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A Review of Archaeological and Paleoecological Radiocarbon Dating in Bolivia

REVIEW

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ABSTRACT

Radiocarbon dating is one of the most useful and widely used chronometric techniques available for archaeologists and other paleo-scientists. Although generally used for answering specific research questions, radiocarbon dates from archaeological sites have become increasingly used to reconstruct population change at meso and macro temporal and spatial scales, and Bayesian modeling of locally and regionally available dates is facilitating interrogating the synchronicity, correlation, and interaction among various socioecological variables. Because the results of these meta-analyses largely depend on the available data, comprehensive compilations of radiocarbon dates and their associated information are critically important. Moreover, a thorough assessment of these compilations can reveal research spatiotemporal foci, trends, and biases, which should be considered when meta-analyses are attempted. In this review, based on the recently compiled Bolivian Radiocarbon Database, I provide a general assessment of the temporal, geographic, and thematic interests that have driven archaeological and paleoecological research in Bolivia over the last seven decades. Along with a detailed review of research in three broad geographical regions (Andean highlands, inter-Andean valleys, and tropical lowlands), I encourage researchers interested in meta-analysis to critically consider biases in data compilations by means of increased engagement with local experts and interdisciplinary collaboration.

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1. INTRODUCTION

Radiocarbon (^{14}C) dating is one of the most valuable and utilized chronometric methods for dating archaeological remains and other Quaternary records (Bayliss, 2009; Bronk Ramsey, 2008; Libby, 1961; Wood, 2015). By assigning a temporal age to past events with a high degree of accuracy and precision, radiocarbon dating can help to reconstruct past complex processes and sequences at various spatial and temporal scales. Moreover, meta-analyses of compiled radiocarbon dates have become increasingly popular to reconstruct demographic, environmental, and socio-ecological processes (Crema & Bevan, 2021; Rick, 1987; Williams, 2012). As a result, several compilations of ^{14}C dates and related analyses have emerged in the last few years, but unfortunately these datasets can incorporate various errors and omissions, which can impact the results of meta-analyses by emphasizing certain biases (Bird et al., 2022; Contreras, 2022; Goldberg et al., 2016; Ziółkowski et al., 2021). The radiocarbon record from Bolivia has been compiled in various works, all of which are either obsolete, inaccurate, or incomplete. To remedy these issues, I created the Bolivian Radiocarbon Database (BRD), which compiles all available radiocarbon dates for the entire country (Capriles, 2023a) and which is described in an accompanying paper (Capriles, 2023b). The database consists of 3269 ^{14}C dates produced between the 1954 and 2021 (Figure 1). In conducting this work, it became apparent that compiling not just archaeological radiocarbon dates (Figure 2) but also those of other related disciplines including paleoecological research (Figure 3) was feasible (Table 1). Relying on that compilation, this article explores the state of Quaternary research in Bolivia based on the application of radiocarbon dating (Table 2).

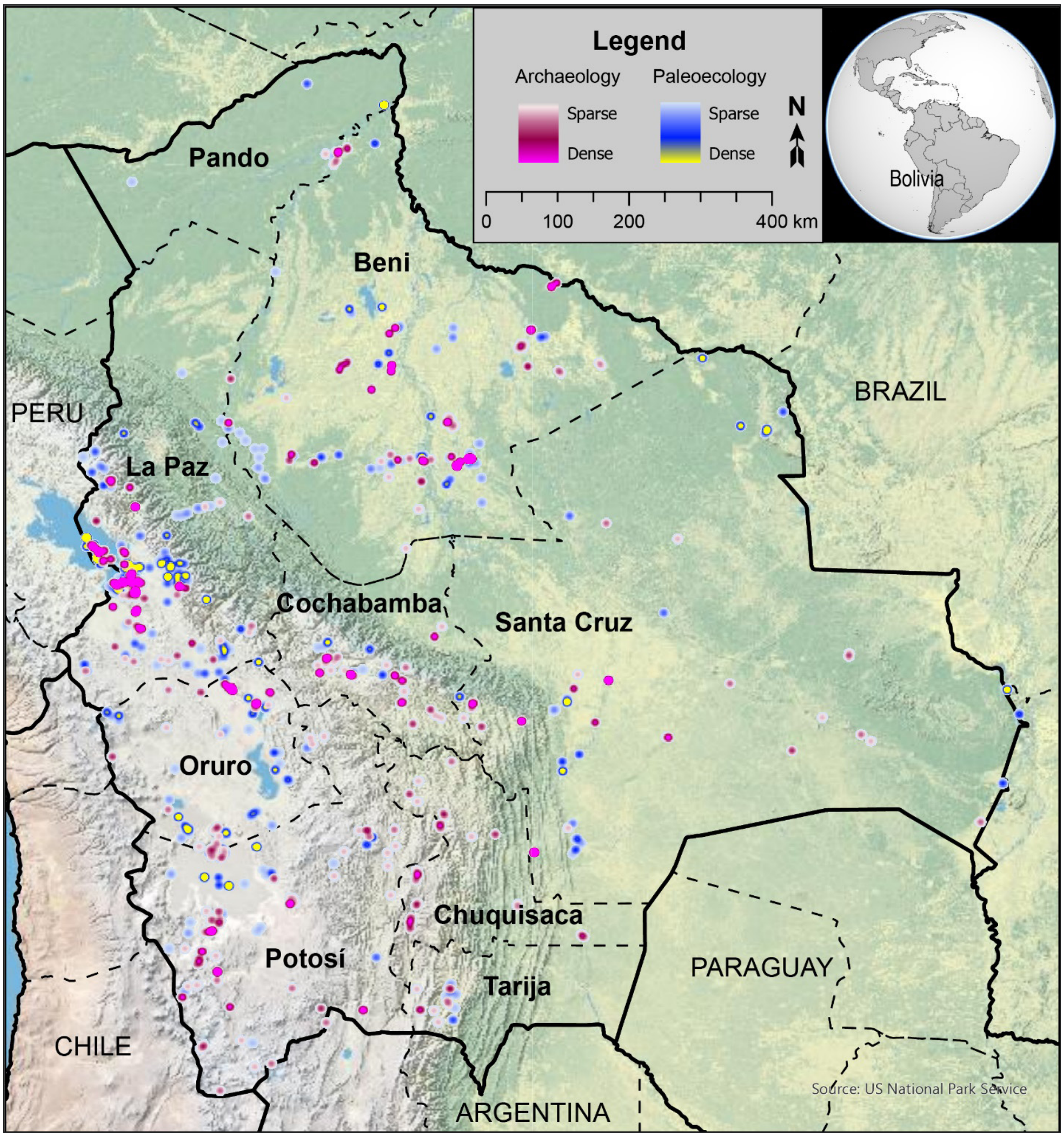

Figure 1 Geophysical and administrative map of Bolivia showing concentrations of all archaeological and paleoecological ^{14}C dates contained in the Bolivian Radiocarbon Database.

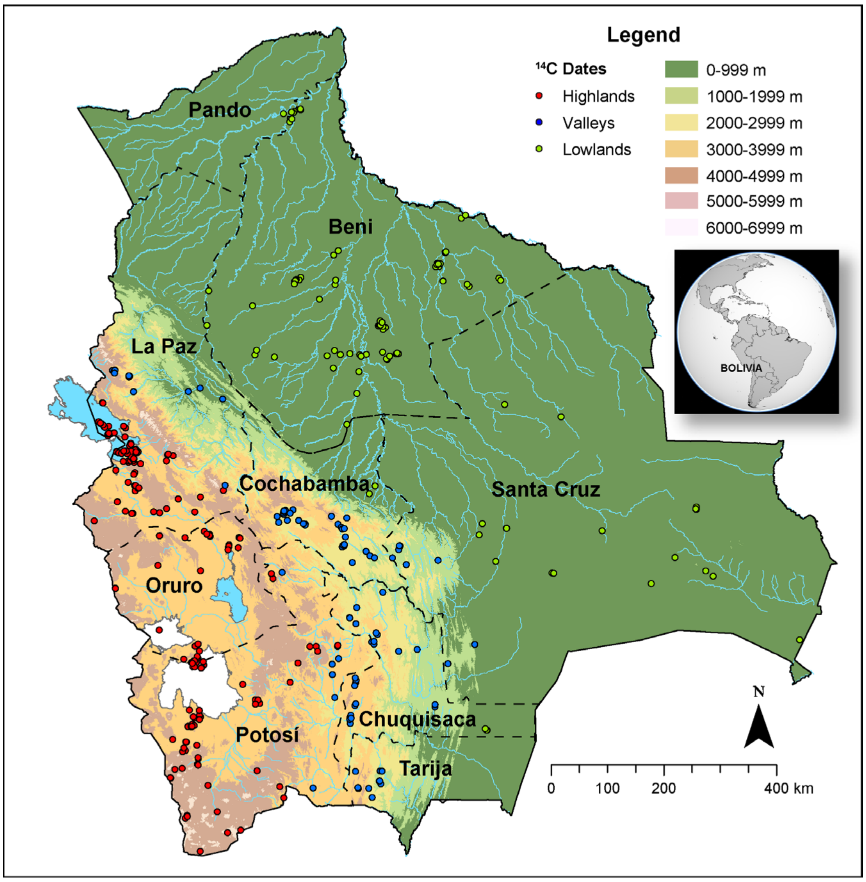

Figure 2 Topographic and administrative map of Bolivia showing the location of all archaeological ^{14}C dates organized by geographic region.

