O'Conner et al., 1968), capping the next set of hills to the west of Stop 4. The Fort Riley Limestone is the only Permian limestone that forms caves large enough to explore (Young and Beard, 1993). It hosts the largest spring in Kansas, Crystal Spring, which is the sole-source water supply for the city of Florence (Macfarlane, 2003) and a magnitude 3 spring (Sawin et al., 1999; Meinzer, 1923).

The Fort Riley Limestone Member also provides important rock for Kansas. It is quarried in southern Kansas and used for rip-rap and aggregate. It is also an important building or dimension stone in Kansas. Part of the state capitol building in Topeka was built of Fort Riley Limestone quarried near Junction City (McCauley et al., 2001).

However, the most important quarry in the Fort Riley Limestone is in Cowley County, along the southern border of Kansas. The product of this quarry is known as the Silverdale Limestone, named for the nearby settlement (McCauley et al., 2001). Lindley Hall of the EEEEC is faced with Silverdale Limestone (Grisafe, written communication) and the stone walls inside Slawson and Ritchie Halls of the EEEEC are also Silverdale Limestone. Other KU buildings faced with Silverdale Limestone include Allen Field House (Grisafe, written communication). A nearby quarry in

Cowley County produces large, weathered boulders (Figure XXX) used mostly in landscaping (Wikipedia) (<http://www.praystoneco.com/boulders/>, accessed 7 June 2018).



Figure XXX: Silverdale (Fort Riley Limestone Member) boulders for sale from the Pray Stone Company (<http://www.praystoneco.com/boulders/>, accessed 6-7-2018).

Flint Hills Topography. There is some debate about the reason for the persistent elevation of the Flint Hills, the most prominent cuesta in eastern Kansas. As described above, relief around Mount Oread in Lawrence is about 30 m (100 ft). Relief in the Flint Hills is as much as 115 m (380 ft). Some argue that the Flint Hills persist because of the resistance of the chert to weathering. However, the prominent escarpment is made by the Fort Riley Limestone Member, which does not contain chert. Jewett (1941) proposed that the non-chert-bearing limestones such as the Fort Riley resist weathering and, when finally breached, the underlying chert-bearing limestones weather relatively easily. According to Jewett (1941), "The Fort Riley limestone holds up benches over hundreds of square miles, but wherever the protective Fort Riley is removed the flinty Florence is reduced to rounded buttes." In central Kansas, the Florence does make a prominent bench, possibly because of a protective cover of younger (Tertiary, perhaps) material that preserved it from weathering for a longer time (Jewett, 1941).

Continuing the trip.

Return to the vans, turn the vans around and re-enter I-70 west. Drive about 6 miles to exit 307, McDowell Creek Road (trip mile 87.7). About halfway to the exit you will see a sign on the north side of the road indicating the Konza Prairie Research Natural Area.

Take exit 307, turn right onto McDowell Creek Road and drive 5 miles to the entrance to the Konza Prairie Biological Station (KPBS or Konza; trip mile 92.7).

Turn right into the KPBS. Drive cautiously around the blind curve. Park outside Konza Lab or the Konza Meeting Hall, the original stone barn from the working ranch that used to be Konza.

Lunch and rest stop. After lunch, we will do a driving tour of Konza. We will then return to the Konza Meeting Hall to do an activity and, if there is time and interest (and it is not too hot), explore a little of the site.

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Stop 5: Konza Prairie Biological Station and Long-Term Ecological Research Site (trip mile 93.2)

Konza occupies 35 km² (13 mi²) of former cattle ranch where only small parts of the lowest floodplains have been altered from its former tallgrass prairie state. It is owned by The Nature Conservancy and managed by Kansas State University (Figure XXX). It began as donated land and grew to its present size in 1979, and it was one of the first six Long-Term Ecological Research Sites (LTER) funded by the National Science Foundation. It has been continuously funded by that NSF program, but individuals also compete for other funding to move the research forward.

