# THE CAMEL OF TIME: RADIOCARBON DATING THE LOWER PECOS CANYONLANDS

by

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# DEDICATION

This thesis is dedicated to my brothers, Alexander McGahagin and Noah McCuistion.

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| Term | Description |
|---|---|
| $\delta^{13}C$ (delta $^{13}C$) | value used to adjust radiocarbon ages for isotopic fractionation. |
| $\Delta R$ (Delta R) | value used to adjust radiocarbon ages for reservoir effects. |
| $\sigma$ (sigma) | standard error of a mean radiocarbon age or date; in radiocarbon dating, estimates are usually given as $1\sigma$ (68%) or $2\sigma$ (95%) probabilities. |
| AMS | accelerator mass spectrometry, a method of radiocarbon measurement. |
| assay | (noun) the sample of material to be radiocarbon dated; (verb) the investigation of a sample of material to determine its contents—in the case of radiocarbon dating, carbon isotope quantities. |
| cal BP | calibrated years before present; the suffix accompanying a radiocarbon date to indicate the number given has been calibrated, and is in years before present (i.e., AD 1950). |
| conventional age | a radiocarbon measurement which has been made according to standards outlined in Stuiver and Polach (1977), including correction for isotopic fractionation, given in RCYBP. |
| conventional (dating technique) | radiometric $^{14}C$ measurement techniques (not AMS) such as gas proportional counting. |

| | |
|---|---|
| IRMS | isotope ratio mass spectrometry, a method of measuring stable isotopes. |
| legacy date | "old dates that a project has inherited from other archaeologists" (Hamilton and Krus 2018:7). Legacy data may be pretreated, measured, or reported with standards different than currently preferred. |
| measured age | a radiocarbon age which has not been adjusted for isotopic fractionation, nor calibrated, and given in RCYBP. |
| normalize | to adjust a radiocarbon age for isotopic fractionation using the $\delta^{13}C$ value. |
| normalized age | see *conventional age*. |
| radiocarbon age | may be a *measured age* or a *conventional age*, given in RCYBP. |
| RCYBP | radiocarbon years before present (i.e., AD 1950; sometimes also given as simply *BP*). |
| radiocarbon date | a conventional age which has been calibrated to correspond with our solar calendar, given as either cal BP or BC/AD. |

# ABSTRACT

Archaeological radiocarbon assays Lower Pecos were compiled (n=473), spanning the Paleoindian through Proto-historic periods, including one hundred newly reported Ancient Southwest Texas Project assays. The data set was then critically vetted to identify potentially unreliable or irrelevant dates. Using Bayesian methods, the radiocarbon data are used to investigate timing of plant baking and the manufacture of fiber goods from evergreen rosettes. Relative human population fluctuations are investigated using a summed probability distribution of radiocarbon dates. The results of these analyses are compared with environmental proxy data and radiocarbon assays dating the intermittent presence of bison in the region. Correlations in these data are preliminary yet promising and warrant further investigation with more sophisticated analyses and a larger sample size of well-reported radiocarbon data.

# I. INTRODUCTION

The radiocarbon record of the Lower Pecos Canyonlands (LPC, Lower Pecos) is comprised of 473 reported and heretofore unreported assays, the product of over 50 years of archaeological investigation. Twenty-eight years ago, the radiocarbon record of the Lower Pecos was compiled and discussed by Solveig Turpin (Turpin 1991). Recently, Turpin and Eling (2017) republished an expanded version of Turpin's 1991 date list. Nonetheless, most samples assayed decades ago remained uncorrected for isotopic fractionation and uncalibrated, and a comprehensive critical evaluation of the samples had not been attempted. These tasks are necessary to develop the LPC's potential as a tool for exploring temporal patterns. For this thesis, all archaeological Lower Pecos radiocarbon assays published prior to 2019, as well as unpublished Ancient Southwest Texas Project (ASWT) assays, are compiled and corrected for isotopic fractionation as needed. In addition, the relationships between the radiocarbon samples, the excavated contexts, and the purported event of interest are critically examined. The vetted radiocarbon data set was then calibrated and used to address research questions pertaining to earth oven baking of desert succulents. This topic is explored using several intersecting lines of inquiry: the use of desert succulents for food and fiber, bison presence, and population patterns. The limitations of the data are also discussed. Additionally, five samples were selected for radiocarbon dating to address research questions relevant to this thesis.

*Radiocarbon Work in the Lower Pecos*

Radiocarbon dating was slow to come to the Lower Pecos. In part this was because early radiocarbon labs were few in number and discriminatory in accepting samples (Taylor 1956:216). In addition, many archaeologists were reluctant to embrace this new form of direct dating, which up-ended established chronologies. For example, Walter Taylor described the loss of his blissfully naive culture focus at the hands of radiocarbon dating while working at Frightful Cave in Coahuila, Mexico, located just south of the LPC. In discomfiting anticipation of his dates, Taylor used a proverb about the camel's nose: "The camel of Time had his nose inside the tent" (Taylor 1956:215). And after receiving them, he wrote, "A little over a year ago, dates began to come back—and with them the camel of Time came completely into the tent!" (1956: 218). In this proverb, the camel represents something which at first seems of little consequence, but upon full realization, is something with great implications. At the time of his writing, the camel of Time had not yet stepped into the Lower Pecos proper, but Taylor stated his suspicion that, based on the surprisingly early dates at Frightful Cave, the Lower Pecos focus would date to earlier than culture chronologists suspected (1956:223). In the late 1950s, J. Charles Kelley echoed Taylor's suspicion; Kelley used dates from Frightful Cave and other North American desert sites to hypothesize about culture continuity on a continental scale in a publication on the Archaic cultures of the Desert Aspect, which included the Pecos River focus (Kelley 1959). However, none of the sites used in his analysis were actually from the Lower Pecos.

The first assay from the Lower Pecos was reported in 1957. The sample came from a box of charcoal from the 1936 Witte excavation of Eagle Cave. The significance of the sample age was discussed relative to Taylor's excavation at Frightful Cave (Scheutz 1957). The Frightful Cave dates were again invoked in an excavation report on Centipede Cave and Damp Cave (Epstein 1963:112-116); like Kelley (1959), Epstein used dates from Frightful Cave and from other sites in adjacent regions to estimate ages for Centipede Cave strata. The Centipede Cave assay results were published in *Radiocarbon* shortly after publication of Epstein's report, along with dates from several other Lower Pecos sites (Tamers et al. 1964). This 1964 *Radiocarbon* reporting represents the start of a robust radiocarbon dating program in the Lower Pecos.

During the Amistad salvage era, as the period of 1960s archaeology work in advance of Amistad Reservoir is known (Black 2013), radiocarbon dates were often applied to sequencing artifact types—most frequently projectile points (e.g., Ross 1965, Prewitt 1966). However, radiocarbon dating was also used to date features of interest and estimate periods of site occupation and abandonment. The potential application of radiocarbon data to other problems, such as understanding hydrogeological processes (Dibble 1967:30), was recognized. Indeed, some radiocarbon data from the Amistad era excavations were used to address environmental questions some years later (e.g., Patton and Dibble 1982).

In the 1970s and 1980s, two significant excavation projects were conducted which contribute substantially to the radiocarbon record of the Lower Pecos: Hinds Cave, excavated by Texas A&M University, and Baker Cave, excavated by the University of Texas at San Antonio. Radiocarbon dates from these projects were applied to a wide range of research problems, including, of course, projectile point chronologies (e.g., Chadderdon 1983), but also including diet breadth studies (e.g., Lord 1984; Brown 1991) and bioarchaeological investigations (e.g., Poinar et al. 2001), as well as to demonstrate the benefits of new radiocarbon measurement methods (Steelman et al. 2004).

The radiocarbon chronology for the Lower Pecos was reviewed by Solveig Turpin in *Papers on Lower Pecos Prehistory* (1991). Turpin's radiocarbon paper focused on how radiocarbon assays (n=268) inform the cultural chronology of the Lower Pecos, and more broadly, on how regional chronologies aid archaeologists in interpreting past behaviors (1991:2). The chronologies reviewed by Turpin (1991:10-12) include those of Dee Ann Story and Vaughn Bryant (1966), Michael Collins (1974), David Dibble (in Elton Prewitt's 1983 thesis), and Harry Shafer (1986). These chronologies, like many others in Texas, focused primarily on using projectile point styles as temporal markers. In this same vein, Turpin used the radiocarbon record to evaluate projectile point chronologies. However, she also discussed broad patterns of ecological and behavioral change. In 2017 Turpin and Eling re-published Turpin's 1991 radiocarbon data set with the addition of 108 Lower Pecos dates published in the intervening years. The authors also present a compilation of 153 dates from outside the poorly defined southern boundary of the Lower Pecos Canyonlands in Mexico, most of which were not reported in 1991. The authors assert that the additional dates are in overall agreement with the chronology proposed by Dibble and do not "notably change the overall prehistoric trajectory of the Lower Pecos region" (2017:105). In regard to the ongoing research focus on earth oven facilities, the authors are antipathetic, writing: "Many of the…dates are derived from thermal features, such as burned rock middens and exposed hearths, to the degree that suggests it is probably time to concentrate on other aspects of the material culture" (Turpin and Eling 2017:105).

Most of the dates published in recent decades have been used to address narrowly focused research questions. Assays were on objects currently in curation, such as burial items (Steelman et al. 2004, Shafer 2009, Turpin 2012a), peyote effigies (Terry et al. 2006), sandals (Sonderman 2017), and coprolites (Poinar et al. 2001, Sonderman et al. 2019). Numerous other dates have been obtained from earth ovens, burned rock middens, and hearths (e.g., Cliff et al. 2003, Johnson and Johnson 2008, Roberts and Alvarado 2012, Basham 2015, Knapp 2015), and contribute to an ongoing research focus on hot rock cooking.

The most significant radiocarbon methodological development in the Lower Pecos in recent decades is dating of pictographs (e.g., Russ et al. 1990, Ilger et al. 1994, Rowe 2003, Steelman, forthcoming cited in Boyd and Cox 2016). While the dating of pictographs is a promising and exciting field of study, pictograph assays are excluded from this thesis. Thus far, only a handful of assays have been published, and their accuracy is called into question due to challenges in pretreatments, difficulties in identification of the dated material (i.e., binder and emulsifier), and possible old wood effects in charcoal-based paints (Steelman and Rowe 2012). In addition, unexpected stratigraphy of Red Linear and Pecos River style pictographs has called some Lower Pecos pictograph assays into question (Boyd et al. 2013). A new program of Lower Pecos rock art dating is currently underway at the Shumla Archaeological Research & Education Center (Shumla) with Dr. Karen Steelman.

*Data Deficiencies and Recommendations*

Calls for increased rigor in selecting samples for assay, in reporting, and in evaluating radiocarbon ages have been made by researchers both in the Lower Pecos and from the larger radiocarbon research community. Archaeologist and archaeobotanist Phil Dering describes some of the issues with the Lower Pecos radiocarbon record:

> …the need remains to apply state-of-the art dating techniques to sites which have been adequately reported. Most excavations in the region were conducted over 25 years ago, and few of these have been reported in detail. As a result, most of the radiocarbon sequence consists of uncorrected dates obtained over 20 years ago from unidentified plant material. The error ranges for many of the dates are very broad, and many dates are questionable due to problems with stratigraphy and reporting (Turpin 1991). (Dering 2002:3.13)

Deficiencies in date reporting have also been highlighted by archaeological chemists Steelman and Rowe, for reporting rock art assays; many of their recommendations are applicable to radiocarbon assays from any material, such as reporting the rational for selecting a given sample for dating (2012: 572-573). Reported assays from the early decades of radiocarbon dating nearly always lack data considered requisite today, a reflection of the standards and technologies of the times. These unreported data (e.g., identification of materials dated beyond “charcoal,” and adequate contextual and provenience descriptions) limit their usefulness in the Lower Pecos radiocarbon data set.

The Lower Pecos radiocarbon record is also complicated by the nature of many of the excavated sites, such as mixed midden deposits and complex rockshelter stratigraphy (Turpin 1991:18, Dering 2002:6.10). To compound the problem, radiocarbon assays preceding the adoption of Accelerator Mass Spectrometry (AMS) required large samples, which were often obtained by combining and assaying many fragments of wood charcoal as a single sample, sometimes from across several meters of a given stratum or zone; such samples are referred to as bulk or composite samples. Many of these composite samples are charcoal from thermal features, such as earth ovens and burned rock middens, which may have incorporated fuels from firing events distant in time from one another (Black and Creel 1997:272). Because burned rock middens and rockshelters are arguably the most visible remnants of indigenous people's activity in the Lower Pecos, aside from rock art, the implications of these mixed deposits on the radiocarbon data set are great. To mitigate problems inherent in the stratigraphy of rock shelters, Dering suggests that chronologies may be more easily established by sampling from terrace sites (2002:6.11), which have discreet cultural layers, than from complex mixed contexts such as those found in dry rockshelters. In addition, problems of interpreting mixed deposits lie not only with sample context, but in the choice of research question to which the dates are applied. For example, Black and Creel argue that most charcoal samples on or near the Edwards Plateau are associated with earth oven plant baking, and thus are useful for understanding the intensification of plant baking, even though the midden from which a sample is derived is a palimpsest (1997:271). These recommendations for radiocarbon research using modern methods, reporting standards, and appropriate applications of the data serve as guides for my thesis research.