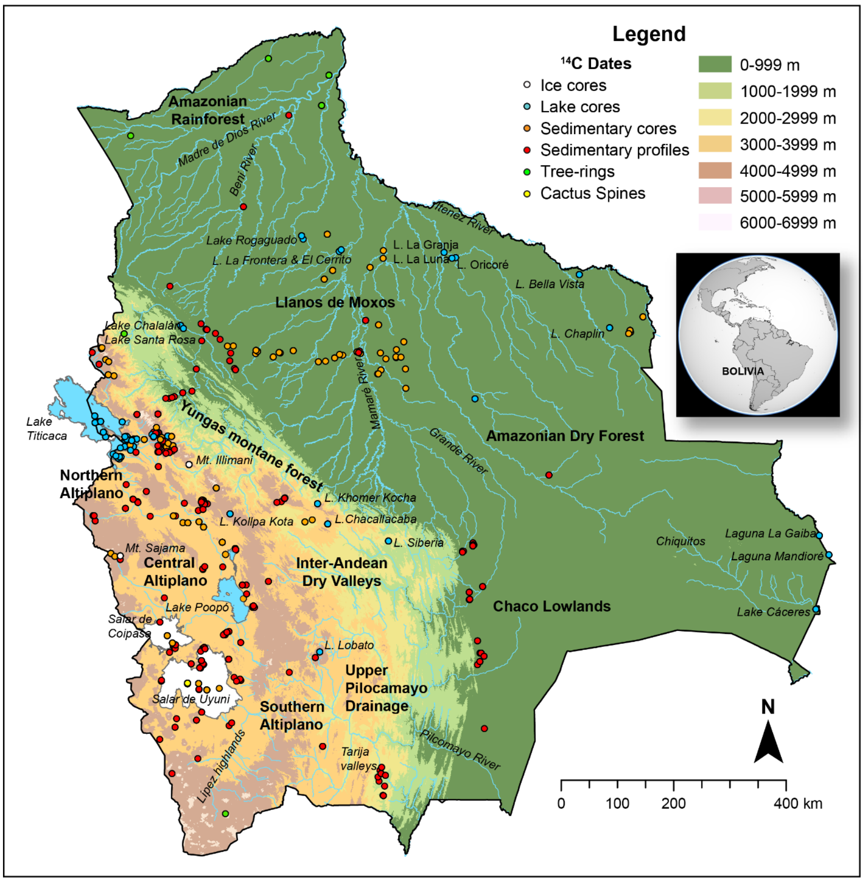

Figure 3 Topographic map of Bolivia showing the location of all paleoecological ^{14}C dates organized by sampling type and including some major geographical features.

DEPARTMENT	HIGHLANDS		VALLEYS		LOWLANDS		ADDED TOTALS		
	ARCH	PALEO	ARCH	PALEO	ARCH	PALEO	ARCH	PALEO	TOTAL
La Paz	579	828	48	20		21	627	869	1496
Oruro	130	196					130	196	326
Potosí	133	137	21	4			154	141	295
Chuquisaca			43		5	1	48	1	49
Cochabamba			96	33	8		104	33	137
Tarija			15	18			15	18	33
Santa Cruz			55	10	57	176	112	186	298
Beni					380	185	380	185	565
Pando					14	56	14	56	70
Total	842	1161	278	85	464	439	1584	1685	3269

Table 1 Number of archaeological (Arch) and paleoecological (Paleo) ^{14}C dates included in the Bolivian Radiocarbon Database organized by geographic region of provenience.

SITE CATEGORY	HIGHLANDS		VALLEYS		LOWLANDS		TOTAL	
	SITES	DATES	SITES	DATES	SITES	DATES	SITES	DATES
Urban center	1	110					1	110
Open-air habitation	101	452	71	211	25	82	197	743
Habitation mound	11	88			11	187	22	275
Rock-shelter	21	47	7	12	2	3	30	62
Fortification	8	25	2	6	1	4	11	35
Funerary	33	68	14	47			47	117
Forest island					33	82	33	82
Ring ditch					15	77	15	77
Agricultural field	22	35	1	2	5	24	28	61
Causeway					3	5	3	5
Offering shrine	6	16					6	16
Antique	1	1					1	1
Total Archaeology	204	842	95	278	95	464	394	1584
Lake core	41	560	3	24	16	115	60	699
Sedimentary core	39	219	2	4	41	146	82	369
Sedimentary profile	145	333	21	47	38	116	204	496
Ice core	2	29					2	29
Tree-rings	1	1	1	10	5	62	7	73
Cactus spines	2	19					2	19
Total Paleoecology	230	1161	27	85	100	439	357	1685

Table 2 Summary of number of sites and ^{14}C dates organized by region and type of either archaeological or paleoecological record.

Bolivia is situated in central South America, is organized into nine administrative provinces known as departments, themselves divided into smaller provinces and municipalities, and it encompasses an elevational gradient that ranges from the Andean highlands to the west through inter-Andean valleys and tropical lowlands to the east (Montes de Oca, 1997). The following review is structured following these general regional geographic divisions by describing the extent of investigations, primary research foci, and sampling intensity. This review is meant to characterize the extent and significance of available research in each specific region and the country, which hopefully, will lead to increasingly thoughtful use of the radiocarbon dates for micro and meso-scale spatiotemporal research.

2. HIGHLANDS

2.1. NORTHERN ALTIPLANO AND LAKE TITICACA

The Northern Altiplano is defined by the extent of the Lake Titicaca basin shared between Bolivia and Peru and situated at elevation of 3,810 m above sea level (asl). Lake Titicaca was one of the most important population and cultural centers in South America and attracted significant archaeological research particularly at Tiwanaku, presently the site with the highest number of radiocarbon dates in Bolivia (n = 110). The first radiometric dates obtained from the site were collected by Alfred Kidder II in 1955 (Ralph, 1959) and subsequent research conducted by Carlos Ponce Sanginés mostly in the Kalasasaya terraced temple helped to build the first chronology of the site and its expansion (Kigoshi et al., 1962; Stuckenrath, 1963; Wendt et al., 1962). Based on nearly two dozen uncalibrated dates (but omitting a few likely rejected for being too recent) Ponce Sanginés (1972) proposed a five-stage chronological sequence for Tiwanaku that ranged between 1,580 BCE and 1,172 CE, which formed the basis for much of subsequent research.

Between the late 1980s and late 1990s, the Wilajawira Agro-Archaeological project directed by Alan Kolata involved major archaeological and paleoecological research in Tiwanaku and surrounding hinterland (Kolata, 1993, 1996, 2003). As part of this effort, radiometric and accelerated mass spectrometry (AMS) ^{14}C dates were analyzed from various ceremonial and residential contexts excavated in Tiwanaku, nearby rural sites such as Lukurmata, and a series of raised fields in the adjacent Katari River valley (Albarracin-Jordan, 1996; Albarracin-Jordan & Matthews, 1990; Bermann, 1994; Binford et al., 1997; Janusek, 1994; Janusek & Kolata, 2004). John Janusek (2003) compiled most of the radiocarbon dates produced in the context of the Wilajawira and previous projects. Subsequent revisions of some specific dates were provided by Owen (2005), Marsh (2012a), and Knobloch (2013) in their discussions of Tiwanaku's expansion into southern Peru, formation of the site, and temporal distribution of certain ceramic styles, respectively. In addition, this dataset also misses a few dates including a date (SMU-2165) from Lukurmata cited by Kolata (1993), a date (INAH-972) from Akapana's excavations directed by Manzanilla (1992), a date (TO-1645) on a bone sample analyzed by Graffam (1990) from the Katari Valley, and three dates (Beta-53774, Beta-53775, Beta-53780) from sites in the Tiwanaku middle valley excavated by Matthews (1992). Furthermore, in the context of constructing the BRD, I was able to access original reports of 14 dates from the decommissioned Southern Methodist University (SMU) radiocarbon dating lab, which had processed 48 of the Wilajawira Project dates, and which included small discrepancies with published dates. In summary, the radiocarbon dates produced in the context of the Wilajawira project total 88, including 31 from Tiwanaku, 19 from Lukurmata, and 38 from other sites in the Tiwanaku and Katari valleys.