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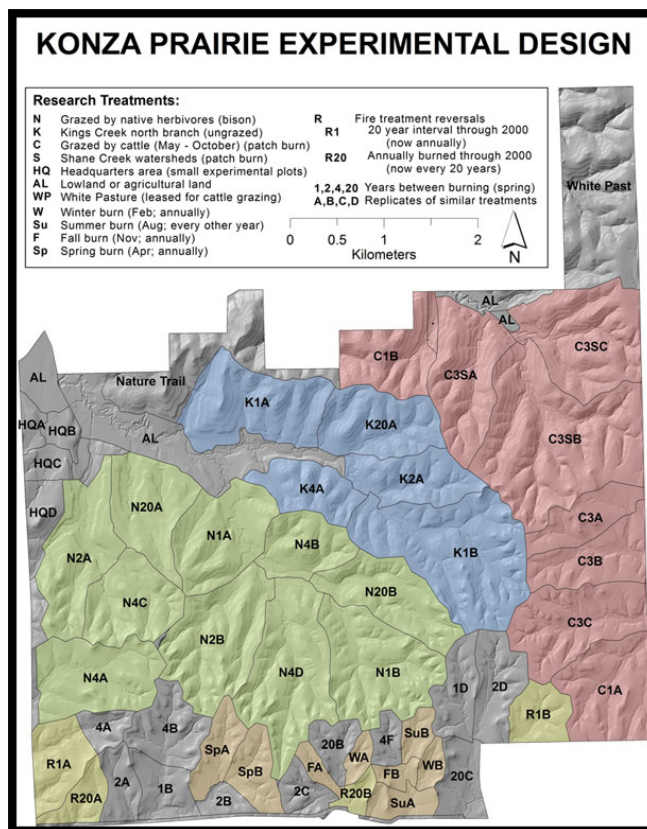


Figure XXX: Shaded relief map (DEM) of the Konza Prairie Biological Station. The uplands have never been plowed, so this is one of the few areas of virgin prairie in the US. Letter and number combinations indicate the several watersheds; each has a particular management plan, e.g. frequency of controlled burning or whether occupied by bison or cattle. One trip leader (GLM) has a decades-long ongoing study of hydrogeology in watershed N4D. <http://lter.konza.ksu.edu/sites/default/files/images/TreatmentsSM.jpg>, downloaded 6/20/2018

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The 60 watersheds on the site are part of an experimental design testing the effects of grazing (none, bison, cattle) and fire frequency (none, 10-year, 4-year, 2-year, annual) on the ecological diversity of, resilience in, and resistance to climate change in tallgrass prairie. Experiments also simulate climate change, controlling the amount of precipitation falling on small plots (rainout shelters) and raising the air temperature, and examine the effects of nutrient additions.

Critical Zone Science. Much of the work here falls under the broader scope of critical zone science, where the critical zone is the area between the top of the vegetation canopy and the bottom of the zone of active weathering. Biologists, ecologists, soil scientists, atmospheric scientists, and geologists work together to better understand the tallgrass prairie. Integration of biotic and abiotic studies are a hallmark of the science done here.

The prairie is considered a temperate mesic grassland, and it is located on the western edge of the original tallgrass prairie biome. Because of its location, it is challenged by the periodic dry years, such as 2017-2018. Average annual rainfall is 835 mm, enough to support forest, so other factors must keep the forest growth in control. The dominant native vegetation includes perennial C4 grasses (big bluestem, *Andropogon gerardii*; Indiangrass, *Sorghastrum nutans*; and switchgrass, *Panicum virgatum*) and many forbs. Riparian zones of higher-order streams have C3 woody species make up the native gallery forest (oak, *Quercus spp.*; hackberry, *Celtis occidentalis*; elm, *Ulmus americana*), but at least since the establishment of the LTER, expansion of smaller C3 shrub species (dogwood, *Cornus drummondii*; sumac, *Rhus glabra*) throughout the slopes and lowland prairie by up to 60% (Ratajczak et al., 2014) in watersheds with burn intervals of 4 years or more has drastically changed the character of the landscape. Although not characterized by Ratajczak et al. (2014), personal observations are that some hilltop benches are now also experiencing woody invasion. A fairly abrupt increase in slope of time-versus shrub cover occurred in 1998, suggesting a threshold behavior.