Archaeologists world-wide are heeding the call to be more diligent in radiocarbon reporting. This is evidenced in part by the increase in online archaeological radiocarbon databases. Currently, the largest North American database is the Canadian Archaeological Radiocarbon Database (CARD). Similar state-level databases have been established, though Texas does not have one at this writing. To make the Lower Pecos radiocarbon data set accessible to researchers, the data I have compiled as part of this thesis will be submitted to CARD.

### *Thesis Organization*

This thesis is organized into seven chapters: Chapter 2 introduces the Lower Pecos Canyonlands environmental context, reviews the history of Lower Pecos archaeology work and radiocarbon dating, and describes chronologies which have been put forth by other researchers. Chapter 3 presents and discusses research questions which are to be addressed with the data, including earth oven plant baking, use of desert succulents for fiber goods, bison presence, and population patterns. Chapter 4 is an overview of radiocarbon dating. This lengthy chapter includes a review of the invention of radiocarbon dating and the subsequent radiocarbon "revolutions," an introduction to the chemistry behind radiocarbon dating, age corrections (i.e., for isotopic fractionation, reservoir effects, and calibration), sample material types and pretreatment methods, reporting standards, and a discussion of critical evaluation criteria. Chapter 5 presents the data, including four assays made for this thesis, one failed assay, and 96 additional previously unreported ASWT assays. Chapter 5 also discusses the Lower Pecos data set, grouped by assaying lab. Chapter 6 contains descriptive statistics of the data set, analyses, and discussion of the results. Chapter 7, the final chapter, presents concluding thoughts and recommendations for future research.

## II. REGIONAL BACKGROUND

This chapter presents a regional environmental overview, a history of archaeological work and radiocarbon research, and a brief overview of chronologies for the Lower Pecos Canyonlands.

The Lower Pecos Canyonlands (Lower Pecos or LPC) cultural area is defined based on the Pecos River Style pictographs and regional projectile point types dating to the Middle and Late Archaic (Turpin 2004:266). The region stretches from Sheffield, Texas to as far south as the Serranías del Burro and the Arroyo de la Babia in the Mexican state of Coahuila de Zaragosa (Coahuila). The east and west extents of the Lower Pecos are near Carta Blanca and Dryden, Texas, respectively (Turpin 2004:266) (Figure 1). Most of Val Verde County, Texas falls within the Lower Pecos, as do small portions of Terrell and Crockett counties. The extent of the Lower Pecos in Coahuila is poorly defined, because access is difficult and little archaeological work has been done there.

### *Environment*

The Lower Pecos Canyonlands is a region of overlapping ecological, geographical, and climactic zones. It lies in the far eastern Chihuahuan Desert region and at the southern margin of the Great Plains, between the moist Texas Gulf coast and the arid west. Diverse landforms are found in the Lower Pecos, including major rivers, plateaus, canyons, caves, springs, mountains, and alluvial formations. Local wildlife includes at least 60 species of mammals and 52 species of reptiles, as well as a diversity of birds and fish (Dering 2002:2.4). Vegetation characteristic of several converging regions are found unevenly distributed here, and canyons and mountains harbor relic plant populations (Dering 2002:2.5).

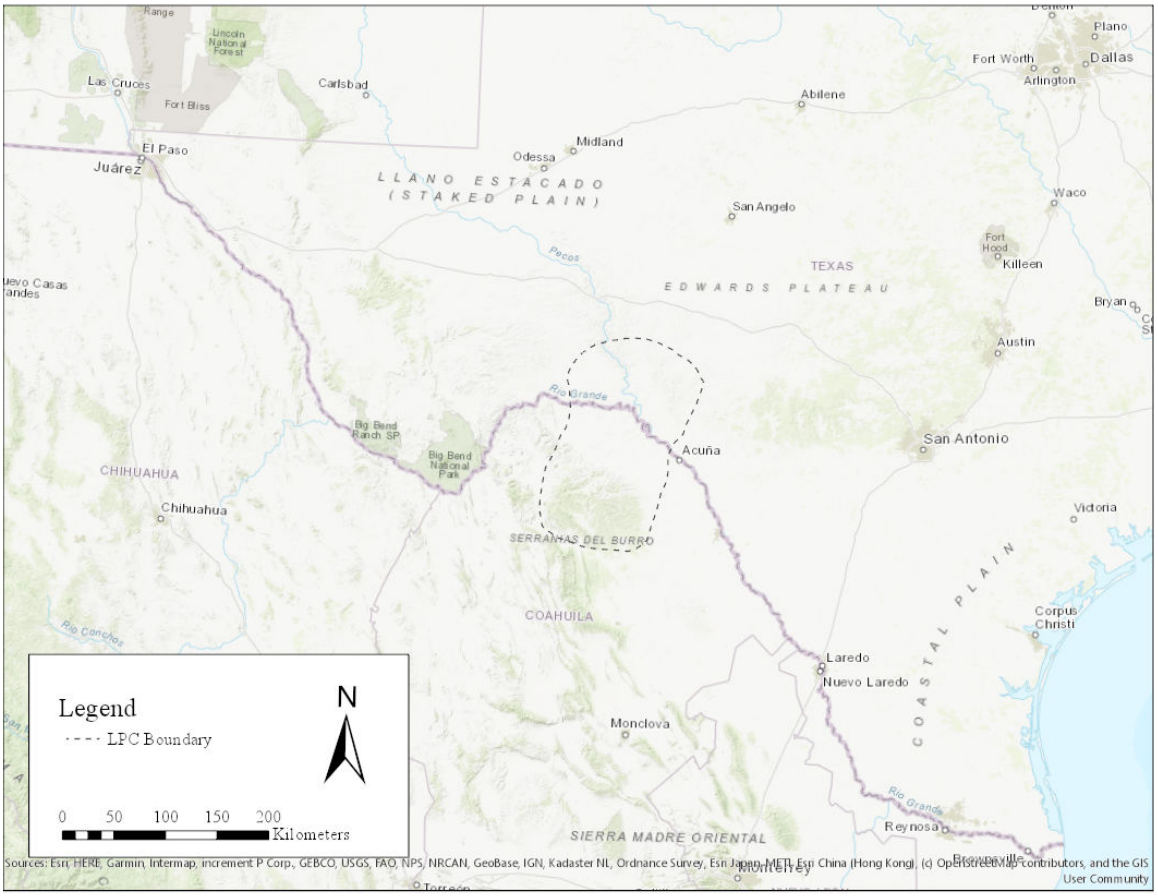


Figure 1. Lower Pecos Canyonlands location, as defined in Turpin 2012b.

Climactically, the modern Lower Pecos environment is semi-arid, with hot summers and mild winters (NOAA 2018). Temperatures on average range between 40-98°F annually (NPS 2017b). Across Texas, Holocene average temperature variations correspond with seasonal regimes (Wong et al. 2015). Unlike temperature, precipitation across Texas does not follow a well-defined seasonal regime. Precipitation variability is due to the influences of several factors, summarized neatly by Wong and colleagues:

> Spring and summer precipitation is associated with the Great Plains low-level jet that transports Gulf of Mexico (GoM) moisture to the continental U.S. (Higgins et al., 1997). Large precipitation events can occur in summer and early fall in association with tropical storms, which occasionally have an eastern tropical Pacific origin and a trajectory crossing the GoM. Late fall and winter precipitation is often triggered by the arrival of northern cold fronts associated with the Pacific winter storm track that also provides much of the western U.S. with the majority of its annual precipitation (Seager et al., 2007). (Wong et al. 2015:156)

In the Lower Pecos Canyonlands, annual average precipitation is 19 inches. However, intra-regional rainfall varies greatly. Extreme examples include an average annual rainfall of 37.75 inches in 1914 in Del Rio, Texas, and a mere 4.34 inches in 1956 (NOAA 2018). The eastern Lower Pecos is wetter (22 inches average annual rainfall) than the west (13 inches) (Arugez et al. 2010). This moisture gradation affects the distribution of biomass of the region—biomass positively correlating with precipitation (Dering 2002:20.7). Vegetation in the region is adapted to survive the extreme fluctuations of the local precipitation (Dering 2002:2.7). Most precipitation falls from April to October (NOAA 2018). Supercell storms form at the mountain range near the southern limit of the Lower Pecos—the Serranías del Burro (Burro Mountains). These storms can result in hurricane-force winds, tornados, and hail on both sides of the Rio Grande (Edwards 2006:1).

During rains, small, ephemeral tributaries flow into the local rivers, and the karst landscape drains surface water into aquifers deep underground, replenishing local springs (Griffith et al. 2007:16); at least 18 springs are mapped in the region, all near rivers (Heitmuller and Reece 2003). While much of the Chihuahuan Desert is internally draining, the Lower Pecos region drains to the Gulf of Mexico (Griffith et al. 2007:8). Major rivers in the region are the Pecos, Rio Grande, and Devils (Figure 2). Both the Pecos and Rio Grande rivers have their headwaters in the Rocky Mountains (Griffith et al. 2007:8-9). The Rio Grande gets a significant additional flow from the largest river in

Chihuahua, Mexico—the Rio Conchos—which originates in the Sierra Madre Occidental. Near the eastern limit of the Lower Pecos, the spring-fed Devils River emerges. Both the Devils River and the Pecos River flow into the Rio Grande. Today, Amistad Dam, completed in 1969, restrains the waters of all three rivers just downstream of their confluences. Lake Amistad's surface coverage is approximately 65,000 acres (NPS 2017a). Since the creation of the reservoir, water has backed into river channels and tributaries of the three rivers, submerging many significant archaeological sites.

The Lower Pecos Canyonlands sit at a convergence of the Chihuahuan Desert, Edwards Plateau, and Southern Texas Plains (in Mexico, also known as the Tamaulipan Mezquital or Tamaulipan thornscrub) (Griffith et al. 2007:v). These three broad regions are further subdivided (Figure 2) to provide a finer picture of environmental variation in each region (i.e., Level IV ecoregions, Griffith et al. 2007:vi), described below.

The Chihuahuan Basins and Playas form the largest sub-region of the Chihuahuan Desert in the Lower Pecos. This area is characterized as low-elevation alluvial basins located around the juncture of the Pecos and Rio Grande Rivers. Shrub vegetation dominates. Creosote is especially characteristic of the region (Griffith et al. 2007:8). Animals common in the region include lizards, birds, and small mammals such as jack rabbits, kit foxes, and kangaroo rats (Griffith et al. 2007:9). Water-use and ranching have altered these river basins and riparian areas, was well as inundation by Amistad Reservoir.

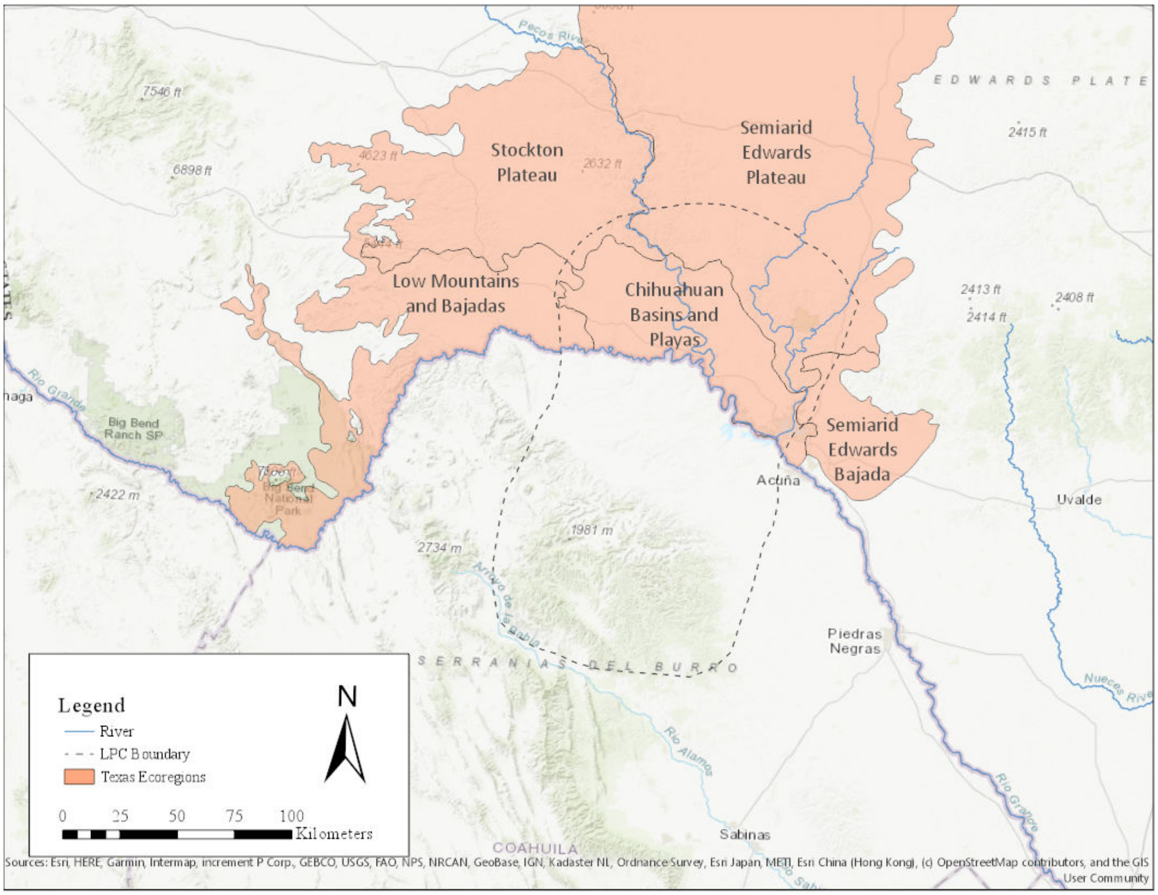


Figure 2. Rivers of the LPC and Level IV Texas Ecoregions as described in Griffith et al. 2007.