During the last two decades, research in Tiwanaku has continued albeit at a smaller scale. For example, excavations in Pumapunku, a stepped pyramid located on the southwestern side of the site revealed significant remodeling and 18 dates from both Tiwanaku and Inca components of this monument were used to verify the antiquity of both occupations (Vranich, 2020; Yaeger & Vranich, 2013). Similarly, the Jach'a Marka Project conducted excavations in Mollo Kontu, a mostly residential sector located towards the south of the Tiwanaku's ceremonial core and resulting in 13 ^{14}C dates from two separate areas, which broaden the relatively small dataset associated with domestic contexts in this large urban center (Couture et al., 2008; Mattox, 2011). Other recent efforts include six dates from Kk'araña (Marsh, 2012b) and Muru Ut Pata (Goldstein et al., 2022) residential areas located outside the ceremonial center of the site. Additional dating from rural sites within the middle and upper Tiwanaku valley has contributed towards a better understanding of cultural dynamics beyond the urban capital (Nakajima & Yoshida, 2012; Roddick & Cuynet, 2020). Finally, recent direct dating on bone collagen from nearly a dozen individuals from Tiwanaku was carried out in the context of paleogenomic research (Nakatsuka et al., 2020; Popović et al., 2021; Valverde, 2016).

The Taraco Peninsula is defined by the northern boundary of the Tiwanaku valley and the southeastern shores of Lake Titicaca. Here lies Chiripa, a site consisting of a sunken court surrounded by rectangular double-walled structures, which according to 14 radiocarbon samples recovered by Alfred Kidder II in 1955, predated Tiwanaku by several centuries (Ralph, 1959). Additional research at the site during the 1970s produced another 14 radiometric dates that furthered help to refine its chronology (Browman, 1998). Beginning in 1992, the Taraco Archaeological Project directed by Christine Hastorf (1999) extended research at Chiripa beyond the center of the site and uncovered a series of additional architectural complexes. Mostly focused on the Formative Period (1,500 BCE – 500 CE), this project has been able to add 70 additional AMS radiocarbon dates and make Chiripa one of the best radiocarbon-dated sites in the Andes (Capriles & Hastorf, 2023; Miller et al., 2021; Whitehead, 1999). Additional research and systematic dating of other Formative Period sites such as Alto Pukara, Kala Uyuni, Sonaji, and Kumi Kipa has since then taken place (Beck Jr., 2004; Bruno, 2008; Whitehead, 2007). In addition, the Tiwanaku administrative centers of Iwawi (Isbell et al., 2002) as well as Lukurmata (see above) have also contributed to increasing the number of well-dated archaeological sites from the Taraco Peninsula.

Towards the south, in the upper Desaguadero River valley, Janusek (2011) directed a multiyear project centered at the site of Khonkho Wankane, a complex Late Formative ceremonial center composed of a series of sunken and terraced rectangular and trapezoidal platform temples, some of which were surrounded by circular structures. This work involved systematic dating of many of the excavated components, including at least 27 AMS radiocarbon dates (Janusek, 2018). These dates have been used to reconstruct a fairly detailed history of the construction and use of architecture at the site, which predates Tiwanaku by a few centuries (Marsh, 2016; Smith, 2016). In tandem, recent research at the nearby site of Iruhito and supported by nine radiocarbon dates, suggests the existence of a possible Tiwanaku administrative center there (Pérez Arias, 2016; Pérez Arias et al., 2017). Additional work carried out by Zovar (2012) at the fortified site of Pukara de Khonkho and supported by ten radiocarbon dates verified that intercommunal violence did emerge in the region after the disintegration of Tiwanaku. More recently, Marsh et al. (2019) used Bayesian models from dates directly associated with specific ceramic styles to improve ceramic seriation and chronology-building in the southeastern Lake Titicaca basin.

The Tiksi Kjarca Archaeological Project involved systematic archaeological research in the Island of the Sun and the Island of the Moon, two of the most prominent isles in Lake Titicaca (Bauer & Stanish, 2001; Stanish & Bauer, 2004). Full-coverage surveys and targeted excavations of nine sites supported by 24 radiocarbon dates provided a framework for assessing the patterns of change in these islands (Bauer & Stanish, 2001). For instance, excavations at the site of Ch'uxacullu revealed that that people might have initially travelled to the Island of the Sun by boat as early as the late Archaic Period (Stanish et al., 2002). Similarly, the Tiwanaku presence in the region was verified and temporally constrained with six dates collected from the Chucaripupata temple complex near the northwest shore of Island of the Sun (Seddon, 1998, 2004). Finally, excavations and dating of building with Inca standing architecture including Pilcocayna, Chincana, and Iñakuyu corroborated the antiquity and persistence of the pilgrimage center that the Inca centered in Lake Titicaca during their imperial expansion.

The Finnish-Bolivian Archaeological Project directed by Martti Pärssinen (2005) conducted long-term research in various regions of Bolivia during the last three decades (Pärssinen & Siiriäinen, 1997). For instance, excavations in the Island of Pariti located to the northeast of Tiwanaku revealed a ceremonial event containing hundreds of finely decorated vessels and other sanctuary artifacts and 15 radiocarbon dates have been used to date this episode, possibly associated with the final days of Tiwanaku (Korpisaari & Pärssinen, 2011). In addition, a series of Tiwanaku burials were documented in Tiraska in the neighboring Island of Cumana, 12 of which were radiocarbon-dated by Antti Korpisaari (2006) as were two from Late Intermediate Period (LIP) burial towers at the site of Qiwaya (Kesseli & Pärssinen, 2005) providing a glimpse into the changing funerary practices of the region. This same research team also dated the Pilcocayna, Chincana and Iñak Uyu buildings located in the islands of the Sun and of the Moon (Pärssinen, 2005).

The Yayamama Archaeological Project directed by Sergio Chávez and Karen Mohr Chávez focused their research on mostly Formative Period sites located in the Copacabana Peninsula including Cundisa, Ch'issi, Kusijata, Qhot'a Pata, and Qupakati (Chávez & Mohr Chávez, 1998; Chávez & Thompson, 2006). More recent research included excavations and at least one date from the Inca site of Intinqala (Bray et al., 2019). In contrast, very few sites have been radiocarbon dated from the northern and eastern shores of Lake Titicaca, but include Qullinkarka and Titimani in the Escoma area (Portugal Loayza, 2017) and Lakaripata and Khollihumachipata in the Santiago de Huata Peninsula (Lémuz Aguirre, 2001). Ongoing research and extensive dating has been taking place through the work of Christophe Delaere (2016), which has focused on exploring the underwater archaeological record of Lake Titicaca including Tiwanaku offerings made in the Khoa reef (Delaere et al., 2019) and residential occupations of various periods in the Puncu port located in the southern shore of the Island of the Sun and Ok'e Supu on the northwestern shore of the Copacabana peninsula (Delaere, 2017; Delaere & Guédron, 2022).

In terms of paleoecological research, Lake Titicaca has witnessed important research over the years, particularly regarding paleoclimatic reconstructions (Abbott, Binford, et al., 1997; Baker, Seltzer, et al., 2001; Dejoux & Iltis, 1992). Most of this work consists of lacustrine and shoreline sediment cores located on both the Bolivian and Peruvian sides of the lake. Cores from the deepest portions of the lake are quite long and old while others from more shallow waters are often shorter but can have better-resolved sequences. Specifically, paleolimnological research in Lake Titicaca using radiocarbon dating began in the early 1980s and involved radiometric dating of small gastropod shells and organic matter (Argollo & Mourguiart, 2000; Mourguiart et al., 1998). During the late 1980s and early 1990s, a project focused on reconstructing a sequence of lake level change of the southern portion during the Late Holocene involved more precise AMS ^{14}C dating particularly of erosional stratigraphic features (Abbott, Binford, et al., 1997). This work was part of a series of direct collaborations between paleolimnologists and archaeologists that pioneered investigating the impact of climate change on the development and collapse of Andean societies (Binford et al., 1996; Binford et al., 1997; Kolata, 1993, 2003).

The Lake Titicaca Drilling Project carried out in the late 1990s and early 2000s, involved the perforation of various long sections including some in the deepest portion of the lake and as a result produced a 170,000-year-old sequence of paleoclimatic change with macroregional-scale implications (Baker, Seltzer, et al., 2001; Fritz et al., 2007; Seltzer et al., 2002). The cores collected in the course of this project were sampled extensively for lithological, sedimentological, geochemical, palynological, diatom and other analyses, which were constrained by age models derived from dozens of AMS radiocarbon dates (Paduano et al., 2003; Rowe et al., 2002; Rowe et al., 2003; Tapia et al., 2003). More recent research continues including occasional collections of both short and long cores and their study often involving interdisciplinary collaborations with archaeologists (Guédron et al., 2023; Guédron et al., 2021; Weide et al., 2017).

2.2. CENTRAL ALTIPLANO

South of Lake Titicaca, the Bolivian highlands feature decreasing temperature and precipitation from the northeast towards the southwest. The Central Altiplano is defined by the Desaguadero River that crosses through southern La Paz and eventually drains into Lake Poopó in Oruro. It is mostly covered by grasslands and small spring-fed streams, which are ideal habitat for camelids. The region was initially colonized by hunter-gatherers who specialized in foraging vicuñas, guanacos, and other highland fauna and research in open air sites has revealed an interesting occupation record beginning around 10,000 years ago (Capriles et al., 2011). Although very few archaeological sites of this period have been investigated, the evidence for a recurrent albeit possibly environmentally constrained presence of humans in the region is compelling (Capriles & Albarracin-Jordan, 2013; Capriles et al., 2018).