Whether the increase in woody vegetation explains the increasing CO₂ in the shallow groundwater at the site (20% increase, 1991-2005; Macpherson et al., 2008; 29% increase, 1991-2009, Liu, 2014) is not known, but the increase has been steady rather than following the abrupt increase in the shrub cover. The increase in CO₂ has been accompanied by increased chemical weathering of the limestone, evidenced by increased dissolved calcium and magnesium and alkalinity.

The Geology at the Site (Figure XXX; Back cover) includes, at the top, the Florence Limestone Member of the Barneston Limestone (cf. Stop 4) down through the Grenola Limestone and including the Beattie Limestone (cf. Stop 3). The limestone beds create the relatively flat hilltops and also protrude as benches along the slopes; the shale beds form slopes (Figure XXX). The entire area is mantled with a thin layer of loess.

There is patchy alluvium in the headwater streams, and in the downstream stretches of Kings Creek, the main drainage at the site, the alluvium is as much about 10 m

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thick. The alluvium consists of a basal chert-limestone gravel overlain by reworked loess that is 40-60% silt (Macpherson and Sophocleous, 1998). Four terrace levels have been mapped along Kings Creek and three along Shane Creek. Radiocarbon dating of the two oldest terraces showed charcoal ages of 8920 ± 120 yr BP and 1770 ± 80 yr BP, suggesting responses to Holocene climate change (Smith, 1990). The younger two terraces, not as extensive as the two older terraces, apparently have resulted from ongoing Holocene downward erosion (Smith, 1990); streams are deeply incised throughout Konza.



Figure XXX: Bison grazing on the Konza Prairie in winter. Note the bench topography underlain by limestone and shale beds on the hill across the draw. Photo by GLM.

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Hydrogeology. Streams are intermittent at Konza and dominantly groundwater fed at discrete points where limestone porosity that is developed along joints or in vugs connects with the shallow aquifers. These points are easily found during very warm or very cold periods, using thermal imaging (Figure XXX; Brookfield et al., 2017; B. Norwood, M.S. thesis in progress). Streams and the limestone aquifers are very flashy, responding rapidly to precipitation events outside of the growing season, with karst-like hydrographs. During the growing season (May-October), most precipitation is intercepted by vegetation; most aquifer recharge occurs during the non-growing season even though the months with the highest rainfall are April to June.

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A groundwater tracer test, begun 7-29-2017, demonstrated that groundwater can flow in opposing directions in adjacent limestone beds, and that the mudstones transmit water through them rapidly at least at times, although the nature of the flow paths is unknown (Barry and Macpherson, 2017). The dye traveled through the Cottonwood Limestone Member of the Beattie Limestone at around 7 m/day, through the Morrill Limestone Member of the Beattie Limestone at around 1 m/day, and through the Eiss Limestone Member of the Bader Limestone at around 6 m/day. Overall, the groundwater flowed north, in the same direction as the stream, in the Eiss and Cottonwood, but south in the Morrill, which lies between the other two.

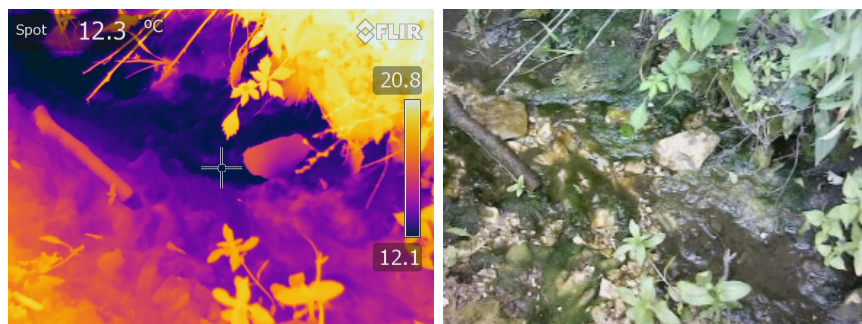


Figure XXX: Thermal image (left) and digital photograph (right) showing cold groundwater (12.3°C at the cross) entering Kings Creek on 5-25-2014 (A. Brookfield, personal communication, 2014).