The Cretaceous-age limestone extending into the Lower Pecos from the northwest is the Stockton Plateau (Chihuahuan Desert). The eastern boundary of the Stockton Plateau is the Pecos River—the Edwards Plateau lies on the river's opposite bank. Despite geologic similarities with the Edwards Plateau, the Stockton Plateau is more ecologically similar to the Chihuahuan Desert (Griffith et al. 2007:16). Typical vegetation includes yucca, sotol, lechuguilla, cacti, mesquite, juniper and oak trees, and grasses. The springs and aquifers of the Stockton Plateau support endemic and threatened fish and turtles.

A small area of the Low Mountains and Bajadas, also part of the Chihuahuan Desert, is found in the southwestern portion of the Lower Pecos in Texas. This area is rocky and exposed, with desert scrub vegetation such as prickly pear, sotol, lechuguilla, and ocotillo. The lack of grasslands distinguish it from the Stockton Plateau.

The Edwards Plateau terminates near the north and east edges of the Lower Pecos; the Edwards Plateau is centered in the Hill Country to the north. Griffith et al. broadly characterize the region as dissected karstic limestone bedrock with numerous springs, hills, and juniper-oak and mesquite-oak savannas. The semiarid Edwards Plateau, which is in the northern part of the Lower Pecos, is drier than other parts of the Edwards Plateau. Like the Stockton Plateau, the canyons are Cretaceous-age limestone, and are more sharply incised than those found in the eastern Edwards Plateau—a result of less rain and less chemical weathering. Vegetation here is a mixture of those characteristic of the oak-savannas of the hill country to the north, the Southern Texas scrublands, and the Chihuahuan Desert. Grasslands were once dominant here, though fire-suppression and ranching have resulted in increased scrub and chaparral. The grasslands here are short-grasses, though the mid-grass transition is nearby to the east (Griffith et al. 2007:52).

The Lower Pecos cultural area in Coahuila is understudied both archaeologically and ecologically, in part due to perceived dangers of border traffickers (e.g., Adams 2011:169), and because the land is privately owned. However, local ranchers have created a coalition, Conservadores de Ecosistemas Del Puerto Del Pino, to protect these ecosystems. From an outsider's perspective, the most notable natural feature of the Lower Pecos in Coahuila is the Serranías del Burro. These mountains are "sky islands," harboring relic Pleistocene vegetation populations (Adams 2011:168). They form part of a chain of sky islands which host migrating animals and are habitat for large mammals uncommon in the rest of the Lower Pecos, including bighorn sheep and one of the largest extant populations of North American black bears (Karges 2012:37). The Serranías del Burro (6700 feet maximum elevation), and their reputation for supercell storms (Edwards 2006), make for an intriguing and understudied contrast to the comparatively low elevation Rio Grande corridor (approximately 1500 feet at Shumla, TX).

Early written accounts by travelers and settlers of the Lower Pecos Canyonlands contrast with some aspects of the present environment, indicating that much has changed ecologically in recent centuries. Historic and modern land management practices have significantly altered the Lower Pecos environment. Since the early 20$^{th}$ century, communities upstream have decreased the flow of the Pecos and Rio Grande rivers with their water-consumption, and local springs have been pumped dry (Griffith et al. 2007:9). Fire suppression has reduced grasslands, and ranching has altered vegetation communities and destabilized soils, resulting in significant erosion and increased scrub vegetation.

The Lower Pecos paleoclimate has been tentatively reconstructed using environmental proxies including pollen and macroplant analysis, bison remains, geomorphic data, and whewellite dating (Dering 2002:2.5-2.7). Dering highlights problems with this paleoclimate data, including stratigraphic mixing and biases in the fossil record due to introduction of choice plants by people in prehistory. Additionally, because rockshelters and terrace sites are located in canyons, the archaeobotanical remains at these sites may reflect relic vegetation, rather than the predominant vegetation communities at that time. This is a result of the relative stability of microenvironments in canyon bottoms, which are likely less sensitive to climactic changes than the uplands. Lower Pecos geomorphic data primarily comes from Arenosa Shelter (i.e., Patton and Dibble 1982), which Dering criticizes as too narrowly focused on flood deposits at the expense of investigations of other geomorphological phenomena, such as paleosols (2002:2.7). Dering identifies the whewellite studies (i.e., Russ et al. 1996) as promising, though unverified (cf. Russ et al. 2000). Whewellite is "a calcium-oxalate-based mineral produced by the lichen *Aspicilia calcarea* that grows on canyon and rockshelter walls" and whose presence may indicate warm, dry periods (Dering 2002:2.7).

Despite the somewhat unsatisfactorily patchwork nature of the Lower Pecos paleoclimactic record, together the data provide a coarse-grained picture of past environments. Pine pollen and bison bones dating to before 10,000 RCYBP indicate a cool and wet climate at that time (Dering 2002:2.5-2.7). By 9000 RCYBP, macrobotanical remains indicate that many of the plant species present today, such as sotol and lechuguilla, were present in the Lower Pecos. The presence of bison bone and increased pine and grass pollen counts indicate the period around 2500 RCYBP was also relatively cool and wet. After 2000 RCYBP, pollen records indicate increasing aridity (Dering 2002:2.7).

No high-resolution, long time-span Lower Pecos paleoclimate data currently exists. However, a Texas-wide climactic model based on speleothems (mineral growths found in caves) collected from a central Texas cave on the Edwards Plateau (Natural Bridge Caverns) provides relatively high-resolution data for the mid-late Holocene (7000 years ago to present) (i.e., Wong et al. 2015). Trace elements taken from the layered mineral deposits of speleothems are used to reconstruct relative moisture conditions through time (Wong et al. 2015:159). Two process related to trace mineral deposition are of interest to speleothem researchers—water-rock interactions and calcite precipitation in drip-water (Wong et al. 2015:159). The authors compared the results of their speleothem study to several other climate proxies from across Texas, spanning as far back as 11,700 calibrated years ago (Wong et al. 2015:163-65). Several patterns emerged: a period of warming and drying from the Pleistocene into the middle Holocene was evident. Proxy records conflict about the timing of the maximum dry period, with some data indicating it occurred between 7000-5000 years ago, and others indicating 5000-3000 years ago. The data indicate a short period of cooler, wetter conditions in the late Holocene, somewhere between 3000-1000 years ago, and a dry period in the last two thousand years. These broad climactic periods correspond with Dering’s assessment (i.e., Dering 2004), though clearly an accurate and precise, high-resolution paleoclimatic chronology for the Lower Pecos is yet to be accomplished.

*History of Archaeological Work and Radiocarbon Research*

This section reviews the archaeological work history of the region, with an emphasis on radiocarbon research. Table 1 presents a chronological list of Lower Pecos fieldwork.

The earliest history of archaeological work in the Lower Pecos is tied to the Big Bend region to the west (Black 2013:140-142); museum staff from institutions such as the Smithsonian and the Museum of the American Indian came to Big Bend and Lower Pecos Canyonlands in the late 1920s, intrigued by reports of fantastic preservation in the dry rockshelters of west Texas. On the coattails of the national museums came regional institutions and researchers: the Witte Museum from San Antonio, archaeologists from the University of Texas at Austin (perhaps the only formally trained Texan archaeologists at the time), and a researcher from Gila Pueblo in Arizona—E.B. Sayles. These early researchers, apart from Sayles, were chiefly interested in finding display-worthy specimens for museums, though some also recorded pictographs. Additionally, some were interested in evaluating the purported relationship between the people of the Lower Pecos Canyonlands and the Basketmaker culture of the American southwest (Black 2013:142). The goals of these archaeologists, by and large untrained in fieldwork, were quite different from researchers today.

Following the museum era was a period of scant archaeological work and increased looting of archaeological sites (Black 2013:143-144). The only notable fieldwork is that of a master's student from the University of Texas. Herbert C. Taylor conducted fieldwork in northern Coahuila and test excavation at rockshelters in Eagle Nest Canyon and Seminole Canyon in 1947 and 1948. Taylor argued that the methods of excavation conducted by his predecessors were too crude to discern culture change (Black 2013:144); this was a timely assertion given that the radiocarbon dating method was announced the year of Taylor's publication (1949), and would contribute to the revolution in the way American archaeologists approached fieldwork and interpreted culture history. However, the radiocarbon revolution was slow to come to the Lower Pecos. The first radiocarbon measurement from the region (i.e., Scheutz 1957) was run on bulk charcoal from the Witte Museum's 1936 excavations at Eagle Cave.

Archaeological research was ignited again in the late 1950s by the proposal to dam the Rio Grande River just below its confluence with the Pecos and Devils rivers. Amistad Reservoir (originally called Diablo Reservoir) would eventually encumber the flow of these rivers at their confluence, inundating adjacent canyons and archaeological sites. A decade of intensive archaeological work, referred to as the Amistad salvage era, ensued in advance of reservoir construction (Black 2013).

The Amistad program was overseen by the University of Texas at Austin's Texas Archeological Salvage Project (TASP). Funding for the Amistad salvage project came from the National Park Service (NPS). Between 1958, when the first survey and reconnaissance survey effort was undertaken, and 1969, when Amistad Reservoir was filled, over 300 archaeological sites were recorded (Koenig 2012:25), and over a dozen major excavations were undertaken inside the footprint of the proposed reservoir and in adjacent areas. Most of these excavated sites were rockshelters. Non-rockshelter excavations consist of three impressively stratified terrace sites, Arenosa Shelter, Devils Mouth Site, and Nopal Terrace, as well as three upland sites (Black 2013:147). As the Amistad salvage era progressed, research focus shifted from establishing cultural-historical chronologies, a hallmark early 20$^{th}$ century archaeology, to investigating ecological aspects of prehistory (Black 2013:147). As Black notes, the curated collections from this robust period in Lower Pecos archaeological history continue to be studied today (e.g., Sonderman 2019).

In the decades that followed the Amistad salvage era, archaeological projects in the Lower Pecos Canyonlands have been undertaken for academic pursuits and for compliance with state and federal law. The scale and focus of these projects vary greatly, and include survey, excavation, and rock art research. Many reports, articles, books, thesis and dissertations, and conference presentations have resulted (see Hall and Black 2010). These resources are diverse in their subject matter and methods, and include experimental archaeology, ethnography, hunter-gatherer diet-breadth models, iconography, and ecological and geological models of prehistory. New chronologies have been proposed, and hypothesis about a myriad of patterns have been put forth, a few of which are discussed in Chapter 3.