Over time, the region witnessed the emergence of pastoralist societies. In fact, one of the anthropogenic features that dominates the Central Altiplano landscape are sizeable mounds produced as a consequence of overlapping human occupations (Ponce Sanginés, 1970). Some of the earliest systematic archaeological research conducted in the region, involved excavating and dating some of the mounds such as Wankarani and Sokotiña (Stuckenrath, 1967; Wendt et al., 1962). Horizontal and vertical excavations and dating of Chuquiña, Kella Kellani, Pusno, and San Andrés during the 1990s and 2000s, provided a stronger temporal framework for addressing questions about the economy and social organization of these early communities (Bermann & Estévez Castillo, 1993, 1995; Fox, 2007; McAndrews, 2005). The formation of these sites began in the second millennium B.C.E. and radiocarbon dates from preceramic layers of these mounds suggest a local transition from earlier hunting-gathering communities (Capriles et al., 2023; Fox, 2007). Moreover, recent radiocarbon dates from La Barca, Pukara 2, and Uspa-Uspa verifies that these mounds were substantially occupied between 3,400 and 2,300 years ago (Beaule & Sejas Portillo, 2010; Bermann, 2008). Postdating this period, research from the Iroco area including work in Korichaca KCH-11, Irucirca KCH-21, and Cochiraya KCH-56 supported by 18 AMS radiocarbon dates suggests that subsistence based on camelids supplemented by wild resources and some cultivation persisted over time (Capriles, 2011, 2014).

The presence of Tiwanaku in the Central Altiplano is manifested in a few key sites related to interregional exchange such as Nazacara and Jachakala located in different sections of the Desaguadero River (Beaule, 2002; Pärssinen, 2005). High-quality raw materials including fine grained basalt and obsidian were exchanged for Tiwanaku vessels occasionally present in burials suggesting local populations persisted with mostly unchanged socio-political systems (Bermann & Estévez Castillo, 1993). The recent dating from the Putuputu site in the Miraflores neighborhood of the city of La Paz conducted as salvage operations during the construction of the Teleférico cable car system has also revealed interesting residential occupations dating to the Late Formative and Tiwanaku periods and their connection with the montane forests east of the Andes (Lémuz Aguirre et al., 2021; Nakatsuka et al., 2020).

The development of communities specialized in camelid pastoralism and limited quinoa and potato farming persisted into the LIP, a time during which segmented lineage-based societies emerged in the Altiplano and practiced an ancestor cult ideology manifested in the construction of hundreds of stone and adobe burial towers locally known as *chullpa*. As part of the Finnish-Bolivian Archaeological Project mentioned above, several burial towers across the Altiplano were directly dated by sampling straw (*ichu*) from either the adobe bricks or the filling used to bind stone blocks (Kesseli & Pärssinen, 2005). For instance, a large cluster of these were sampled near Caquiaviri, which was the capital of the Pacajes, one of the largest Aymara polities, and where also some earlier and later residential contexts were sampled in sites such as Pajcha Pata and Tiquischullpa (Pärssinen & Siiriäinen, 1997). The Lauca River, near the Bolivian-Chilean border, included another interesting cluster where dated burial towers have decoration patterns that resemble polychrome textiles (Kesseli & Pärssinen, 2005; Pärssinen, 2005). Among other scholars, Jedú Sagárnaga (2017) has also contributed to the investigation and dating of various *chullpa* burial towers. Regarding the Inca Period, the most significant research has been carried out in the large administrative center of Paria, which connected the Cochabamba valleys with the main Inca road that headed towards the Lake Titicaca basin (Gyarmati & Condarco Castellón, 2014).

The study of the late Quaternary climatic history and landscape formation of the Bolivian highlands developed as part of the same broader multidisciplinary scientific efforts mentioned for Lake Titicaca (Dejoux & Iltis, 1992; Servant & Fontes, 1978, 1984). For instance, some of the earliest paleoecological radiometric dates were used to date peats from paleo-wetlands for reconstructing landscape evolution (Servant et al., 1981) and building age-depth models for constraining the chronology of sediment records (Graf, 1981; Ybert, 1981). Due to the abundance of peats and wetlands, the highland Andes are particularly well suited for palynological research. Kurt Graf (1992) provides one of the first attempts for a cohesive reconstruction of paleo-vegetation from a series of high-elevation peats and wetlands, locally known as *bofedales*, following a gradient across the Andes. This work includes at least 59 radiocarbon dates from over a dozen different sites located in Bolivia, most of which have been recently uploaded to the Neotoma online database and used for macro-regional syntheses (Flantua, Blaauw, et al., 2016; Flantua et al., 2015; Flantua, Hooghiemstra, et al., 2016). More recent palynological work from *bofedales* in the Bolivian highlands involve increasingly detailed information about how vegetation communities responded to changes in the hydroclimate over the course of the Holocene (Escobar-Torrez et al., 2018; Ledru et al., 2013).

Radiocarbon dating has been used widely to date geomorphological features such as moraine and wetland deposits associated with the latest glacial advances (Clapperton et al., 1997). Paleoclimatic research specifically designed to measure the extent of different glaciations and their impact on the landscape in various regions of the Andean cordillera has focused on measuring the organic materials deposited in moraines and glacial tills (Seltzer, 1990). Glacial advances and regressions related to the paleoclimatological drivers behind lake-level fluctuations have also been studied by radiocarbon dating tills, moraines, peats, wetlands, and lakes in both the eastern and western Cordilleras (Blard et al., 2011; Clayton & Clapperton, 1997; Seltzer, 1994). Some of this work extends into the highlands located east of Lake Titicaca in the northern Altiplano (Abbott, Seltzer, et al., 1997; Seltzer, 1992). Additional research focused on glacial advances in the Cordillera as well as landscape changes in the eastern piedmont were also conducted (Gouze et al., 1986). Recent innovative work in the region includes cosmogenic ^{14}C dating of quartz crystals to evaluate landscape erosion and soil denudation rates in relation to both climate and human impact in the Central Altiplano (Hippe et al., 2019; Hippe et al., 2021; Hippe et al., 2012).

Radiocarbon dating has also been used for helping to constrain the temporal extent of ice-cores collected from tropical glaciers (Sigl et al., 2009; Thompson et al., 1998). In Bolivia, two very high-altitude mountain tropical glaciers have been cored and studied systematically. In 1997, Lonnie Thompson and his colleagues (1998) collected two ice cores from the top of Sajama, which at 6548 m asl, is Bolivia's tallest peak. In 1999, a European team drilled two ice cores at Nevado Illimani located at 6300 m asl (Kellerhals et al., 2010), and due to small sample sizes, paired organic carbon particles composed of hydrocarbons of low to medium molecular weight and elemental carbon composed of highly polymerized hydrocarbons were radiocarbon dated to produce a refined age model (Sigl et al., 2009). These records complement the Quelccaya, Huascaran, and other high-elevation and high-resolution South American tropical ice core records (Thompson et al., 2006).

2.3. SOUTHERN ALTIPLANO

The Southern Altiplano, mostly distributed over the Potosí department, includes Salar de Uyuni, which expanding 12,000 km^2, is the world's largest salt flat. Towards the south, a series of closed basins comprise dozens of high-elevation lakes. Due to the high-elevation and extreme aridity, the archaeological record of this region includes various examples of exceptional preservation of stratigraphy and standing architecture.

Work in the late 1980s and early 1990s by Patrice Lecoq (1999) involved research in the region between the Coipasa and Uyuni salt lakes as well as in village settlements from a series of highland valleys including dating sites that extended our understanding of early village life and social interaction towards the southern inter-Andean dry valleys (Lecoq & Céspedes, 1997). Following up on this work, recent research involving more radiocarbon dating and quantification of sites containing dozens of storage facilities suggests that quinoa farming became increasingly sophisticated even as environmental conditions deteriorated starting during the XIII century CE (Cruz et al., 2022; Cruz et al., 2017). Towards the east, Ann Helsley-Marchbanks (1993) conducted valuable research that involved dating sites in areas that still remain poorly investigated. Focusing on earlier time periods, Jorge Arellano López (2000) excavated and dated samples from Abrigo Ramaditas, Mallku, and Savala to begin building a chronology of Lípez in southwestern Bolivia.