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Activity: Comparing joint orientations and identifying joints using

GoogleEarth. Because most groundwater flows through solution-enlarged joints in these thin limestones as well as in more massive karst, the activity for this stop will include comparing joint orientations measured during this field trip and using remote sensing to attempt to identify major joint orientations. Smith (1990) found two dominant joint directions, N325-335° and N55-65°. Compare these with Figure (XXX) and with measurements made on this field trip. Open GoogleEarth and examine the straight stream segments. Do they coincide with joint orientations measured or published?

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Continuing the trip: Load up in the vans and return to Lawrence.

Trip leaders will arrange to drop off participants at their cars or their hotels. Please work to distribute participants in vans by destination.

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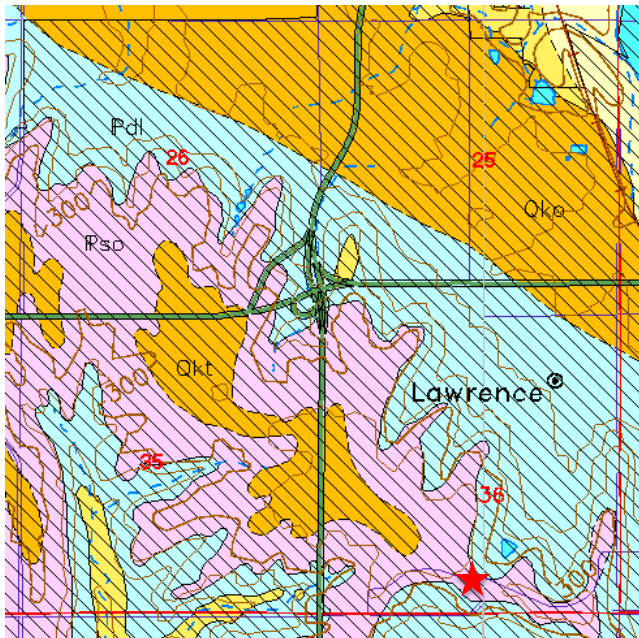
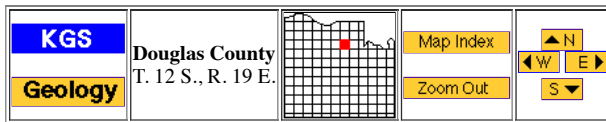
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Appendix

Appendix 1: Geologic Map of the area around Stop 1, including part of the KU campus. Cartographic Services, Kansas Geological Survey, Updated April 1999. http://www.kgs.ku.edu/GeneralGeology/County/def/dg/dg_4_7.html. Downloaded June 15, 2018. Star shows location of Stop 1.