Table 1. Chronology of major Lower Pecos archaeological fieldwork, emphasizing those with radiocarbon assays, but including early fieldwork and select other projects as well.

| | Year | Research Institution/Principle Investigator(s) | Archaeological work |
|---|---|---|---|
| Museum Era | 1929 | Witte Museum: "Miss Emma" Gutzeit | Probing shelters for museum; documenting pictographs |
| | 1931-1938 | Smithsonian Institution: Frank M. Setzler | Goat Cave, Moorehead Cave, and Goode Cave excavation |
| | 1932 | University of Texas: James Pearce and A.T. Jackson | Fate Bell Shelter excavation |
| | 1932 | Gila Pueblo: E.B. Sayles | trenched Eagle Cave and two other rockshelters; reconnaissance |
| | 1933 | Witte Museum: George C. Martin | Shumla Caves excavation |
| | 1933 | Smithsonian Institution: Frank Setzler | Goat Cave and Moorehead Cave |
| | 1933-1943 | Forest and Lula Kirkland | rock art recording |
| | 1935 | Witte Museum and Southwest Texas Archaeological Society: J.Walker Davenport and Harding Black | Eagle Cave and Jacal Canyon probing excavations |
| | 1936 | Witte Museum in partnership with Southwest Texas Archaeological Society: J.Walker Davenport and Harding Black | Eagle Cave excavation |
| | 1936 | University of Texas: A.M. Woolsey | Horseshoe Ranch Caves excavation |
| | 1937 | Texas Technical College: W.C. “Curry” Holden | Murrah Cave excavation |
| | 1947-1948 | University of Texas: Herbert C. Taylor | Excavation in two rockshelters in Eagle Nest and Seminole Canyons and investigations in Coahuila |

Table 1. Continued

| | Year | Research Institution/Principle Investigator(s) | Archaeological work |
|---|---|---|---|
| Amistad Salvage Era | 1958 | TASP: John A. Graham and William A. Davis | Recording of 188 sites during reconnaissance for Amistad Reservoir |
| | 1958 | TASP: Jeremiah F. Epstein | Centipede and Damp Caves |
| | 1958 | Walter W. Taylor and Francisco Gonzales Rul | Survey for Amistad Reservoir in Mexico; 68 sites recorded |
| | 1958 | Roswell Museum and Art Center: David S. Gebhart | Rockart recording |
| | 1958; 1962 | Texas Archaeological Society; TASP | Coontail Spin Rockshelter |
| | 1959; 1961-1962; 1967 | TASP: LeRoy Johnson Jr. | Devil's Mouth Site |
| | 1962-1966 | James H. Word and Charles L. Douglas | Baker Cave |
| | 1963 | TASP and University of Texas: Richard E. Ross | Eagle Cave |
| | 1963 | TASP: Mark L. Parsons | Fate Bell Shelter |
| | 1963-1964 | TASP: David S. Dibble | Bonfire Shelter |
| | 1965 | TASP: Elton R. Prewitt | Piedra del Diablo |
| | 1965-1968 | TASP: David S. Dibble | Arenosa Shelter |
| | 1964-1966 | TASP: Dee Ann Story and Edward Jelks | Paleoecology project |
| | 1966 | TASP: Burney McClurkan | Javalina Bluff |
| | 1967 | TASP: Michael B. Collins | Perry Calk, Techo Bajo, 41VV79, 41VV160, 41VV161, 41VV162, 41VV163, 41VV176, 41VV186 |
| | 1967 | TASP: Robert Kirk Alexander | Cueva Quebrada |
| | 1967 | TASP: William M. Sorrow | Nopal Terrace |
| | 1967-1968 | TASP: Robert Kirk Alexander | Parida Cave and Conejo Shelter |
| Post-Amistad | 1975-1976 | Texas A&M University: Harry J. Shafer and Vaughn M. Bryant | Hinds Cave |
| | 1976 | University of Texas at San Antonio: Thomas R. Hester and Robert F. Heizer | Baker Cave |
| | 1981 | University of Texas at Austin: Solveig Turpin | Black Cave |
| | 1982-1984 | University of Texas at Austin: Solveig Turpin | Bonfire Shelter: Bone Bed 1 |
| | 1984-1985 | University of Texas at Austin: Solveig Turpin | Seminole Sink |
| | 1984-1985 | University of Texas at San Antonio: Thomas R. Hester | Baker Cave |

Table 1. Continued

| | Year | Research Institution/Principle Investigator(s) | Archaeological work |
|---|---|---|---|
| Post-Amistad | 1998-present | Shumla Archaeological Research & Education Center founded | Rock art recording and radiocarbon dating of pictographs |
| | 1999 | Texas Archeological Society field school: Michael B. Collins | 41VV661 |
| | 2000 | PBS&J/TxDOT | 41VV1892, 41VV1893, 41VV1895, and 41VV1897 |
| | 2011 | ASWT: Stephen L. Black and Ashley Knapp | Little Sotol |
| | 2012 | ASWT: Stephen L. Black | Tractor Terrace Midden, Hibiscus Shelter, Rancid Cactus Midden |
| | 2012 | Texas Archeological Society field school: Margaret Howard | 41VV48, 41VV837, 41VV838, and 41VV1012 |
| | 2013-2014 | ASWT: Stephen L. Black and Matt Basham, Dan Rodriguez | Skiles Shelter, Kelley Cave, Torres Ranch House, Lone Star Bridge |
| | 2014-2017 | ASWT: Stephen L. Black and Charles Koenig, Christina Nielsen | Eagle Cave |
| | 2015-2016 | ASWT: Stephen L. Black and Amanda Castaneda | Horse Trail Shelter |
| | 2016 | ASWT: Stephen L. Black and Victoria Pagano | Sayles Adobe |
| | 2017- | ASWT: J. David Kilby | Bonfire Shelter |

Twenty-first century Lower Pecos research is reflective of technological developments available to researchers in recent decades. For example, AMS (accelerator mass spectrometry) for radiocarbon measurement, developed in the 1980s, allows for dating of smaller samples which has catalyzed changes in site sampling strategies. Research interests, however, have not changed much from the later part of the Amistad salvage era; students of Lower Pecos archaeology are still trying to understand the ecological contexts and cultural developments of the Lower Pecos people, and relate them to the archaeology of adjacent regions.

Across the world, researchers are taking an increasingly critical look at preceding hypothesis and assertions, and this is no less true in the Lower Pecos. In radiocarbon research, critical evaluations of legacy data and refinement of chronologies using

Bayesian statistics are popular. Archaeologists are grappling with how to appropriately use large legacy data sets, and data hygiene criteria are being developed to exclude dates that are inaccurate or too imprecise to address a given research question. New applications of statistical methods and radiocarbon innovations, such as plasma oxidization and XAD-purification, contribute to the current reorganization of radiocarbon data, and the climate in which this thesis is undertaken.

*Chronologies of the Lower Pecos Canyonlands*

Like the earliest archaeological work, the first chronologies of the Lower Pecos were associated with those of the Big Bend and the greater Southwest. In line with widely-held archaeological perspectives of North America, it was believed that ancient people of the Lower Pecos lived in a cultural stasis (see Trigger 1989:195). As previously noted, Herbert C. Taylor criticized the excavation methods of his predecessors as being inappropriate for identifying culture change through time (Taylor 1949:82). His assertion is reflective of a shifting perspective in American anthropology. For his master's work at the University of Texas, Taylor presented a tripartite Lower Pecos chronology using the Midwestern Taxonomic Method (see Trigger 1989:190): The first peoples of west Texas arrived "sometime before 1,000 A.D." and had a material culture characteristic of the Pecos River focus (Taylor 1949:85). Circa 1000 AD, Taylor hypothesized 70 years ago, a dry climactic period spurred an exodus from the Big Bend region to the Lower Pecos, or alternatively, people who shared the culture of Big Bend were already living in the Lower Pecos and remained there during and after the dry period. These people, he purported, subsisted primarily off plant foods and river mussels because large game was scarce. The large game pictured in Pecos River Style pictographs indicated to Taylor that a hunting-cult was developed to invoke these scarce game (Taylor 1949:86). The second period of prehistory, according to Taylor, was the intermittent occupation of the region by "Jumano-like" people; this period started after the adoption of agriculture in other parts of North America (Taylor 1949:86). Red-and-black pictographs depicting hunters wielding bow-and-arrow are ascribed to these people. Taylor believed the last indigenous people to inhabit the Lower Pecos were Apache, who displaced the Jumano-like people, and likely were responsible for the historic-era pictographs (Taylor 1949:86). Taylor credits his chronology in large part to J. Charles Kelley (Taylor 1949:73), who was then teaching at the University of Texas and served as Taylor's mentor. This was the first published synthesis of a Lower Pecos chronology.

After Libby's announcement of radiocarbon dating in 1949, but before radiocarbon dating was used in the Lower Pecos, another Taylor (unrelated) was working in Coahuila at Frightful Cave. Walter W. Taylor hypothesized that the Lower Pecos focus would date earlier than suspected based on the surprisingly early radiocarbon ages at Frightful Cave, a site south of the indistinct southern boundary of the Lower Pecos (Taylor 1956:223). This Walter Taylor was one-and-the-same who lambasted the cultural-historical approach in American archaeology and presented his conjunctive approach as an alternative (Trigger 1989:276). Taylor's conjunctive approach is cited as being a precursor to New Archaeology, albeit controversially (Hudson 2008, Trigger 1989:278). The conjunctive approach emphasized a functional understanding of archaeology at the site-level, which could then be related to larger patterns in prehistory, and ultimately a "general understanding" of human culture (Trigger 1989:278). Taylor's involvement in the Lower Pecos Canyonlands proper was minimal, but his proposition about the antiquity of Lower Pecos archaeology was often cited by Lower Pecos archaeologists thereafter.

In 1959, J. Charles Kelley, citing Taylor's Frightful Cave dates, concluded that the Archaic lifeways of North American desert peoples began as far back as 8000 BC and persisted in parts of the Texas southwest and northern Mexico into historic times (Kelley 1959:276). However, none of the data Kelley used in his analysis were from the Lower Pecos. Kelley's conclusion is also problematic because it suggests a nearly 8000-year cultural stasis in the region.

It wasn't until the Amistad salvage era that finer-grained Lower Pecos chronologies were developed—some region-wide, others for specific sites, and still others for artifact sequences (namely projectile points). In 1967, LeRoy Johnson, Jr. published a statistical analysis of the Archaic period in central and southwest Texas, using data from several Lower Pecos sites. Johnson lamented the inconsistencies of the radiocarbon record for the region (1967:39). As an appendix, Johnson listed a compilation of radiocarbon dates organized by period (1967:86); 28 dates listed are from the Lower Pecos. In 1991, Solveig Turpin published a then-exhaustive list of radiocarbon dates for the Lower Pecos and a synthesis of Amistad salvage era chronologies: those of Story and Bryant (1966), Collins (1974), Dibble (in Prewitt 1983), and Shafer (1986). In an unpublished commentary, LeRoy Johnson, Jr. critiqued Turpin's 1991 chronology, stating, "Unfortunately, Turpin included assays from mixed contexts in her lists of core dates, and they are consequently unreliable" (Johnson 1991:1, in Appendix D). Johnson proposed a revision of her periods, excluding very problematic dates and presenting the periods in calibrated date ranges. In 2002, Dering reviewed Turpin's (1991 and 1995) and Shafer's (1986) chronologies and presented a "simplified cultural sequence based on previous chronologies" for Amistad National Recreation Area (Dering 2002:3.5). In 2004, Turpin published a slightly revised version of her 1995 Lower Pecos chronology, and in 2017 Turpin and Eling published an addendum of sorts to Turpin's 1991 radiocarbon database, stating, "the addition of 108 radiocarbon dates to the inventory published in 1991 resulted in very few changes in our understanding of the cultural trajectory of the Lower Pecos people" (Turpin and Eling 2017:118). This chronology, which has prevailed for over 25 years, is summarized below.

The first people came to the Lower Pecos Canyonlands during the Paleoindian period between twelve and fourteen thousand years ago; this period is known as the Aurora subperiod. These hunter-gatherers had a culture centered around big game hunting; this is evidenced by extinct butchered megafauna at Cueva Quebrada (Turpin 2004:268). Bonfire Shelter's Bone Bed I is contemporaneous with this period, though irrefutable evidence of human involvement has yet to surface (Turpin 2001:269). The Aurora Subperiod is followed by the Bonfire Subperiod (10,700 to 9800 RCYBP). During the Bonfire subperiod, Lower Pecos people are believed to have been specialized bison hunters, such as those found elsewhere in North America at that time. There is little evidence of this period in the Lower Pecos record, apart from Bone Bed II at Bonfire Shelter, which contains the remains of butchered bison associated with Folsom and Plainview projectile points. The climate during the Bonfire subperiod was mesic (Turpin 2004:269).

The Oriente subperiod (9400-8800 RCYBP) spans the Late Paleoindian period (9400-9000 RCYBP) into the Early Archaic period, which is said to correspond with increasing aridity (Turpin 2001:269). This subperiod marks a change from exploitation of big game to a broader diet, as seen at the Golondrina Hearth feature at Baker Cave (Hester 1983), and the appearance of fiber artifacts in the archaeological record (Turpin 2001:269).

The Viejo subperiod (8900-5500 RCYBP) marks full-blown Early Archaic (9000-6000 RCYBP) and stretches into the early Middle Archaic (Turpin 2004:269). Turpin points out that the resolution in our understanding of this period, which spans over 3400 radiocarbon years, is poor. The climate of the period is thought to have been increasingly arid (Turpin 2004:269). It was during this period that people started intensively inhabiting rockshelters, which were soon filled with burned rock middens, latrines, perishable plant-fiber artifacts, painted pebbles, and rare clay figurines. Projectile point types and sandal types, which are found in other portions of Texas and Mexico, point to a "multiplicity of possible external relationships" (Turpin 2004:270). The Seminole Sink cemetery dates to this period, and analyses of the 21 skeletons show minimal dietary stress or trauma (Turpin 1988). It is inferred, from the similarity of the mortuary treatment, that the society was egalitarian (Turpin 2004:270).

The Eagles Nest subperiod (5500-4100 RCYBP) of the Middle Archaic (6000-3000 RCYBP) is said to be a period of regionalization or "insularity," evidenced by the small range of occurrence of the Pandale projectile point (Turpin 2004:270). It was also extremely arid and interpreted as a time of stress, resulting in broadening of diet breadth and increased earth-oven cooking of desert succulents (Turpin 2004:270). According to

Turpin, the San Felipe subperiod (4100 to 3200 RCYBP) which followed was even more hot, dry, and culturally insular than the Eagles Nest subperiod. This insularity is evidenced by further regionalization of projectile points (e.g., Langtry and Val Verde), and the origination of the elaborate polychrome Pecos River Style pictographs (Turpin 2004:270). Interestingly, Turpin notes that the Pecos River Style pictographs at the southernmost area of the Lower Pecos area are similar thematically to those around the confluence of the Pecos, but are stylistically different; from this she infers diffusion of religious ideas rather than movement of communities (Turpin 2004:271). The San Felipe subperiod is also believed to be a time of increased population density on river corridors, a result of resource scarcity on the uplands (Turpin 2004:272).