The long-term investigation of Lípez directed by Axel Nielsen (2002) from Argentina's National Council of Research and Technology (Conicet) is among the most significant research carried out in southwestern Bolivia (Nielsen, 1998). Nielsen's fieldwork involved dating a myriad of sites mostly associated with late pre-Hispanic social interaction and his collaboration with Argentinean, Bolivian, and Chilean colleagues has helped to reconstruct a complex history involving regional interaction networks among mostly decentralized pastoralist societies facilitated by llama caravans (Nielsen & Barberián, 2008; Nielsen et al., 1999). An initial compilation of 15 radiometric dates from 11 sites (Nielsen 1998) was followed up by specific research in selected locations such as Alto Laqaya, Bajo Laqaya, and Cruz Vinto that involved extensive mapping, excavations, and radiocarbon dating (Nielsen, 2001a, 2001b, 2002, 2006). In addition, extensive sampling of sites such as small herding locations, temporary camps that connected a complex network of waypoints, and ritual and funerary features across the Lípez highlands allow a complex reconstruction of interactions across the region (Nielsen, 2018). Most of this research is associated with Late Intermediate Period standing architecture including fortified villages and funerary structures but habitation sites with both earlier and later occupations have also been studied (Nielsen et al., 2019; Nielsen et al., 2010). More recent research dating effort involved dating specific materials such as human remains and individual quinoa grains recovered from dry rock shelters (López et al., 2012; López & Nielsen, 2013). In the context of this work, the first example of dendrochronological dating of archaeological deposits in the country involved dating lintels made of *Polylepis tarapacana* wood from burial towers in the site of Llaqta Qaqa that were cross-dated using tree-rings and validated using radiocarbon dating (Morales et al., 2013). The regional tree-ring sequence of *Polylepis tarapacana* has also contributed to developing the South American drought atlas, which currently provides 600 years of high-resolution paleoclimatic data for reconstructing hydroclimate variation (Morales et al., 2020).

The presence of Tiwanaku in the southern Altiplano is mostly manifested in high-status burials such as those of Juch'uypampa, which included elaborate polychrome tapestry textiles but also related to mining and smelting activities (Cruz, 2009). More importantly, this region was important for connecting Tiwanaku with the important population and consumption center of San Pedro de Atacama in northern Chile, which seemed to have very close ties with the Titicaca basin through a network of Middle Horizon sites (Cruz et al., 2023). The southern Altiplano was also an important region during the early Colonial period because of the existence of many important silver mines including Potosí, Porco and others, most of which were already known and exploited by prehispanic societies such as the Charca, Qharaqhara as well as the Inca. Research in Jesús del Valle, Kayuna Pampa, Porco and other sites near Potosí has involved studying some of these associations including limited use of radiocarbon dating (Cruz, 2007; Cruz & Absi, 2008; Van Buren & Weaver, 2012).

The southern altiplano also contains some of the richest and oldest evidence of human adaptation to highland habitation. Specifically, research in Cueva Bautista, a large ignimbrite dry rock shelter located in the Sora River valley, revealed the earliest human occupation documented in Bolivia (Capriles & Albarracin-Jordan, 2013). Systematic excavations, stratigraphic and artifact analyses supported by 17 AMS radiocarbon dates, verify a use surface containing small hearths, and fragmented bone remains and stone tools, dated between 12,700 and 12,100 years ago (Capriles et al., 2016). Cueva Bautista's Late Pleistocene human inhabitation is followed by an occupation hiatus stratigraphically manifested by thick strata containing owl pellets, microfaunal bones, and airborne sediment which was potentially associated with increasingly arid conditions during the Early and especially Middle Holocene. Reoccupation of the site and region occurred approximately 4,000 years ago during the Late Archaic Period and was followed up by more occasional and largely ritual and funerary use of the caves by later pastoralist communities as verified by the neighboring Cueva del Chileno rock shelter (Albarracin-Jordan et al., 2014). Ongoing research in Jatun Cueva near Betanzos and San Bartolomé near Potosí is revealing other early human occupations, suggesting a much more complex record of human occupation at the onset of the Holocene in the southern highlands.

Radiocarbon dating was used for constraining the geochronology of a series of large paleolakes that encompassed large areas around Lake Poopó, Salar de Coipasa, and Salar de Uyuni by mapping and dating carbonate precipitates in paleo-shorelines and subsurface coring (Argollo & Mourguiart, 2000; Fornari et al., 2001; Servant et al., 1995; Sylvestre et al., 1999). More recent research using a combination of intensive AMS radiocarbon and U-Th dating has helped to refine the sequence of paleo-lake high and low stands (Placzek et al., 2006; Placzek et al., 2011). Presently, four cycles of great lake transgressions are relatively well-constrained spatially and temporally (Placzek et al., 2013). Additional cosmogenic dating is helping to constrain even more the timing of some of the lake level transgressions and glacial advances and resolve big questions such as how the high amplitude hydroclimatic changes observed in the tropical highland systems were connected to the Late Glacial Maximum (LGM) and other global paleoclimatic variability (Blard et al., 2013; Martin et al., 2020).

The collection and analysis of a long sedimentary core from Salar de Uyuni, resulted in a well-resolved paleoclimatic sequence for reconstructing the hydroclimate that extends beyond 50,000 years, using radiocarbon dates for the first few meters and gamma radiation for the remainder (Baker, Rigsby, et al., 2001; Fritz et al., 2004). A more recent core from Salar de Coipasa involved radiocarbon dating in addition to diatom and carbon and nitrogen stable isotopic analyses for reconstructing lake variability over a 40,000-year period (Nunnery et al., 2019). In addition, recent acanthochronology research used fairly recent radiocarbon dating on spines from very tall columnar *Echinopsis pascana* cacti from islands situated in Salar de Uyuni have helped to determine a growth model and reconstruct mortality profiles for this broadly distributed species of the Andean highlands (English et al., 2021).

3. INTER-ANDEAN VALLEYS

The Inter-Andean valleys in Bolivia run from northwest to the southeast along the eastern flank of Andes, drain into either the Amazonian or La Plata Basins and vary in terms of microclimatic conditions from very humid to mostly dry from north to south.

3.1. YUNGAS MONTANE FORESTS

La Paz contains a series of mostly humid montane forests on its eastern slopes, locally known as *yungas*, as well as arid high-elevation semi-arid valleys that provided excellent conditions for agriculture during precolonial times. Research here is challenging because the steep topography and high erosion rates have constrained the location of the best-preserved human settlements and agricultural fields to areas covered by later reoccupations. Archaeological research in these valleys has been limited but include a few radiocarbon dates from a ritual cache containing equipment for the consumption of hallucinogenic substances from Qalliicho in the Charazani valleys (Wassén, 1972) as well as two dates from Iskanwaya, a pre-Inca settlement with very well-preserved standing architecture (Arellano López, 1978).

Recent work in the Charazani valleys headed by Sonia Alconini (2011) has involved excavations of Formative, Tiwanaku and Inca period sites. In addition, Lynn Kim (2020) analyzed a series of radiocarbon dates from soil in agricultural terraces located on the eastern piedmont that produced mostly modern ages. Similarly, more recent research at Iskanwaya by the Gobierno Autónomo Departamental de La Paz has produced a new set of 21 radiocarbon dates that help to constrain the site's occupation between 1200 and 1450 CE (ArqLine, 2020). Other important but less disseminated research was carried out in Noperini near Palos Blancos and in Poco Marca near Quime (Cruz, 2010; Michel López et al., 2018).

Stratigraphic documentation and sampling of various recently exposed incidental profiles was carried out near Tipuani and Guanay as well as other headwaters of the Beni River in La Paz (Hérail et al., 1994; Strub, 2006). In addition, dendrochronological research with *Pseudolmedia rigida* in Madidi National Park in northern La Paz, has contributed to identify the recent distribution of radiocarbon over southeastern Amazonia (Andreu-Hayles et al., 2015).

3.2. INTER-ANDEAN DRY VALLEYS

The Cochabamba valleys of eastern central Bolivia were important population centers given their high agricultural productivity. In fact, the Inca invested significantly in improving their agricultural infrastructure, management, and defense. The initial radiocarbon dates from this region involved dating sites with standing architecture such as the habitation sites of Chullpapata near Cliza and the Lakatambo site near Mizque as well as textile material recovered from a dry rock shelter in Omereque (Crane & Griffin, 1959; Oeschger & Riesen, 1965; Wendt et al., 1962). An early attempt to separate and date both collagen and apatite from human bones includes samples from the sites of Cruzpata, Mesadilla and Santa Lucía (Valastro et al., 1977). The heavily mineralized bones from a skeleton found in Jaihuayco, near the Cochabamba airport were dated to 13,050 years ago (Fra-102), but this date is likely erroneous and should be validated using modern collagen extraction protocols (Berger & Protsch, 1991; Capriles & Albarracin-Jordan, 2013).

The Cochabamba Formative Period Project led by Donald Brockington and David Pereira Herrera and other researchers from Universidad Mayor de San Simón produced nearly 40 radiometric dates from excavations conducted between the 1980s and 1990s (Brockington & Sanzetenea, 2005; Brockington et al., 1995; Lecoq & Céspedes, 1997). The sites range from Sierra Mokho within the urban sprawl of the city of Cochabamba to open air settlements in various smaller valleys such as Conchupata, Khopi, Sehuencas, Yuraj Molino and El Tambo (Pereira Herrera & Brockington, 2000). Some of these sites such as Mayra Pampa include preceramic components, which complement research in a few rock shelters with rock art such as Kayarani and Sotal Pereta (Lizarraga-Mehringer, 2004; Querejazu Lewis, 2001).