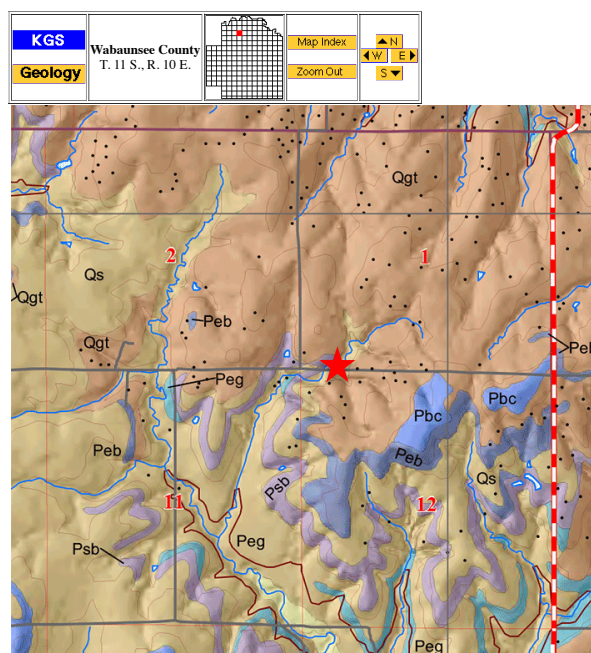


Quaternary		Pennsylvanian	
Pleistocene Series		Virgilian Series	
Alluvium		Shawnee Group	
Qal	Alluvium	Pst	Topeka Limestone
Qtn	Newman Terrace deposits	Psdo	Calhoun Shale and Deer Creek Limestone
Qtb	Buck Creek Terrace deposits	Psl	Tecumseh Shale and Leocompton Limestone
Qtu	Undifferentiated terrace and colluvial deposits	Pso	Kanvaka Shale and Oread Limestone
Qkt	Till and upland glacio-fluvial deposits	Douglas Group	
Qka		Pdl	Lawrence Formation
		Pds	Top of Haskell Limestone to the base of Tonganoxie Sandstone of Stranger Formation
		Ppw	Base of Tonganoxie Sandstone (Stranger Formation) to the top of Stanton Limestone
		Missourian Series	
		Lansing Group	
		Pls	Stanton Limestone
		Ply	Vilas Shale and Plattsburg Limestone

Appendix 2 Members of the Lecompton Limestone

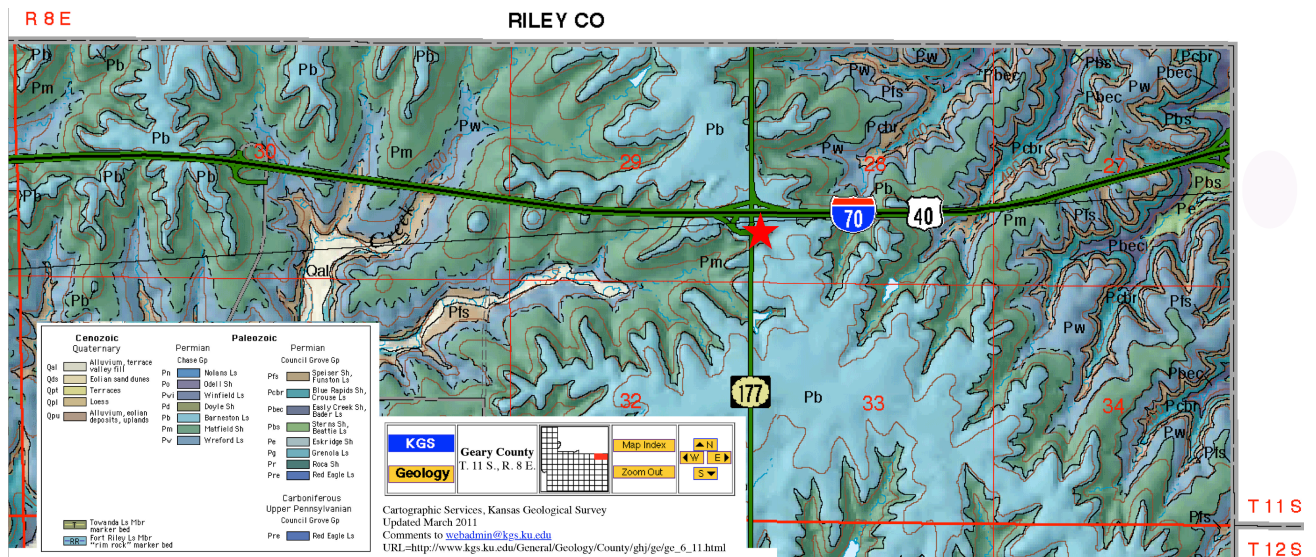
Members of the Lecompton Limestone	Description (Jewett et al., 1968)
Avoca Limestone Member (Super limestone)	...[D]ark bluish-gray, somewhat earthy limestone occurring in one or more beds. Large fusulinids are the most common fossils. In southeastern Kansas "cryptozoon"-bearing limestone is characteristic of the member. Algal-molluscan limestone beds occur at the top of the Avoca in some outcrops. The thickness ranges from about 1 to 20 feet (0.3 to 6 m).
King Hill Shale Member	...[G]reenish-gray to reddish-gray shale that is calcareous in northeastern Kansas. Brachiopods occur sparsely in the upper part of the member. The thickness ranges from about 4 to 20 feet (1.3 to 6 m).
Beil Limestone Member (Upper limestone)	...[T]hin- to medium-bedded, abundantly fossiliferous, bluish-gray limestone averaging 8 to 10 feet (2.6 to 3 m), but ranging from 4 to 15 feet (1.3 to 4.5 m) thick. In northern outcrops the upper part includes interbedded calcareous shale and thin limestones, whereas in southern outcrops the member is more massive and contains fewer shaly beds. Fossils are very abundant, especially horn corals, bryozoans, and fusulinids.
Queen Hill Shale Member	The upper part of the Queen Hill Member is a bluish-gray or yellowish-gray shale, and the lower part is a hard, black, fissile shale, containing conodonts. The thickness ranges from about 2 to 6 feet (0.6 to 1.8 m).
Big Springs Limestone Member (Middle limestone)	This member is a dark bluish-gray, dense limestone, commonly occurring as a single bed with closely spaced vertical jointing. It weathers yellowish-brown. Locally two or three limestone beds are separated by thin shale beds. Fusulinids are abundant in the member. The thickness ranges from 1 to 5 feet (0.3 to 1.5m).
Doniphan Shale Member	...shale, sandstone, and thin, earthy limestone beds. It is thicker and contains some red shale and prominent sandstone beds in southeastern Kansas. Fusulinids are plentiful in the basal part at some exposures. Thickness ranges from about 2 to 34 feet (0.6 to 10 m).
Spring Branch Limestone Member (Lower limestone)	...a gray, somewhat sandy limestone that weathers deep brown and occurs in massive, slightly uneven beds. Fusulinids are abundant in most outcrops. In northeastern Kansas the thickness is commonly 5 feet, but locally as much as 14 feet, with shale and earthy limestone in the upper part. In southeastern Kansas this member locally is very sandy, impure limestone about 4 feet (1.3 m) thick.