The Cibola subperiod (3150-2300 RCYBP) dates from the terminal Middle Archaic to the middle of the Late Archaic. Climactically, this period is said to be relatively cool and moist; an expansion of the southern Great Plains was welcome habitat for bison herds which (seasonally?) occupied the region, hundreds of which fell to their deaths when they were driven off the cliff at Bonfire Shelter (Turpin 2004:272). The period is believed to be one of changing settlement patterns which reflect changing resource exploitation strategies, and possibly an influx of new hunter-gatherer people following bison herds into the region. Turpin also ascribes Red-Linear pictographs to this period (cf. Boyd et al. 2013). The characteristics of the Cibola subperiod are not believed to be represented south of the border (Turpin 2004:273).

The Flanders subperiod of the Late Archaic begins around 2300 RCYBP and has an unknown end-point (Turpin 2004:273). The subperiod marks a return to aridity, and resource exploitation characteristic of the arid periods of the Early and Middle Archaic.

The Shumla dart point is associated with the subperiod and is found extensively in northern Mexico and in the Lower Pecos of Texas; Turpin hypothesizes that this reflects a migration of people to the region from what is now Nuevo Leon and Coahuila, Mexico. Turpin also hypothesizes that the Serpentine petroglyph style, characterized by sinuous lines and atlatl motifs, is associated with this period (Turpin 2004:273-274).

The Blue Hills subperiod (2300-1300 RCYBP) begins around the same time as the Flanders subperiod, and ends in the early Late Prehistoric period (1000-350 RCYBP) (Turpin 2004:274). It is differentiated from the Flanders based primarily on projectile point types and distributions (e.g., Ensor and Frio). The Blue Hills subperiod is a period of cultural diffusion, which stands in contrast the insularity of the Middle Archaic. There is an elaboration of the fiber industry at this time; numerous burials dating to the period are bundled and wrapped in painted mats. Treatment of the dead is apparently egalitarian, except for special treatment of infants, who have more elaborate burials (Turpin 2004:274). As with the Flanders subperiod, resource procurement and diet-breadth during Blue Hills are said to be similar to that of the arid Archaic periods which came before (Turpin 2004:274).

The Flecha subperiod (1320-450 RCYBP) spans the core of the Late Prehistoric period. Associated with this period is the adoption of the bow-and-arrow, and the construction of ring-middens at upland earth oven facilities (Turpin 2004:274). Different mortuary practices, such as cairn burials, and cremation and internment in vertical shafts, are seen at this time (Turpin 2004:275). The relatively widespread Red Monochrome style pictographs are believed to have been introduced here from adjacent regions, making a case for an influx of new people (Turpin 2004:274-275). It is unclear whether the Bold Line Geometric pictographs or line-and-circle petroglyphs date to this period (Turpin 2004:275). Some issue has been taken with Turpin's interpretations of radiocarbon ages for the Flecha subperiod (i.e., Kenmotsu and Wade 2002:114). Their concerns are based on the presence of temporally diagnostic artifacts (e.g., ceramics and arrow points) which seem out-of-place for the purported period, which indicates "that either the stratum was mixed or that dates for the Flecha and Infierno phases need some adjustment" (Kenmotsu and Wade 2002:114). In addition, the authors question the strict ascription of certain features (i.e., cairns, ring middens, and crescent middens) to the Flecha subperiod, citing small sample sizes, and the occurrence of projectile points ascribed to different time periods.

The Infierno Phase (450-250 RCYBP), as described by Turpin, is coincident with the terminal Late Prehistoric and early Historic period. Kenmotsu and Wade believe the endpoint of the phase is more accurately dated to 1780 A.D. (2002:115). However, Kenmotsu and Wade also note the scarcity of radiocarbon dates which correlate the purported diagnostic materials to these dates. Based on ethnographic accounts and Spanish descriptions, the Lower Pecos likely experienced a return of grasslands, bison, and bison-pursuing people during the Infierno Phase. Associated material culture includes tipi or wikiup rings in upland settlements and a narrowly defined toolkit which includes plain bone and calcite tempered ceramics. The Infierno toolkit is similar to that of the Toyah phase of central Texas (Kenmotsu and Wade 2002:119; Turpin 2004:276-277). How these two phases are related remains uncertain.

The Historic Period dates from 350 BP to the mid-20$^{th}$ century, according to Turpin's chronology. Native American sites dating to this period are scarce in the region, but those with metal arrow points or pictographs depicting people in Spanish garb or churches are easily identified as historic (Turpin 2004:275). The beginning of the Historic Period is marked by Nuevo Leon's Lieutenant Governor, Gaspar Castano de Sosa, who led over 160 people through the region in route to the Pecos Pueblo in 1590 (Turpin 2004:277). However, it is believed that the indigenous people here had felt effects of the intrusion of the Spanish before the latter set foot in Lower Pecos proper. Ethnographic accounts cite many native groups as being active in the region: "Jumanos and Cibolos are often mentioned as allies of the Spanish" (Turpin 2004:278). Later, the Rio Grande corridor was dominated by the Apache, until the Comanche and Kiowa forced the Apache further south. Other unnamed indigenous groups, including groups from northern Mexico, were likely caught in the fray of warfare and unrest during this period. The overt displacement and extermination of native people by the governments of the United States and Mexico continued in west Texas and northern Mexico until as late as 1881. The known Lower Pecos Historic Period Native American sites are not ascribed to any named historic native group in Turpin's chronology.

Kenmotsu and Wade conducted a detailed study of the ethnohistoric period in the Lower Pecos (Kenmotsu and Wade 2002). They divide the ethnohistoric period into two parts: 1535-1750 and 1750-1880. The authors identify 31 native groups affiliated with the Lower Pecos region between 1535-1750, based on historic documents. After 1750, many of these groups ceased to be mentioned in historic documents. From their disappearance from the written record it is inferred that these peoples moved out of the area, were subsumed by other groups, or ceased to exist for other reasons. A reason for their disappearance may be the increased dominance of the Apache and the regular use of a colonial travel corridor between San Antonio and the Rio Grande Mission after 1700. Native groups affiliated with the Lower Pecos are believed to have been highly mobile after 1750, and did not settle in the region. Dominant native groups after 1750 were the Lipan and Mescalero Apache, Comanche, and Comanche allies such as the Kiowa and Kiowa-Apache. By the mid-nineteenth century, Native groups in the region included those previously named, as well as groups from the east (e.g., Seminole, Seminole Maroon, Caddo, and Cherokee). Today, 17 modern, federally-recognized tribes are affiliated with the Lower Pecos, and an additional 16 might have affiliations. Kenmotsu and Wade stress that the movement of native people in the Lower Pecos during the historic period was overlapping and complex, and that an appreciation of the period cannot be realized without considering the history of surrounding areas, as well as the perspectives and biases of those who created the historical documents (Kenmotsu and Wade 2002:xv-12).

While incipient, it is worth noting that Carolyn Boyd and her rock art research institution, Shumla, are developing and testing new hypotheses about the relationships of Archaic Lower Pecos people and the larger Southern Uto-Aztecan region. Fascinating parallels between the imagery in Lower Pecos Style pictographs and the ideology of modern-day Huichol Indians, whose modern homeland is 600 miles south of the Lower Pecos, points to a much broader picture than captured in long-accepted Lower Pecos chronologies (Boyd and Cox 2016:9). Shumla has a staff radiocarbon expert and archaeological chemist, Karen Steelman, who has promising research underway which is anticipated to yield a directly-dated chronology of pictograph styles in the region, and contribute to our understanding of the movement of people and ideas across the American southwest and Mesoamerica.

## III. RESEARCH QUESTIONS

The focus of this thesis is on the timing of earth oven use for baking evergreen rosette desert succulents. Earth oven cooking is pertinent to questions of subsistence, diet breadth, and landscape use by Lower Pecos people. Several complimentary subjects are explored in relation to the timing of earth ovens: the timing of the use of desert succulents for fiber goods, the intermittent presence of bison in the southern Plains, and hypotheses about Lower Pecos population fluctuations. Timing of desert succulent fiber artifact manufacture, as contrasted with the use of these same plants for food, contributes to a more wholistic view of the importance of these plant resources. Bison presence is a useful proxy for environmental change in the southern Great Plains—an ecologically transitional region sensitive to environmental change—and is a foil for low-ranking desert succulents in discussions of diet-breadth. Additionally, population size may be related to questions of how population pressures affected the intensification of earth oven cooking of desert succulents. Previous research on these four subjects is discussed below.

### *Earth Oven Plant Baking*

Earth oven cooking is a method of hot-rock cooking which entails burying heated rocks and food items together in layered arrangements and letting the foods slowly cook underground or under an earthen cap (see Black and Thoms 2014 for a more detailed explanation of earth oven construction). Earth ovens in the Lower Pecos were primarily used for baking desert succulents (Dering 1999:659; Black and Thoms 2014:212). Desert succulents, such as lechuguilla and sotol, require long cooking times and moist heat, which is provided by earth ovens, to remove toxins (Dering 1999:661) and convert long-chain carbohydrates into edible sugars (Black and Thoms 2014:209).

Oven heating elements, oven pits, and burned rock middens comprise the most visible archeological evidence of earth oven cooking in the Lower Pecos. Heating elements are typically identified as discreet clusters or arrangements of burned rocks which may be cracked in place. They are often found within a pit, in strata containing ash, charcoal, and thermally altered sediments (Black and Thoms 2014:213-217). Earth oven facilities are oven pits that people repeatedly returned to, and surrounding accumulations of discarded fire cracked rock (FCR), broken down by thermal fracturing until they are too small to effectively retain heat, and other debris. These accumulations (burned rock middens) contain mixed deposits of carbon stained fine matrix, charred plant remains, and ash, which were re-deposited during earth oven clean-out. A problem encountered when radiocarbon dating earth ovens and burned rock middens is that these features are always palimpsest. When an earth oven pit was reused, the spent rock was displaced by clean-out and discarded nearby, forming a midden. Large rocks could be recycled and supplemented with additional new rocks to construct the next earth oven heating element. Despite stratigraphic problems of mixing and the palimpsest nature of many earth oven facilities, most charcoal sampled from these contexts are associated with plant baking, and thus retain utility for addressing the timing of earth oven use (Black and Creel 1997:271). Radiocarbon dates associated with plant baking are not limited to charcoal or charred plants; other materials useful for addressing earth oven timing include plant material recovered from coprolites (Dollar 2015) or chewed baked plant leaves known as quids.

Lower Pecos earth oven cooking is often discussed from an economic perspective (e.g., Brown 1991, Dering 1999, 2007 and 2008). Dering (1999) has demonstrated that earth oven cooking entails a significant investment in time and energy and yields relatively little energetic gain. He hypothesizes that earth ovens are evidence of broadening diet breadth in times of stress (Dering 2007 and 2008), and that the intensity of earth oven use fluctuated through time from about 6500 RCYBP through the Late Archaic (Dering 1999 and 2007). Dering also hypothesizes that Lower Pecos people may have increasingly used sotol (as opposed to lechuguilla) during the Archaic period (1999:669-670). The apparent increase in sotol use is interesting because it has lower caloric yields than lechuguilla. Dering suggests the increase in sotol use may result from a scarcity of the preferred resource, lechuguilla.

Brown (1991) postulates that changes in diet breadth corresponded with climate shifts in the Lower Pecos, and that this is reflected in timing of earth oven use. He hypothesizes that the onset of the hypsithermal, a period of climactic warming in the middle Holocene also known as the altithermal, is characterized by least-risk economic strategies, an increase in processing and storage of foodstuffs, and increasing earth oven use (Brown 1991:125). Brown hypothesizes that after the hypsithermal, diet breadth narrowed and average-payoff economic strategies prevailed. Brown also posits that there is a spatial change in earth oven use across time—that early plant baking in the Lower Pecos was done at basecamps in rockshelters, and that later earth oven cooking primarily occurred in uplands, by task groups (1991:127).

*Bison*

Because they are high-ranked resources, the timing of bison presence in the Lower Pecos complements investigations of the intensification of low-ranked resources such as desert succulents. Additionally, because Texas falls at the southern margin of the Great Plains where bison presence was intermittent, by examining when bison were present in the region we should come closer to understanding not only subsistence practices (Dering 1999:670), but also perhaps population movements (Turpin 2004:279) and mobility and social organization (Lohse et al. 2014:94). Bison studies also dovetail with environmental studies and bison can be used as proxy environmental data (Robinson 1997, Lohse et al 2014:95). In the Lower Pecos, bison remains found archaeologically are assumed to indicate that the climate was relatively cool and wet, supporting grasslands and thus extending bison's range south during these periods.

The only Lower Pecos radiocarbon assays on bison bone are from Bonfire Shelter (Dibble and Lorrain 1968). These assays were made prior to developments of current standards in pretreating bone, and therefore the dates are considered less accurate than were they processed using current methods. Other Lower Pecos dates correlated with bison are only stratigraphically associated, rather than directly dated, and are therefore regarded as imprecise (Lohse et al. 2014:114). Though the Lower Pecos has few extant direct dates on bison remains, understanding bison presence may be an important approach to understanding earth oven intensification, contributing to discussions of both resource availability and diet breadth, and as a climate proxy.