More recent work by the German scholars Olga Gabelmann (2008) and Christophe Döllerer (2013) has also explored the pre-Inca record of the Cochabamba valleys. In particular, research in Santa Lucía, a Formative Period mound, involved 16 radiocarbon dates used to reconstruct the site's development using Bayesian modeling (Gabelmann et al., 2009). Salvage excavations by Karen Anderson (2019) in Piñami, a large habitation mound located within the Cochabamba urban expansion, allowed improvement of the chronology associated with the Tiwanaku occupation of this highly productive valley. Also exploring Tiwanaku's influence, Timothy McAndrews directed investigations at the site of Pirque Alto, and produced 11 ^{14}C dates that include earlier Formative Period contexts (McAndrews, 2007, 2009; Rogers, 2009; Seifert, 2009). Finally, the transformational Inca presence in Cochabamba, has been documented by a few albeit important dated sites including the administrative and religious centers of Incallajta and Incarraqay (Coben, 2012; Gyarmati & Varga, 1999).

Towards the east, the work of Albert Meyers (1998, 2016) at Samaipata, an iconic and ceremonial site that features a large outcrop completely carved with geometric and figurative designs, involved 13 radiocarbon dates from Inca and both earlier and later contexts. More recent research from three habitation sites near Pulquina Arriba provides ten additional dates from both Inca and pre-Inca contexts (Warren, 2019). Finally, ongoing research by Claudia Rivera Casanovas, Sergio Calla Maldonado, and Matthias Strecker, at Paja Colorada and other similar rock shelters containing abundant and complex rock art depictions is helping to improve their chronology and function.

Regarding the eastern piedmont Pärssinen and Siiriäinen (2003) tested a few sites associated with the Chiriguano and Tupi-Guarani settlements including Placitu Mayu, Cumandaiti de Ingri, and Agoaguasu near the Chaco lowlands. More recent research in Incahuasi, a pre-Hispanic cemetery discovered in the context of building a natural gas processing plant, involved a detailed archaeometric study of many of the individuals recovered during the salvage excavations including direct radiocarbon dating. Three initial AMS dates on charcoal were followed up by 23 direct AMS radiocarbon dates from human remains, which along with additional bioarchaeological and artifact analysis produced one of the best sequences of bio-sociocultural change in the eastern Andes (Alconini, 2019).

The inter-Andean valleys have less intensive research than other regions. Having said this, a deep sedimentary core was perforated in Cala Conto, producing a sequence of several thousand years (Graf, 1992). Another extensive record (40,000 years old) was collected from Laguna Siberia, located in the montane forest region of western Santa Cruz whose analysis suggests that during the LGM, the weakening of the intertropical convergence zone, produced increased aridity and decrease of species diversity (Mourguiart & Ledru, 2003). Research focused on glacial advances in the Cordillera as well as landscape changes in the Huara Loma Valley, northwest Cochabamba was also recently carried out (May et al., 2011). Towards the east, research in Lake Challacaba situated in Vacas near the Incallajta administrative center, and adjacent to a well-know Precolumbian road, has produced a Late Holocene palynological and charcoal sequence supported by six radiocarbon dates, which suggests human impact in the region was significant starting 1340–1210 years ago (Williams, Gosling, Coe, et al., 2011). A longer (18,000-year-old) sequence recovered from the nearby Upper Laguna Khomer Kocha by the same research team, suggests that increasing fire conditions started 14,500 years ago as a consequence of climatic change and producing highland forest retraction, which only diminished during the arid conditions that prevailed during the mid-Holocene (Williams, Gosling, Brooks, et al., 2011). Humans, however, could have also been a force shaping environmental change and causing some of the changes observed even in the earliest pulses of burning present in this record.

Relevant to this work is the collection of a series of speleothems from Torotoro National Park in northeastern Potosí, which are conveniently located near the central extent of the Bolivian inter-Andean valleys and highlands, and therefore, could serve as a very important record of climatic change for the entire region (Apaéstegui et al., 2018). Specifically, four speleothems from the Umajalanta and Chiflonkhakha caves produced a relatively well-resolved record that extends beyond 1400 years as dated by U-Th, and which has helped to evaluate the influence of climate on environmental and cultural change in southwestern Amazonia (de Souza et al., 2019).

3.3. UPPER PILCOMAYO DRAINAGE

Radiocarbon research in Chuquisaca and the upper drainage of the Pilcomayo River, a major tributary of the La Plata basin, began with the pioneer work of Heinz Walter (1966) in Chullpamoqo, a habitation site with standing architecture near the town of Icla. More recent research featuring dating of Pukarilla, Hatun Yampara, Oroncota, Cuzcotoro, and others helped to corroborate demographic and sociopolitical processes inferred from ethnohistoric sources (Blom & Janusek, 2005; Pärssinen & Siiriäinen, 2003). Full-coverage survey and excavation research by Sonia Alconini (2016) in both Oroncota and Cuzcotoro has allowed to clarify the nature and extent of the Inca presence in this socioecological frontier.

The work of Claudia Rivera Casanovas (2004) in the Cintis valleys of southwestern Chuquisaca including Camargo, Villa Abecia and San Lucas, has been significant as it has involved systematic radiocarbon dating of a wide range of sites containing important ceramic style diversity (Rivera Casanovas, 2011). In collaboration with Sergio Calla Maldonado, they have investigated dozen sites that range from the Archaic to the Inca, but with a stronger focus on the pre-Inca regional cultural dynamics (Rivera Casanovas, 2011; Rivera Casanovas & Calla Maldonado, 2011). More recently, research in Chipihuayco, Bilcapara and other sites of the upper drainage of the Pilcomayo River provide a glimpse into the complexity of early community formation and integration of the southern inter-Andean valleys (Ávila, 2011; Echenique, 2019; Nielsen et al., 2015).

Towards the south in Tarija, a surprisingly low but expanding number of radiocarbon dates exists (Delcourt, 2001; Ventura et al., 2010). Recent research in collaboration with Sergio Calla Maldonado and Sara Juengst is focused on dating a series of residential camps and funerary sites located in the paleo-shores of the Tajzara and Pujzara high-elevation lakes (Juengst et al., 2019). Moreover, paleontological work has helped to record additional dates mostly from buried paleosols related to constraining the age of extinct Lujanian-age Quaternary megafauna (Coltorti et al., 2007; 2010). In this regard, a few successful attempts to directly date megafauna include extinct fossils of equids recovered from Tarija (Villavicencio, 2016).

4. TROPICAL LOWLANDS

4.1. AMAZONIAN RAINFOREST

The northernmost region in Bolivia, mostly dominated by Amazonian rainforest, is the least densely populated region of the country today and has attracted least amount of archaeological research. There are only 14 radiocarbon dates from Pando, mostly dating the earthwork sites of El Círculo, Candelaria, and Chacra Teleria (Saunaluoma, 2013). A few others come from neighboring Beni, including Estancia Giesse, which includes a Late Pleistocene charcoal date, which might be a signature of a natural fire (Saunaluoma, 2010) but also part of the early peopling of Amazonia which is increasingly well documented in the Llanos de Moxos (see below). Additionally, four radiocarbon dates from the enigmatic site of Las Piedras, provide chronological control for one the furthest incursions of the Inca towards the eastern tropical forests, likely following the Madre de Dios River (Pärssinen & Siiriäinen, 2003). Nevertheless, this region likely contains many more sites that are increasingly exposed as forest canopy disappears due to unfortunate increase in deforestation, forest fires, and agricultural development.

Radiocarbon dating in the Bolivian Amazonian rainforest in Pando and northern Beni has also been applied in dendrochronological studies. Specifically, AMS ^{14}C dating has been used to evaluate if tropical species have consistent seasonal growth and specifically test if they do indeed produce annual growth rings using the post-bomb zones SH1-2 calibration curve for dates postdating 1950 (Hua et al., 2013). The involved species include *Cedrella odorata*, *Cedrelinga catenaeformis*, *Peltogyne cf. heterophylla*, *Clarisia racemosa*, *Amburana cearensis*, and *Couratari macrosperma* (Baker et al., 2015; Baker et al., 2017; Brienen & Zuidema, 2005; Soliz-Gamboa et al., 2011).

4.2. LLANOS DE MOXOS

The initial radiocarbon dates from archaeological sites in the Beni Llanos de Moxos were conducted by Argentinean researchers Bernardo Dougherty and Horacio Calandra under the auspices of the Smithsonian Institution in the early 1980s. Their work involved test excavations and charcoal sampling on various mounds locally known as *lomas* to determine if they had an anthropogenic origin and to assess their age (Dougherty & Calandra, 1984). As a result, 40 radiometric dates from six lomas situated both to the east and west of the Mamoré River mostly dated these settlements between the late second millennium BCE and the early 1400s CE. Also during the 1980s, three human skeletons were excavated and dated from a site near San Borja in the western Llanos de Moxos (Schmid, 1986).