Appendix 3. Geologic Map of the Stop 3 Area. Cartographic Services, Kansas Geological Survey, Updated October 2010. [http://www.kgs.ku.edu/General Geology/County/ghj/wb/wb_4_7.html](http://www.kgs.ku.edu/General%20Geology/County/ghj/wb/wb_4_7.html). Downloaded June 15, 2018. The Admire Group and the Council Grove Group (here mislabeled as Chase Group) up to the Red Eagle Limestone are now considered to be Pennsylvanian, not Permian (Sawin et al, 2006). Star shows location of Stop 3.



Cenozoic		Paleozoic	
Quaternary		Permian	Pennsylvanian
Qal	Alluvium	Chase Gp	Wabaunsee Gp
Qtr	Travertine	Pdb	IPb
QT2	Newman terrace	Pmw	IPpn
Qt	Terrace deposits	Psf	IPfj
Qt1	Buck Creek terrace	Pbc	IPfg
Qs	Sanborn Fm	Peb	IPdd
Qsa	Sappe Fm	Psb	IPpm
Qgi	Grand Island Fm	Peg	IPrt
Qic	Glacial ice-contact deposits	Prr	IPwe
Qgt	Glacial till	Pjf	IPhr
Qog	Older gravel	Admire Gp	Auburn Sh
		Phf	
		Pvf	
		Pha	
		Pt	

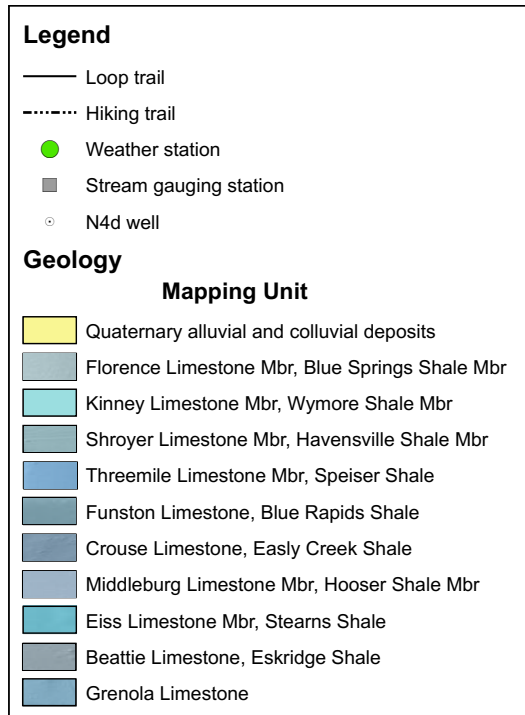
Appendix 4. Geologic map of the area around Stop 4 (Red Star). Cartographic Services, Kansas Geological Survey, Updated March 2011.
http://www.kgs.ku.edu/General/Geology/County/ghj/ge/ge_6_11.html. Downloaded June 15, 2018.