In the southern Great Plains, Lohse et al. (2014:105) identify four main periods of bison presence using directly dated bison bone. However, though the Lower Pecos is included in the southern Great Plains, the aforementioned problematic Bonfire dates were not included in this analysis. The periods of bison presence Lohse et al. identified are: ca. 5955-5815 cal BP; 3295-3130 cal BP and 2700-2150 cal BP and from 650 to 530 cal BP. Additionally, ethnographic documents describe bison exploitation by native groups during the historic period (Kenmotsu and Wade 2002).

As noted previously, bison are highly relevant to discussions of diet breadth in the Lower Pecos. Dering states that the abundance of bison at Bonefire Shelter's Bonebed II, which dates to the Paleoindian period, may support the hypothesis that diet breadth was narrow at that time (2007:191). By the Late Paleoindian, bison were leaving the southwestern Edward's Plateau, though they persisted in the east (Dering 2007:189). During the Archaic period the intermittent availability of bison likely affected changes in the Lower Pecos broad-spectrum diet (Dering 1999:671).

*Plant Fiber*

The extant literature on the use of desert succulents for fiber goods primarily describes fiber artifact form and discusses chronology from a culture-historical perspective (i.e., Andrews and Adovasio 1980, McGregor 1992, Turpin 2003, and Turpin 2012b). Andrews and Adovasio's study of Hinds Cave fiber artifacts found that *Yucca* species comprise about 45% of the fiber artifacts from that site, *Agave* species comprise approximately 40%, and sotol 8%, with willows, grasses, sedges and a small handful of other local plants comprising the remaining 6% (Andrews and Adovasio 1980:325, 333). McGregor found that sotol and yucca were the most common materials for making basketry, specifically (as opposed to cordage, netting, etc.) (1992:19). Andrews and

Adovasio argue that the fiber technologies of the Lower Pecos were diffused from Mexico and were regionally uniform (though styles changed with time) from approximately 7500 years ago through the Late Prehistoric (1980:365-369). However, for this thesis I am interested in how the timing of the use of desert succulents used in earth ovens compare to the timing of their use in manufacture of fiber goods. I am not the first to suggest a relationship between the exploitation of these plants for food and fiber may exist (i.e., Miller et al. 2011:355, Black and Thoms 2014:210). In their study of earth oven facilities along the Sacramento Mountains of New Mexico, Miller et al. write:

> Studies of pit baking tend to focus only on the subsistence aspects of agave and yucca, ignoring the critical non-food uses that were important components of prehistoric economies. (2011:355)

The authors cite non-food uses including fiber extraction and fermentation of plant liquids, as well as "ritual and social dimensions" of agave use. Patterns in non-comestible evergreen rosette desert succulents are expected to contribute to discussions of the significance of these plants in regional economic models.

*Population*

Population patterns may affect or be related to earth oven intensification. Mauldin et al. (2017) assembled radiocarbon dates from Central Texas and the Lower Pecos and compared relative population fluctuations over the last 9,000 years of prehistory. Adjustments for taphonomic bias of open sites were applied to the Central Texas data, but as Lower Pecos data did not have many assays from open sites, rockshelter dates were used exclusively instead, thereby mitigating the problem of taphonomy as well. The 2017 study revealed preliminary population fluctuations—most notably, the decline in the Lower Pecos curve, which coincides with an increase in the Central Texas curve, at 5100 cal BP. Shafer postulates that there may be a population peak in the Lower Pecos between 4,500 to 3,000 years ago (2013b:50). Turpin also hypothesizes a population change during that period, however, not a population rise but a reorganization of settlement resulting in densely populated river corridors (Turpin 2004:272). Population research is also of interest in addressing possible intermittent abandonment. Shafer (2013a:57) suggests that there might have been an abandonment of the Lower Pecos between the Viejo and Eagle Nest periods, perhaps in part a result of climatic warming. It is expected that if the Lower Pecos population was fluctuating substantially through time, there would be a correlation in the intensity of earth oven use. A n increased population may have put pressure on the resources available, resulting in changes in diet breadth.

In sum, the use of earth ovens through time can perhaps be correlated to population changes, to the presence of bison or a change in climactic conditions favorable for bison, and to the use of the same desert succulents baked in earth ovens for fiber goods. However, it is known that the Lower Pecos data set is inadequate to effectively address these secondary research questions. Nonetheless, it is my hope that patterns will emerge by looking at these data together.

## IV. METHODS IN RADIOCARBON DATING

On December 23, 1949, Willard Libby's radiocarbon dating method was published in *Science* magazine (Arnold and Libby 1949). Since this seminal publication, radiocarbon dating methods have changed considerably—from field collection to lab to interpreting the results. The following is a review of four so-called radiocarbon revolutions—the invention itself, radiocarbon calibration, accelerator mass spectrometry (AMS) measurement, and Bayesian statistical modeling—as well as an overview of the scientific understanding of radiocarbon ($^{14}C$), laboratory methods, age corrections, and reporting standards. Finally, I discuss how radiocarbon data are evaluated and interpreted in the twenty-first century.

### *Overview of Radiocarbon Processes*

Radiocarbon is an unstable isotope of carbon which makes up a tiny fraction of the carbon in our atmosphere—less than 1% of carbon in nature (approximately $10^{-12}$%). The remaining natural carbon is either $^{12}C$ or $^{13}C$. The most abundant carbon isotope is $^{12}C$, comprising over 98% of natural carbon. The atomic weight of an isotope is the sum of their protons and neutrons—symbolized as the superscript before the elemental letter. All three carbon isotopes have six protons—it is their neutron count that differs. All carbon isotopes behave similarly, chemically speaking, despite having different atomic weights (Fry 2006:4-5). However, their weights do have some effect on their behavior, as in isotopic fractionation, for example.

Most $^{14}C$ is a product of thermal neutrons from cosmic rays reacting with $^{14}N$ (an isotope of nitrogen, and the most abundant element in Earth's atmosphere) in the upper atmosphere. Cosmic rays are generated from activity outside the solar system, such as supernovae, and by the sun. Cosmic rays are comprised of subatomic particles: electrons, protons, and, importantly for the creation of radiocarbon, neutrons. When cosmic neutrons collide with $^{14}N$ they occasionally cause $^{14}N$ to eject a proton which is then replaced with the cosmic neutron, and thus creates $^{14}C$. This reaction is rare, which is why $^{14}C$ comprises such a tiny fraction of carbon in the atmosphere. $^{14}C$ and the other natural isotopes of carbon then react with oxygen to become carbon dioxide ($CO_2$), which is distributed throughout the atmosphere by stratospheric and tropospheric winds (Taylor and Bar-Yosef 2014: 21).

Photosynthesis is the primary mechanism by which atmospheric carbon is incorporated into terrestrial plants. Carbon is transferred via the food chain to animals. Though living organisms continue to take in carbon through their diet, carbon levels are maintained in relative equilibrium with the atmosphere due to metabolic processes (Taylor and Bar-Yosef 2014:21-22). In essence, carbon in living organisms is replenished and mobile due to biological processes until organismal death (or isolation, as in tree rings and hair). However, radioactive decay is always occurring regardless of the vitality of the organism.

Upon death of any organism, some $CO_2$ is released back into the atmosphere. In addition, $^{14}C$ begins to return to $^{14}N$ through beta-decay. Radioactive decay of $^{14}C$ is caused by a neutron in $^{14}C$ ejecting an electron and an electron anti-neutrino, in the process creating a proton and becoming $^{14}N$.

The decay rate of $^{14}C$ is its half-life—the amount of time it takes for half of a given quantity of $^{14}C$ to transform into $^{14}N$. Radioactive decay is a random process, and the half-life of radiocarbon is still not known with perfect accuracy; this is an area of radiocarbon research that needs further study (Bronk Ramsey 2008:254). The half-life of $^{14}C$ is currently calculated as 5730 ± 40 years; this is called the Cambridge half-life. The half-life used to calculate radiocarbon ages is different, and is called the Libby half-life: 5568 ± 30 years. The Libby half-life continues to be used for the sake of consistency—a convention established in the early days of radiocarbon dating, when the half-life of $^{14}C$ was not as precisely known. Despite the inexactitude of our knowledge of the $^{14}C$ half-life, research has shown that the decay rate is constant (Taylor and Bar-Yosef 2014:44).

To determine a radiocarbon age, the $^{14}C$ quantity in each sample is counted, as are quantities of stable carbon isotopes $^{12}C$ and $^{13}C$. By comparing the quantity of $^{14}C$ to the stable carbon isotopes, the original quantity of $^{14}C$ can be estimated. Then, the half-life is used to calculate how much time has passed since exchange with the atmosphere has ceased (i.e., death). Most carbon measurements today are made with accelerator mass spectrometry (AMS), but prior to AMS, measurements were made by liquid scintillation spectrometry, gas proportional counting, or, in radiocarbon dating's infancy, Geiger counter. These methods are discussed in greater detail below in *Radiocarbon Revolutions: Accelerator Mass Spectrometry* section. Additionally, adjustments must be made to the radiocarbon age to account for isotopic fractionation. This is discussed in the *Age Corrections* section in this chapter.

Though radiocarbon dating rests on the assumption that atmospheric carbon is consistent across the planet at any given time, levels of $^{14}C$ in the atmosphere vary through time; to account for this, radiocarbon ages are adjusted using calibration curves. Quantities of $^{14}C$ in the atmosphere are affected by the earth's magnetic field, solar flares, major volcanic eruptions, and, in more recent centuries, by the burning of fossil-fuels and by nuclear detonations. These fluctuations are accounted for by adjusting radiocarbon ages using calibration curves which have been created using dendrochronology, and more recently, elemental measurements from corals. Calibration curves approximately correlate radiocarbon years with calendar or solar years, which is necessary for relating sample ages to most chronologies.

Aquatic organisms (both animals and plants) have a more complex carbon exchange network than most terrestrial plants; they take in dissolved non-atmospheric carbon from ocean, lakes, and rivers as well as atmospheric carbon that has become incorporated into marine systems. As a result, carbon ratios in aquatic organisms, and the terrestrial animals that derive a large part of their diet from them, often seem older than that of contemporaneous terrestrial organisms. The difference in carbon levels between a given environment and the atmosphere is called a *reservoir effect*; adjustments to radiocarbon ages can be applied to ameliorate this effect (Taylor and Bar-Yosef 2014:27).

Radiocarbon dating rests on the idea that $CO_2$, and therefore $^{14}C$, is evenly distributed in the atmosphere. However, there are many specific complexities in dating certain materials. Issues relevant to radiocarbon dating specific materials pertinent to the Lower Pecos (e.g., bison bone, plants with crassulacean acid metabolism) are discussed in the *Methods* section of this chapter, along with a more in-depth discussion of isotopic fractionation, reservoir effects, and calibration curves.

### ***Radiocarbon Revolutions: Invention, Calibration, AMS, and Bayesian Modeling***

Certain developments in radiocarbon dating are often referred to as "revolutions" (e.g., Harris et al. 1987; Bronk Ramsey 2008; Bayliss 2009; Wood 2015). These revolutions are technological changes with philosophical ramifications (Van Strydonk 2017:1241); they have caused chronologies to be rewritten and changed the way radiocarbon data are collected and analyzed. The invention of radiocarbon dating is cited as the first radiocarbon revolution. It upended previous culture chronologies, created chronologies where they did not exist before (Bayliss 2009:124), and was perhaps the first union of the "hard" sciences of physics and chemistry with the humanities-focused discipline of anthropology. In subsequent decades, three revolutions in understandings of radiocarbon dating and changes in radiocarbon technologies have reformed theoretical and practical aspects of the method. These are: the calibration of radiocarbon ages, accelerator mass spectrometer (AMS) dating, and Bayesian statistics. Each radiocarbon revolution is reviewed below, including brief histories and some of their effects on the discipline of archaeology.

#### *Invention of Radiocarbon Dating*

The radiocarbon dating method was published a week before calendar pages turned to January 1950 (Arnold and Libby 1949). January 1, 1950 would, in time, become a significant placeholder on the Western time scale: day-zero Before Present (BP). The year 1950 was elected to divide radiocarbon time because global atmospheric carbon levels were, by then, drastically altered by human activities. Fossil fuel emissions diluted quantities of $^{14}C$ (the Suess Effect) while atomic testing resulted in increases in the production of $^{14}C$ (known as bomb carbon) (Taylor and Bar-Yosef 2014:23). It has also been proposed that "BP" stand for "Before Physics," meaning before atomic testing, to avoid the confusion of "present" (Flint and Deevey 1962). The year A.D. 1950 represents a turning point in chronometrics and is an homage to Willard Libby and his colleagues' accomplishment. Arguably, "BP" is also a symbol of an increasingly secular world, one in which scientific breakthroughs such as the atom bomb were rippling across the world.