During the early 1990s and 2000s, Clark Erickson (2000a) conducted extensive surveys in the Llanos de Moxos, but most of this work consisted of understanding the complex landscape infrastructure and only nine radiocarbon samples from three sites have been reported in the course of this work (Erickson, 2000b; Erickson et al., 1991). Following up on this work, John Walker (2004, 2018) has focused his research in Yacuma and neighboring regions, and has used radiocarbon dating for timing the chronology and association of large-scale raised field complexes with human settlements to reconstruct cultural change in relation to the transformation of huge extension of land for agricultural purposes. Supported by around 40 radiocarbon dates from test pits and trenches in forest islands and ring ditched sites such as El Cerro, Estancita, San Francisco, and San Juan, this work has helped to reconstruct the historical ecology of the Llanos de Moxos as a process of integration between human societies and their agricultural fields in relation to the seasonally inundated interfluvial systems (Walker, 2000, 2014).

Beginning in the early 1990s, Heiko Prümers of the German Archaeological Institute conducted a series of intensive research efforts in the Bolivian tropical lowlands that among other research methods has involved comprehensive surveys, extensive horizontal excavations, detailed ceramic seriations, and intensive radiocarbon dating. In the Llanos de Moxos, the focus of has been at Loma Mendoza and Loma Salvatierra, east of Trinidad (Prümers et al., 2022). Loma Mendoza is a large mound that had been traversed by the main road between Trinidad and Santa Cruz de la Sierra, and research here consisted of exposing and mapping long sections of the western profile as well as complementary excavations (Prümers, 2015). These excavations included 46 radiocarbon dates, which together with a thorough ceramic attribute analysis carried out by Carla Jaimes Betancourt, helped to define five sequential phases between 600 and 1400 CE (Prümers, 2015; Prümers & Jaimes Betancourt, 2014). Similar work at the nearby site of Loma Salvatierra, a well-preserved mound complex previously investigated by Dougherty and Calandra (1984), revealed extensive residential and funerary contexts (Prümers, 2013). Approximately 48 radiocarbon dates and detailed ceramic seriation from Loma Salvatierra has revealed five phases cross-correlated to those from Loma Mendoza (Jaimes Betancourt, 2010; Prümers et al., 2022).

In the northeastern Llanos de Moxos, research featured settlements encircled by ringed ditches and possibly palisades near Baures including Jasiaquiri and Bella Vista where a cemetery area contained dozens of burials deposited in large ceramic vessels (Prümers et al., 2006). Approximately 17 radiocarbon dates from the excavated sites bracket the construction of the large zanjas features between 1–1300 CE (Prümers, 2014). Subsequent work by researchers working on dating other large-scale works such as fish weirs have verified their antiquity (Blatrix et al., 2018). More recent research near Versalles and the Brazilian border has revealed contemporary developments associated with Amazonian dark earths revealing more information about environmental changes associated with the adoption of agriculture (Robinson et al., 2021).

Similarly, the work of Umberto Lombardo and colleagues has contributed to understanding landscape evolution in relation to hydroclimatic, geological, and human disturbance in the Llanos de Moxos (Lombardo, 2014; Lombardo et al., 2012; Lombardo et al., 2018). Combining geoarchaeological research using sedimentary cores with archaeological excavations of selected sites, this work is helping to improve our understanding of how the Llanos de Moxos were formed and were eventually modified by humans who settled there at the beginning of the early Holocene (Lombardo et al., 2013). Extensive mapping, sampling and dating of sediment cores across the interfluvial savannas has revealed various buried river paleochannels and associated paleosols correlated to periods of landscape stability with lasting consequences for soil fertility (Lombardo et al., 2018). As part of this work, systematic excavations in forest islands has revealed a unique record of Early and Middle Holocene middens composed of charcoal and burned and unburned shell, bone, and clay as well as human burials, suggesting significant central place foraging and possibly enhanced territoriality (Capriles et al., 2019). Furthermore, recent phytolith analysis has revealed evidence of early cultivation of manioc, squash, and even maize farming verifying the importance of the Llanos de Moxos as a domestication center (Lombardo et al., 2020). Within this research, at least 36 ^{14}C AMS dates originate from archaeological excavations in four forest islands (Isla del Tesoro, San Pablo, La Chacra and Isla Manechi) and 31 from cores in other forest islands where mostly the earliest anthropogenic strata were dated. Although the sampled forest islands are dispersed throughout the Llanos de Moxos, a few areas with more intensive research were north of Trinidad, west of Santa Ana de Yacuma, and north of Baures.

The related work of Leonor Rodrigues et al. (2015) in the western Llanos de Moxos included 20 AMS ^{14}C dates from raised fields used to reconstruct the chronology and soil formation dynamics and variability associated with lowland agricultural infrastructure (Rodrigues et al., 2016). Specifically, research at Bermeo near San Ignacio de Mojos, Filones near Río Rapulo and El Progreso near San Borja involved sampling various agricultural fields including different types of raised fields and canals used for draining water and conducting various multi-proxy studies including radiocarbon dating to facilitate understanding of their function and antiquity (Rodrigues et al., 2018).

Additionally, excavations of two mounds located near Trinidad, Loma Chocolatalito and Loma Pancho Román, featured nearly 50 radiocarbon dates, but specific data such as their lab codes are presently unavailable (Sanematsu, 2010). In the Beni River that defines the western limit of the Llanos de Moxos, Karwowski (2018) conducted salvage work in an eroding profile with evidence of large burial urns at the site of Uaua-Uno. Ongoing collaborative with Sergio Calla Maldonado has facilitated dating some of the earliest components of the pre-Columbian settlement of Rurrenabaque.

Geomorphological work conducted by Lombardo and colleagues (2012, 2014, 2018) has involved a systematic coring program aimed at reconstructing the paleogeography of the Llanos de Moxos. As part of this research, sedimentary cores have revealed the existence of organically rich paleosols buried underneath a few meters of more recent alluvial deposits, typically formed by recent strong seasonal flooding. Many of the paleosols were documented in a transect crosscutting the southern portion of the Llanos de Moxos following the main road east and west of Trinidad, but also in selected areas towards the northwest and northeast. These features seem to suggest periods of climatic and landscape stability that might contrast with today's strong seasonality. The paleosol chronology is built on several dozen AMS radiocarbon dates and ranges between the Early Holocene and the onset of the Late Holocene, with peaks of landscape stability during much of the Middle Holocene in association with the previously cited early human occupations (Lombardo et al., 2020; Lombardo et al., 2012; Lombardo et al., 2018). In tandem, phytolith identification from these sediments suggests vegetation turnover in relation to climate change but also shifts in river courses related to both climatic and neo-tectonic forcing (Lombardo, 2014). Sediment cores from beneath raised fields have verified that some were placed above buried paleosols (Boixadera et al., 2019; Rodrigues et al., 2016). Additionally, riverbanks of many Amazonian waterways hold important sedimentary records, of which only a few have been systematically studied and dated including the large meandering Beni and Mamoré rivers (May et al., 2015; Plotzki et al., 2013; Strub, 2006).

Paleoenvironmental research has been carried out from sediment cores collected from a few tropical lakes in the region. For instance, Dunia Urrego et al. (2013) collected and analyzed cores from the lakes of Santa Rosa and Chalalán producing palynological and microcharcoal sequences expanding the last few thousand years that verify environmental dynamics, especially driven by humans over the last few thousand years. At the large Lake Rogaguado, located towards the northwest of the Llanos de Moxos, lacustrine cores have produced an initial sequence of approximately 8100 years that has been extended into the Late Pleistocene with additional deeper cores (Brugger et al., 2016; Giesche et al., 2021). The resulting detailed palynological vegetation reconstruction featured indicators of anthropogenic impact as well as maize cultivation nearly 7000 years ago, corroborating archaeological research in forest islands (Lombardo et al., 2020).

A critical question that has emerged out of the increased discoveries of significant earthworks constructed by humans in the Llanos de Moxos, particularly during the Late Holocene, is how these features were related to managing regional seasonal flooding but also how landscape transformation, agricultural intensification and population growth were impacted by climate change. Using palynological analysis of sedimentary cores from

Laguna Granja and Laguna Orícore in the eastern Llanos de Moxos, Carson et al. (2014) have argued that the many of the extensive geometric earthworks currently underneath primary forests were built during not after forest clearance by humans, but during periods of savanna grassland expansion likely caused by increased regional aridity approximately two thousand years ago. Similar results were produced in Laguna La Luna contiguously located to a forest island dominated by cacao trees, which were likely planted relatively late in pre-Columbian times (Carson et al., 2016). More recent research, from the Quinato wetland near Santa Ana de Yacuma, has verified that hydrological engineering might have helped to manage the increasing precipitation in the region over the course of the Late Holocene (Duncan et al., 2021). Additionally, research in lakes around some raised field systems such as Laguna El Cerrito and Laguna Frontera near the site of El Cerrito and a large complex of raised fields has allowed reconstructing the vegetation dynamics associated with their use as well as indirectly time when they were likely used (Whitney et al., 2014).