Appendix 5. Florence Limestone Member of the Barneston Formation and upper part of Blue Springs Shale Member of the Matfield Shale at I-70 milepost 305 (Twiss and Underwood, 1988)

Unit #	Description
14	Skeletal calcilutite; massive; yellowish gray (5Y7/2), weathers yellowish gray (5Y7/1) to medium gray (N5); silicified skeletal fragments abundant; no chert.
13	Clayey calcilutite or marl; largely covered; forms shale-like slope.
12	Chert-bearing skeletal calcilutite; massive; colors same as unit 7; two chert horizons in upper 1 ft (30 cm); upper chert horizon contains nodules 2 to 5 in (5 to 25 cm) in diameter; lower-chert horizon, 6-12 in (15-30 cm) below upper chert, 1 to 5 in (2.5 to 12.5 cm) thick and continuous; chert with silicified echinoid spines, brachiopod fragments, and fenestrate bryozoans enclosed in skeletal calcilutite; forms vertical cliff.
11	Clayey calcilutite or marl; shale-like slope; less resistant to weathering than lower units; color as in unit 7; largely covered.
10	Chert-bearing skeletal calcilutite; contains 5 chert zones evenly spaced vertically; lower 4, 2.5 in (6.5 cm) thick; uppermost, 6 in (15 cm) thick and more continuous; capped by skeletal calcilutite 0.5 to 2 in (1.5 to 5 cm) thick, sparsely fossiliferous with algal-coated grains; some brachiopod and fenestrate bryozoan fragments; not as fossiliferous as lower units; color as in unit 7; forms near-vertical cliff.
9	Cherty-bearing skeletal calcilutite; massive, forms near-vertical cliff; color as in unit 7; six horizons of irregular chert nodules. Capped by 5-in. (12.5-cm) thick skeletal calcilutite with some chert nodules, 0.5 to 1 in (1 to 2.5 cm) diameter, more rounded and rod like; calcilutite contains brachiopod fragments, whole valve of <i>Derbia</i> sp., echinoid spines, and fenestrate bryozoan fragments. 5th chert horizon approximately 6 in (15 cm) thick; nodules in skeletal calcilutite. 4th chert horizon 20 in (50 cm) thick and in contact with third horizon; irregular tabular chert masses 2 to 4 in (5 to 10 cm) long and 2 to 3 in (5 to 7.5 cm) thick, smaller than those below. 3rd chert horizon 7 in (19 cm) above 2nd; lower half of horizon contains horizontal and discontinuous chert zones. 2nd chert horizon; base 12 in (30 cm) above 1st chert horizon; ranges from 2 to 6 in (5 to 15 cm) thick; intervening skeletal calcilutite. Skeletal calcilutite; very irregular chert nodules 0 to 3 in (0 to 8 cm) thick, elongated horizontally; not as numerous as in unit 8.
8	Chert-bearing calcilutite; massive, forms vertical cliff; weathers to rubble of chert masses; color as in unit 7; 9 horizons of discontinuous, horizontally elongated chert masses enclosed in skeletal calcilutite; contains algal-coated skeletal grains of fenestrate bryozoans and algae, traces of brachiopod and echinoid fragments and spines; upper surface is microkarst with silicified fenestrate bryozoan bryozoans and algae, traces of brachiopod and echinoid fragments. Skeletal calcilutite cap, 4 in (10 cm) thick. 9th chert horizon: 1.5 to 3 in (4 to 7.5 cm) thick; 4-5 in (10-12 cm) about 8th. 8th chert horizon: 2 to 5 in (5 to 12 cm) thick; 7 in (18 cm) above 7th.