The roots of radiocarbon science predate Libby's 1949 accomplishment. Many others' work laid the foundation upon which radiocarbon dating was born. Just 15 years before, it was not known that $^{14}C$ existed. Physicist Franz Kurie was the first to publish suspicions that $^{14}C$ may be artificially created (Kurie 1934), based on anomalous particle behavior (recoil tracks) seen when $^{14}N$ was bombarded with "fast neutrons" in a particle accelerator; if the recoil tracks were from a proton being ejected, and not from an alpha-particle, $^{14}N$ must transform into $^{14}C$. Imagery of the recoil tracks led Kurie to posit that it was a proton being ejected, though additional work was needed to confirm this possibility (Kamen 1963:235). The next year, two parties (i.e., Bonner and Brubaker and Chadwick and Goldhaber) independently reported that the same particle behavior could be created with "slow neutrons," though it was still uncertain whether the particle was a proton. In 1936, further support for Kurie's supposition came from a study by Burcham and Goldhaber, which showed that the particle emission produced in this interaction was almost certainly a proton. Also in 1936, physical chemist Martin Kamen completed a doctoral dissertation for which he examined 730 recoil tracks; his observations were the same as those made by Kurie (Kamen 1963:236). In 1937, Kamen and Kurie began working together at the Berkley Radiation Laboratory with the aim of investigating neutron-nuclear interactions. At this point the existence of $^{14}C$ sufficiently proved, at least in a laboratory setting, though little was known about the isotope. It was believed that $^{14}C$ was an unstable, radioactive, isotope, and that the half-life was short—mere hours or days, or at most, months. However, this was yet to be confirmed.

The late 1930s were a time of burgeoning research into the use of isotopes as biological tracers. It was hoped that a radioactive-isotope of one of the abundant biological elements—Hydrogen, Oxygen, Carbon, or Nitrogen—would be found to have a long-enough half-life to be used for biological tracer studies (Kamen 1963:239). Thus, research into $^{14}C$ during this time was focused on its possible utility in such applications. Technological advances in cyclotrons made by Ernest Orlando Lawrence, and internal-target preparation advances by Kamen, set the stage for the future of radioactive-isotope research. Finally, in 1940, Kamen and Samuel Ruben, a student of Willard Libby, found that $^{14}C$ had a much longer half-life than previously believed (Kamen 1963:241); however, Kamen and Ruben believed the half-life of $^{14}C$ was 25,000 years (AIP 1979b)! The inaccuracy of their half-life calculation aside, Kamen and Ruben are credited for "discovering" $^{14}C$ (AIP 1979b), at least as a tool for biological and chemical research.

Not only was the $^{14}C$ created in labs artificial, so were the neutrons that produced $^{14}C$ though bombardment of $^{14}N$. In the 1930s it was unknown whether either neutrons or $^{14}C$ occurred naturally. In the late 1930s, cosmic-ray physicist Serge A. Korff at the Bartol Research Foundation was trying to detect neutrons in natural radiation by sending Geiger counters to various levels of the atmosphere with balloons (Schuur et al. 2016:26). Eventually Korff and Danforth (1939) found increasing neutron intensity with elevation.

They suggested that this was the result of cosmic radiation interacting with the atmosphere. It followed that if neutrons could be identified in the atmosphere, $^{14}C$ must also be present. This study was, according to Libby, the catalyst for his radiocarbon dating work (AIP 1979b).

Willard "Wild Bill" Libby (1908-1980) graduated from University of California, Berkley with his undergraduate degree in 1931. He triple-majored in chemistry, math, and physics, and built the first Geiger counter in the United States for his senior project (AIP 1979a). In 1933, Libby was awarded his doctoral degree from Berkeley (Schuur et al. 2016:23). After receiving his PhD., Libby continued at Berkley as faculty; he is regarded as Berkley's first nuclear chemist (Marlowe 1999:10).

It would be five years between reading Korff and Damforth's (1939) article and Libby taking time to develop the radiocarbon method; in 1940, Libby obtained a Guggenheim Fellowship and took sabbatical from Berkley to conduct research at Princeton University. Soon thereafter, the United States entered World War II, and Libby went to work on the Manhattan Project at Columbia University to develop atomic bombs. In 1945, after the war, Libby began working at the University of Chicago, which was then becoming the leading institution in atomic sciences. It was there, at Chicago's Department of Chemistry and Institute for Nuclear Studies, that Libby would develop radiocarbon dating. Thirty years later, when asked why he was the person to come up with the method and not someone else, Libby answered that the obstacle for others was the idea of global mixing: "Here I was talking about the ocean, I mean the entire ocean mass, the entire biosphere, the entire atmosphere, as though it were in my test tube…Once you get over that, the whole carbon dating thing falls into place" (AIP 1979b).

Libby's early work with radiocarbon dating was conducted in total secrecy, for fear that funding would be withheld from him because of the outlandish-nature of this project (AIP 1979b). Without breaching his secrecy, Libby put a student and an assistant to researching $^{14}C$; graduate student Ernest Anderson was applied to the task of identifying the natural abundance of $^{14}C$, and James Arnold was tasked with isolating and measuring $^{14}C$. Anderson was able to complete his project by obtaining samples of modern wood from around the world, and thereby also solved the aforementioned obstacle of worldwide mixing (AIP 1979b).

The radiocarbon dating method, though conceptually straight-forward, faced several practical challenges. Libby still needed to determine if it was practicable given the costs of access to equipment, sample sizes, and time— it often took four days of round-the-clock counting to get the measurement for a single sample. Libby and his colleagues also needed access to a detector that was sensitive enough to count $^{14}C$ (AIP 1979b). In addition, obtaining samples of historical materials to date was not easy and required the assistance of archaeologists. Libby stated, "Those museum dogs were not going to give it [samples] to a bunch of physical chemists to burn up, no way" (AIP 1979b). Once samples were obtained, they required cleaning of contaminants, another step Libby cites as critical in the development of radiocarbon dating.

The shared history of radiocarbon dating and archaeology begins in 1947. At this point Libby is certain radiocarbon dating is feasible but needs funding and access to equipment to test the method. Libby first discloses his plans for radiocarbon dating to those close to him in 1946, and in 1947 James Arnold's father provides unsolicited Egyptian specimens to Libby, obtained from Ambrose Lansing at the Department of Egyptian Art at New York's Metropolitan Museum of Art (Marlow 1999:11-12). The year 1947 also saw the informal creation of a University of Chicago seminar club to discuss the role of social science in the atomic age, spearheaded by Chicago researchers Harold Urey (a 1934 Nobel laureate in chemistry, and an ally of Libby's), associate professor Harrison Brown, and anthropologist and dean of social sciences, Robert Redfield (Marlow 1999:13). That same year, radiocarbon dating was for the first time presented to an audience outside Chicago, at a Viking Fund Supper Conference. Though two-dozen anthropologists and archaeologists were in attendance, it was asked that the development of radiocarbon dating not yet be made public (Marlow 1999:19). Soon after the supper conference, the Viking Fund financially backed Libby's radiocarbon dating project. Many people, most notably Urey and the Viking Fund's director of research, Paul Fejos, were involved in the events culminating in this funding being secured.

Though communication about the radiocarbon method was slow and fraught with misunderstandings (for example, some thought that radiocarbon dating was being developed by Urey), Libby's project had well-connected advocates and garnered plenty of interest, as well as controversy, among archaeologists. Before the method was even shown to be practicable, debate swirled around who should oversee the integration of the new method into archaeology. Organizations proposed for this task included the Society for American Archaeology, the American Anthropological Association, the Committee for the Recovery of Archaeological Remains, the National Research Council, and the Viking Fund, among others (Marlow 1999). In great part the calls to delegate an organization came from fears that the radiocarbon method was going to be controlled by the University of Chicago or the Viking Fund, and that the technique would not be made available to all who sought to use it (Marlow 1999:22). There were other concerns as well, such as whether old-world archaeologists would have representation in discussions of radiocarbon dating. A historic meeting occurred in January 1948 at a Viking Fund Supper Conference with a presentation by Libby, which was well attended by archaeologists. Here, the dispute over who should represent archaeologists was settled—the American Anthropological Association was chosen as the representative body, "to collaborate with Libby's group, coach its brethren to be scrupulous in fulfilling their reciprocal responsibilities, and mediate the inevitable disputes and misunderstandings that arose" (Marlow 1999:25).

For many archaeologists at the time, radiocarbon dating was intimidating. In part this was due to its association with the atom bomb; while radiocarbon dating was not directly related to the development of the bomb, it was developed by atomic scientists and in a social climate of fear and awe of the power of the atom (Marlow 1999:23). Additionally, most archaeologists lacked the necessary background to understand how radiocarbon dating worked, and thus were reluctant to adopt the technology. Radiocarbon dating was also viewed as a threat to established dating methods and chronologies. Some even postulated that it could render obsolete their job as an archaeologist, as all the questions could suddenly be easily answered (Marlow 1999:22-23).

The first published radiocarbon assays were on wood with known or assumed dates (Arnold and Libby 1949). These samples consisted of two dendrochronological samples, a floor fragment from a Syrian palace, two ancient Egyptian wood fragments (from a coffin and a funerary boat), and two samples from Egyptian tombs which were assayed as one sample. The measured ages were found to be satisfactory in comparison to expected dates of the samples. The half-life used to calculate the ages was 5720 ± 47 years. The study established that the radiocarbon method was useful for up to 4600 year ago and expressed the author's hope that future research could evaluate the accuracy of the method up to 20,000 years ago. This article was radiocarbon's seminal unveiling to the wider scientific public.

Though the new technology was discomfiting to many archaeologists at the time of its development, by the end of the 1950s it was widely accepted in archaeology as well as in other fields of study (e.g., geology); by then twenty radiocarbon labs had been established around the world, and the journal *Radiocarbon* was being published to consolidate radiocarbon date lists from the labs and ensure sufficient information was being published (Taylor and Bar-Yosef 2014:288). Most of these early radiocarbon labs were established at universities or research institutions, though one commercial lab was opened in the United States as well. In 1960, Libby won the Nobel Prize in Chemistry for the radiocarbon dating method. Taylor and Bar-Yosef point out that archaeology has only been mentioned once in a Nobel award citation, and that was for Libby's Nobel (2014:289).

*Calibration*

The second revolution in radiocarbon dating came with the recognition that radiocarbon ages required calibration to account for fluctuations in $^{14}C$ production, using calibration curves. Calibration curves correspond radiocarbon time (the measured age of a sample) with solar time and are based on estimates of the amount of carbon in the atmosphere in the past, calculated using proxy records. Dendrochronological tree rings, corals, and marine sediments are proxies for variation in atmospheric $^{14}C$ (Bronk Ramsey 2008:269).

Solar and radiocarbon time differ because the concentration of $^{14}C$ in the atmosphere is not uniform through time. This variation in $^{14}C$ abundance is reflected in the amount of radiocarbon an organism incorporates (Bronk Ramsey 2008:250). This difference is sometimes slight, and other times significant—$^{14}C$ measurements on tree rings have demonstrated that discrepancies between radiocarbon and solar time exists on the magnitude of hundreds of years during certain periods (Taylor and Bar-Yosef 2014:55).

Concentrations of atmospheric $^{14}C$ are the product of the abundance of cosmic particles impacting earth's atmosphere (as measured in the cosmic ray flux index), and how many of these particles are deflected by earth's magnetic field. Earth's magnetic field is in turn affected by solar activity (Bronk Ramsey 2008:251). In sum, cosmic forces, the sun, and earth's magnetic field all factor into the amount of $^{14}C$ created in the atmosphere at any point in time.

Prior to the development of the first calibration curve was Libby's "Curve of Knowns," in which he plotted known-age ancient Egyptian and dendrochronological samples in relation to his first published $^{14}C$ half-life (5720 ± 47) (Arnold and Libby 1949; Taylor and Bar-Yosef 2014:46). With additional known-age samples, Libby developed a second Curve of Knowns, using a half-life of 5568 ± 30, the Libby Half-life conventionally used today (though the half-life Libby used in his 1949 publication is closer to the half-life as it is measured today) (Taylor and Bar-Yosef 2014:46). Early on, Libby considered that the amount of $^{14}C$ in the atmosphere might vary with time, as well as with latitude and reservoir (Anderson and Libby 1951). However, in these early days of radiocarbon dating, adequate agreement between the expected dates and the calculated ages supported the hypothesis that $^{14}C$ abundance did not vary significantly over the last 10,000 years or so.

As radiocarbon dating reached the end of its first decade of use, it became apparent that measured radiocarbon ages for certain periods of time were consistently different than the expected age (Taylor and Bar-Yosef 2014:48). In the late 1950s, European researchers, physicist Karl Otto Münnich and nuclear scientist and biophysicist Hessel de Vries, suggested that calendrical and radiocarbon time differed (Taylor and Bar-Yosef 2014:19). Libby, however, argued that it was the "known ages" that were incorrect, not the radiocarbon method (Libby 1963). In the 1960s, Libby's argument was disproved when consistent radiocarbon ages on tree rings were found to disagree with their dendrochronological dates (Taylor and Bar-Yosef 2014:50). University of California professor Hans Suess was the first to assemble a database of paired dendrochronological dates and radiocarbon ages over a substantial span of time: 7000 years (Taylor and Bar-Yosef 2014:52).