4.3. AMAZONIAN DRY FOREST

Santa Cruz is the largest department in Bolivia, but systematic archaeological research has been rather limited here. In addition to some of the work carried out in Samaipata and other sites towards the last western ranges of the Andes, there have been a few attempts to conduct long-term archaeological research. The first attempts to conduct systematic research in the region date to the early 1990s, when Prümers (2000, 2002) worked at the sites of Grigotá near the center of San Cruz de la Sierra and Pailón, nearly 50 km to the east (Prümers, 2000). These sites provided abundant ceramics and bone remains, which supported by 26 radiocarbon dates, suggest complex cultural dynamics. The site of Grigotá dated to the second half of the first millennium BCE while the occupation in Pailón ranged between 600 and 1300 CE in two separate phases (Prümers, 2002). These cultural developments seem for the most part different than what is observed in the Beni's Llanos de Moxos and more recent dates from Warnes and other nearby locations support this chronology.

In the Cochabamba tropical region, the sites of Valle Ibirza and El Chasqui were investigated in the context of the Cochabamba Formative Period project referred to above (Pereira Herrera & Brockington, 2000). Some sites investigated by the Italian researcher Antonio Paolillo have not been fully published but have produced important dates from archaeological sites in areas that have otherwise not attracted additional research (Ziólkowski et al., 1994). Towards the east, research at La Chonta in the Guarayos Province of Santa Cruz, near Beni provides one of the few instances of systematic ecological research on Amazonian dark earths in Bolivia (Paz-Rivera & Putz, 2009). More recently, exploratory research at sites in the Roboré region of the Chiquitano forest including a few rock shelters produced a wide range of dates ranging from 9000 years ago to modern times (Drakic Ballivian, 2022).

Various paleoecological projects have tested a few of the large and smaller lakes present in the region, which involve the collection of sedimentary cores and radiocarbon dating has been extensively used for building age-depth models to constrain the sedimentation sequences. For instance, significant research from Laguna Chaplin (Burbridge et al., 2004), Laguna Bellavista (Mayle et al., 2000), and Huanchaca Mesetta (Maezumi et al., 2015), has helped to reconstruct the forest to savanna dynamics in relation to changes in the hydroclimate of southeastern Amazonia during the last 15,000 years. The charcoal records from these cores also revealed a complex dynamic initially attributed to natural processes progressively enhanced by human activity. In this same region, Panfil (2001) conducted field transects that included radiocarbon dates of soil samples for reconstructing geomorphological dynamics, and although around 26 samples were dated and included both fairly recent but also considerably old, unfortunately the lab codes of these dates have not been fully published. Another interesting work on paleosols was situated in the site known as Laguna Sucuara, which has been used to contribute towards reconstructing long-term temperature and precipitation variability on soil formation (Zech et al., 2009).

Towards the east, a series of lakes that are part of the headwaters of the Paraguay River and many of which are intersected by the international border with Brazil, have been sampled to reconstruct paleoenvironmental change. Specifically, cores from Laguna La Gaiba (or Lagoa La Gaíva) and Laguna Mandioré on both sides of the border, provide extensive records of vegetational dynamics and formation of the biodiverse Pantanal and associated biomes (McGlue et al., 2012; Metcalfe et al., 2014; Plumpton et al., 2020; Whitney et al., 2011). Particularly significant has been evaluating the response of forests to increasing aridity during the Middle Holocene. Recent research in Lake Cáceres and nearby lakes in Brazil complements this work (Rasbold et al., 2021). Towards the west, a core from Laguna Yaguarú included four ^{14}C dates complemented by seven ^{210}Pb that has been used to evaluate Late Holocene forest expansion connected with hydroclimate change (Taylor et al., 2010).

4.4. CHACO LOWLANDS

In the 1990s, the construction of the gas pipeline between Santa Cruz and Corumbá in Brazil involved a large transect that crossed-cut huge regions of primary forests and wetlands where the archaeological record was completely unknown. As a result, several mostly ephemeral sites were identified and 15 radiocarbon dates from four of these provided evidence for sustained human occupation, particularly during the early half of the second millennium CE (Myers & Esquerdo, 2001). One of the dated contexts however, included a human burial that was directly dated to approximately 4600 years ago, suggesting the existence of substantially earlier occupations. Around the same time and also motived by salvage work, research around Cerro Don Mario mine in the eastern Chiquitano dry forest included three radiometric ^{14}C dates (Rivera Casanovas & Michel López, 2017).

Towards the south, a handful of sites associated with the Guaraní occupation have been investigated in connection with occupations found in the inter-Andean valleys to the west (Cruz, 2017). Furthermore, the site of Ñuapua, also known as Ñuagapua, located in the Chuquisaca Chaco is noteworthy. Initially discovered as a Quaternary fossil locality, research in the late 1970s organized for collecting megafaunal bones revealed the presence of a human skeleton. An early radiometric date of this specimen produced a date of 7640 BP, although its association with megafaunal remains was not fully clarified but featured a much earlier but incompletely reported date from a Glyptodont (MacFadden & Wolff, 1981). Recent research at the site verified the existence of megafaunal remains within a highly eroded landscape and charcoal of a hearth associated with stone tools in an eroding profile was dated to the Middle Holocene (Coltorti et al., 2010; Coltorti et al., 2012).

South of Santa Cruz de la Sierra and towards the Chaco lowlands, a few projects have explored the formation of fans, dunes, and alluvial plains for reconstructing the last episodes of glaciation and landscape change in the region. Initial work carried out by Servant et al. (1981) in the Río Piraí drainage was followed up by research in the piedmont region that intersects the Andes and the Chaco basin (May, Argollo, et al., 2008). Specifically, geomorphological research in exposed profile sequences has been used to reconstruct the landscape dynamics during the Holocene in the region near Charagua and the Río Parapetí drainage (May, Zech, et al., 2008). Extensive sampling of quebradas and incidental profiles of seasonally dry drainages has produced an extensive record of paleoenvironmental change as well as paleosols with rich organic content, which have been interpreted as a result of aridity and natural forest burning (May & Veit, 2009), but are also suggestive of increasing anthropogenic impact starting during the Middle Holocene.

5. CONCLUSIONS

In compiling the BRD, I attempted to systematically synthesize all radiocarbon dates from the entire country of Bolivia. Compared to previous compilations of radiocarbon dates, the BRD includes several significant improvements in terms of quantity and quality of available information. These improvements were facilitated by engagement with national institutions, local specialists, interdisciplinary teams, and a long-term research commitment with the country. Based on this information, this review summarizes the state of radiocarbon dating and related archaeological and paleoecological research in Bolivia. While some of the most significant research efforts have been referenced, given space constraints, not every single publication nor date was explicitly mentioned. Clearly some of the observed patterns are related to availability and suitability of certain sites for both archaeological and paleoecological research, but various spatial, temporal, and thematic biases have also affected the radiocarbon record. Certainly, between and within each region, differential research foci and sparse funding for research have shaped the structure of the record. While most sites have one date associated with them, a few sites such as Tiwanaku and Chiripa have dozens. Similarly, whereas some areas such as the shores of Lake Titicaca have been intensively sampled, others such as northern La Paz, Pando, and eastern Santa Cruz have not. While it might be apparent that differential population and occupation density underly differential sampling, it is precisely with a more comprehensive database that such hypotheses can be evaluated.

Most of the compiled research derives from problem-oriented research primarily funded and directed by a few key foreign organizations and scholars, and in most cases, these also involved collaborations with national institutions and scholars including the supervision of the Bolivian Ministry of Cultures. Furthermore, unlike in other countries, salvage archaeology in Bolivia still is a growing field but an increasing number of dates are being produced in the context of this work. In relation to paleoecological research, a similar pattern is observed with perhaps even fewer projects supporting most of the research. More importantly, because of the significance that Indigenous communities have, particularly regarding land use and management, ongoing and future archaeological and paleoenvironmental research should continue to foster open collaboration with these stakeholders. Good examples exist in all regions and the synergy created will likely have strong positive impacts in terms of protecting cultural heritage and natural landscapes.

Overall, research intensity has been undoubtedly uneven and various causes underly the observed trends including research interests, findings, and funding as well as the production and preservation of the radiocarbon record itself. By integrating all this information together, I hope to incentivize the existing trend of fruitful collaborations between archaeologists and other paleo-scientists. For these purposes, the Bolivian Radiocarbon Database is currently available in a digital repository where periodic updates will be made available. Readers are welcome to contribute additional data and corrections to the author.

DATA ACCESSIBILITY STATEMENT

This review derives from the compilation of radiocarbon dates included in the Bolivian Radiocarbon Database V. 1 (Capriles), which is presently archived at tDAR (https://core.tdar.org/collection/71234) and can be downloaded from id: 472749 (dataset) and id: 472810 (document).

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COMPETING INTERESTS

The author has no competing interests to declare.

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