	7th chert horizon: 0 to 5 in (0 to 12.5 cm) thick; 5 in (12.5 cm) above 6th. 6th chert horizon: 2 to 5 in (5 to 12.5 cm) thick; 12 in (30 cm) above 5th. 5th chert horizon: 2 to 7 in (5 to 18 cm) thick; 3 in (7.5 cm) above 4th. 4th chert horizon: 1 to 5 in (2.5 to 12.5 cm) thick; 2 in (5 cm) above 3rd. 3rd chert horizon: 2 to 4 in (5 to 10 cm) thick; 1 to 3 (2.5 to 7.5 cm) above 2nd. 2nd chert horizon: 2 to 5 in (5 to 12.5 cm) thick; 2 to 4 in (5 to 10 cm) above 1st. 1st chert horizon: 2 to 3 in (5 to 7.5 cm) thick; 5 in (12.5 cm) above top of unit 7.
7	Chert-bearing calcilutite; massive, forms vertical cliff; contains algal-coated fenestrate bryozoans, echinoid spines, and miscellaneous skeletal debris; yellowish gray (5Y7/2), weathers yellowish gray (5Y7/1) to medium gray (N5); contains 5 chert horizons. 5th chert horizon: 2 in (5 cm) thick; 6 in (15 cm) above 4th. 4th chert horizon: 3 in (7.5 cm) thick; 6 in (15 cm) above 3rd. 3rd chert horizon: 4 to 5 in (10 to 12.5 cm) thick; horizontal diameter up to 14 in (35 cm); 9 in (20 cm) above 2nd. 2nd chert horizon: 4 to 5 in (10 to 12.5 cm) thick; horizontal diameter up to 14 in (35 cm); 2 in (5 cm) above 1st. 1st chert horizon: about 2 in (5 cm) thick; horizontal diameter up to 8 in (20 cm). Chert nodules range from very light gray (N8) to medium gray (N5), weather medium gray (N5) or dark yellowish orange (10YR6/6); nodules contain algal-coated, mostly silicified skeletal debris; chert nodules irregular, discontinuous, and elongate parallel to bedding.
6	Clayey chert-bearing calcilutite; more calcareous and more resistant than unit 5; contains some widely spaced chert masses 2 in (5 cm) thick and 2 to 4 in (5 to 10 cm) across horizontally; color as in 5.
5	Clayey calcilutite; platy and lenticular; yellowish gray (5Y7/1) mottled to moderate yellowish brown (10YR6/4); contains crinoid columnals and fragments of brachiopods and platy algae.
4	Clayey calcilutite; massive; forms steep slope; light gray (N7), weathers very pale orange (10YR7/2), horizontal zones of grayish orange (10YR7/4); contains platy algal fragments near base that decrease upward; echinoid spines and brachiopod fragments in upper part; possibly bioturbated near top; basal contact sharp and undulating.
3	Blue Springs Shale Member, Matfield Shale. Mudstone; weathered; dark yellowish brown (10YR4/2); tabular bedding; nonfossiliferous; transitional with unit 2 at base, but forms sharp undulating contact with overlying Florence Limestone.
2	Clayey calcilutite; blocky structure; yellowish gray (5Y7/2), weathers pale yellowish orange (10YR7/2) with moderate yellowish brown (10YR5/4) iron-oxide splotches; nonfossiliferous; forms steep slope.
1	Mudstone, greenish gray (5GY5/1), weathers light greenish gray (5GY7/1); nonfossiliferous, tabular to blocky; nonfossiliferous; forms shale-like slope.



Back Cover: Geologic map of the west portion of the Konza Prairie Biological Station, showing major units (Smith, 1990). Intervals are mapped from the base of a shale formation to the top of a limestone formation, unlike those on the Kansas Geologic Survey maps (base of limestone to top of shale). Distinct benches on hill slopes show positions of major limestone beds. Dips are very low, so contacts closely follow contour lines. GIS map by G.L. Macpherson.

Konza Prairie Biological Station, west side