By the 1960s, the idea that radiocarbon ages needed to be calibrated took hold. However, there was uncertainty about how broadly the early curves could be applied (Taylor and Bar-Yosef 2014:54); concern stemmed from inconsistencies between radiocarbon labs, whether the curves could be applied to material types other than wood, and whether a curve could be used for samples from anywhere in the world. Eventually, global variations in atmospheric $^{14}C$ concentrations were identified, most notably between the northern and southern hemispheres. In addition, short and medium-term variations in atmospheric carbon were identified, which account for the wiggles in the calibration curve (the de Vries Effects, or the Suess wiggles); these variations are thought to be caused by solar activity (Taylor and Bar-Yosef 2014:58-60). By the 1980s, radiocarbon labs were producing $^{14}C$ measurements with enough accuracy and consistency that earlier concerns over the accuracy of paired dendrochonological and radiocarbon data from disparate labs were allayed.

In recent decades, calibration curves have been pushed back from around 8000 cal BP to as far as 50,000 cal BP, due to additional proxies for atmospheric $^{14}C$. Separate curves for the Northern and Southern Hemispheres have been established (IntCal13 and SHCal13, respectively), as well as a "hypothetical" marine reservoir curve (Marine13). IntCal13 and SHCal13 are based on data from mid-latitudes, so are less accurate at the poles and equator (Reimer et al. 2013a:1870). The Marine13 curve was developed from samples from tropical and sub-tropical latitudes, and therefore is less accurate for high latitude samples. Calibration curves are an estimation, not an absolute value, and they continue to be refined as new atmospheric data becomes synthesized (Reimer et al. 2013a).

The recognition that calibration was necessary caused more waves in the turbid wake left by the invention of radiocarbon dating (Bayliss 2009:124-125). Calibration, coupled with an increase in dated samples (in great part due to increases in the availability of labs), resulted in another bout of upheaval in archaeological chronologies. In some places this not only restructured prehistoric timelines, but also had the effect of turning understandings of technological diffusion in prehistory upside down. Bayliss argues this second upheaval was a contributing factor to the rise of New Archaeology (2009:125).

*Accelerator Mass Spectrometry*

Arguably, the third radiocarbon revolution is the development and widespread use of accelerator mass spectrometers (AMS) for radiocarbon measurement (Harris et al. 1987; Bronk Ramsey 2008; Bayliss 2009). The biggest difference between AMS and conventional methods of radiocarbon dating (i.e., beta counting) is the greater sensitivity of AMS; it can measure smaller quantities of $^{14}C$. With this more sensitive instrument came faster measurement times, the ability to make measurements on older samples, and a reduction in the sample size required.

Prior to AMS, $^{14}C$ was measured using beta counting systems. These include proportional solid-carbon counters, gas counters, and liquid scintillation counters. Beta counting systems detect electrons as they are emitted during radioactive decay, and the counts are then compared with a modern standard (Taylor and Bar-Yosef 2014:112). In other words, these beta counters measure the amount of $^{14}C$ that have decayed over a given period of time (the measurement time); they are unable to detect $^{14}C$ that has not yet decayed. There is nothing inherently wrong with this method, but it has no advantages over AMS. Rather than counting beta decay, AMS directly detects quantities of $^{12}C$, $^{13}C$, and $^{14}C$ by separating them by their isotopic mass in a particle accelerator. The radiocarbon age is then calculated by comparing the ratio of $^{14}C$ to the stable carbon isotopes of $^{12}C$ and $^{13}C$ (Taylor and Bar-Yosef 2014:112). AMS was developed not only for measuring carbon isotopes, but for other cosmogenic isotopes as well.

In the late 1960s, Swiss physicist Hans Oeschger was among the first to suggest that $^{14}C$ could be more sensitively detected with a mass spectrometer (Taylor and Bar-Yosef 2014:291-292). Mass spectrometry and accelerated mass spectrometry differ; however, Oeshger's suggestion was a step towards the eventual development of AMS. In the early 1970s, Michael Anbar and his colleagues at the Stanford Research Institute attempted to use a conventional mass spectrometer for measuring $^{14}C$, though their experiment failed due to an inability to separate out the carbon isotopes from other, more abundant, molecules of similar mass.

AMS was developed in the late 1970s and early 1980s (Van Strydonck 2017:1243), and went through separate, competing iterations during that time—the cyclotron AMS and the tandem accelerator. The history of cyclotron AMS is entwined with that of nuclear defense. Its development can in part be attributed to a think tank for the US government seeking to detect low levels of radioactive atoms behind passing nuclear submarines (Taylor and Bar-Yosef 2014:292). In 1976, University of California-Berkley researcher and think tank participant Richard Muller began experimenting with using a cyclotron as a "high-energy," or accelerator, mass spectrometer. Over a decade of work, Muller achieved uneven success with the Berkley cyclotron for radiocarbon dating (Taylor and Bar-Yosef 2014:291-292).

While Muller was developing the cyclotron for AMS, tandem accelerators for radiocarbon measurement were also being developed. In fact, they were developed by two independent groups at the same time: Earle Nelson from Simon Fraser University

(Canada) and his colleagues, and nuclear physicists Harry Gove and Ted Litherland, both from the University of Rochester, with Kenneth Purser, a private business owner (Taylor and Bar-Yosef 2014:292-293). Nelson's group was interested in trying to measure $^{14}C$. The American physicists were initially interested in developing AMS for other purposes, though they turned their attention to $^{14}C$ around the same time as Nelson's group. Nelson considered using a tandem accelerator with a magnetic spectrograph to make $^{14}C$ measurements, but was inspired to use a detector telescope in place of the spectrograph, for distinguishing between ions of the same weight. His inspiration to use a detector telescope came from a 1977 article by cyclotron AMS developer Muller (Taylor and Bar-Yosef 2014:293). After that, tandem accelerators for radiocarbon dating were quickly tested. Before the end of 1977, Nelson published his tandem accelerator method, as did the American physicists, in the same issue of *Science* magazine no less.

The first archaeological samples were not measured by AMS until 1982 (Harris et al. 1987:23). In the early days of AMS for radiocarbon dating, the technique was expensive and wait lists could be long, because the machines were usually utilized for research unrelated to $^{14}C$ as well (Van Strydonck 2017:1243). With time, smaller and more affordable AMS machines were developed. In the 1990s, AMS labs became common, and their prevalence in radiocarbon dating has only increased since (Taylor and Bar-Yosef 2014:113).

While AMS in and of itself does not give more precise or accurate ages than beta counters, AMS offers the possibility of a more detailed chronology through smaller sample sizes, which also allows for more stringent pretreatment methods (Taylor and Bar-Yosef 2014:112). Only one milligram of graphitized carbon is needed for AMS (and in the case of the most sensitive instruments, mere micrograms), compared to one gram in conventional methods. Because of this, materials once not considered suitable for radiocarbon dating can now be measured (e.g., residue from a pottery vessel) (Harris et al. 1987:23-24; Taylor and Bar-Yosef 2014:112; Wood 2015:65). Taylor and Bar-Yosef point out the importance in distinguishing between the sample material and the graphitized carbon which is derived from the sample (2014:112). With conventional methods, one measurement on bone could require 300 grams of sample material (Van Strydonck 2017:1243), and in the early days of radiocarbon dating, recommended sample size for ivory or teeth was a now-unthinkable five pounds of sample material (Harris et al. 1987:26).

With the drastically decreased sample size needed for AMS, archaeological site sampling changed substantially; dates can be obtained from strata, features, and artifacts with comparatively little organic material present, and multiple measurements can be made from a single sample to evaluate controversial or unexpected dates (Harris et al 1987:27). Accurate $^{14}C$ measurements can also now be made by isolating particular fractions of a sample, such as lipids or amino acids, and thereby excluding even more potential contaminants.

Despite the benefits of AMS, Bayliss believes the technique does not constitute a radiocarbon revolution, because it did not contribute to developments in archaeological theory (2009:125). Others disagree, believing that AMS was "clearly revolutionary" (Bronk Ramsey 2008:268; Harris et al. 1987). Regardless, AMS has transformed radiocarbon dating by accommodating a larger spectrum of possible samples.

*Bayesian Statistics*

The current radiocarbon revolution is the application of Bayesian statistics to archaeological chronologies. Bayesian statistics are widely applied by various scientific disciplines; however, this section discusses its application to archaeological dating. Bayesian analysis (also known as Bayesian modeling or a Bayesian approach), is an inferential statistical method which uses qualitative and quantitative data to create probabilistic chronologies. The Bayesian approach takes the form of two methods. Most commonly, it is used to narrow the date ranges for a radiocarbon data set from the same archaeological site, thus creating an intra-site chronological model with much tighter precision. The second method of Bayesian analysis investigates the timing and tempo of something (termed a *phase*) across many sites or a region; this may relate to typologies, seriation, the environment, or history (Bayliss 2015:678-679; Hamilton and Krus 2018:2). The Bayesian revolution in radiocarbon dating has done more than simply refine chronologies, it also refocused attention on the reporting of radiocarbon data (e.g., sample material, laboratory treatments, and sample context), and has prompted revaluations of the theoretical frameworks that underpin how archaeological time is conceived and constructed.

Bayes' theorem (also Bayes' rule or Bayes' law) was developed by Thomas Bayes (1701-1761), an English mathematician and Presbyterian minister (Buck and Juarez 2017:5). Bayes' theorem, in simple terms, uses prior probabilities and standardized likelihoods to inform the posterior belief (Hamilton and Krus 2018:4; Whittle et al. 2011). In a simplified mathematical format, Bayesian statistics are often summarized as:

$$\text{prior probabilities} \cdot \text{standardized likelihoods} = \text{posterior beliefs}$$

In radiocarbon dating, prior probabilities are inferences or interpretations gleaned from the archaeology (e.g., superposition of samples). Standardized likelihoods are chronometric information, such as radiocarbon dates. Other types of chronometric information can be incorporated as well (e.g., date on a historic coin). The posterior belief is the outcome—the probability of an event or events. In other words, by combining radiocarbon dates with other available information, a more precise chronology can be created.

The first published use of Bayesian modeling of radiocarbon data is that of Naylor and Smith (1988) (Bayliss 2015:677). At the time, computer processing capabilities inhibited widespread adoption of the method by archaeologists (Taylor and Bar-Yosef 2014:148-149), and it was assumed that archaeologists would necessarily work with statisticians to develop models, rather than do it themselves (Buck et al. 1991:819). Many archaeologists lacked the background in statistics required to understand the newly applied method, and therefore failed to appreciate advantages of Bayesian modeling (Buck et al. 1991:808).

In the mid-1990s, advancements in personal computing technology and increased availability of software made Bayesian statistical methods more accessible (Taylor and Bar-Yosef 2014:148-149; Buck and Juarez 2017:2). However, though Bayesian modeling has seen dramatically increased use, it is still not commonly taught outside the United Kingdom. As a result, Bayesian models remains poorly understood by many, and the method is frequently employed incorrectly (Hamilton and Krus 2018:2).

Several software programs were developed specifically for Bayesian analysis of radiocarbon dates, including OxCal and BCal. Other programs, not specifically designed for radiocarbon dates, are also used, such as the R Project for Statistical Computing. The first Bayesian program to be developed for radiocarbon data was OxCal, developed in the early and mid-1990s (Bronk Ramsey 1995). Christopher Bronk Ramsey, OxCal's developer, is an English physicist, mathematician, and radiocarbon specialist at the University of Oxford. OxCal's development has its roots in a problem encountered while dating Ötzi the Iceman—radiocarbon dates on the Iceman's bone and skin were different. To address this problem, Bronk Ramsey developed code that could combine the probabilities for the dates (Bayliss and Bronk Ramsey 2004:25). Soon after this code was written, the program's capabilities were expanded to include Bayesian modeling. This expansion was done in consultation with two English archaeologists employing the Bayesian method—Caitlin Buck and Cliff Litton—with the end goal of replicating their previous work (i.e., Buck et al. 1991). Today, the Bayesian archaeologist has more software options for performing Bayesian analyses than ever, though OxCal continues to be widely used. It is important to note that Bayesian software programs are complex, and each time a model is run a slightly different output will be computed.

In recent decades the Bayesian diaspora has spread from the United Kingdom, where it first flourished as an archaeological tool, to archaeologists around the world. This increasing use of a Bayesian approach is reflected in the number of journals publishing Bayesian chronologies (Bayliss 2015:678). Bayesian modeling seems to have displaced some older statistical methods, namely chi-square wiggle matching and summed probability distributions (Bayliss 2015:678). However, as previously noted, the booming popularity of Bayesian chronologies has not resulted in a booming offering of formal Bayesian training, the lack of which has resulted not only in misapplications of the method, but also a scarcity of qualified peer-reviewers to highlight mistakes (Hamilton and Krus 2018:2-3).

Early pioneers of the Bayesian approach name three essential components to a Bayesian model: the archaeological information, the radiocarbon information, and the statistical information (Buck et al. 1991:809). Advocates of Bayesian modeling stress the importance of critically evaluating the components of a model (Griffiths 2014; Bayliss 2015; Buck and Juarez 2017). The archaeological information under consideration includes the context from which the sample was taken. For example, the depositional environment of the sample should be considered; if the sample was from mixed or redeposited sediments, interpretations would likely be different than if it were from a sealed deposit. A second essential consideration is the relationship between the event of interest to the archaeologist and the organismal death of the sample (e.g., death of the plant or animal, or divorce from carbon exchange, as in the case of seasonal shedding of hair or antler) (Bayliss 2015:689; Buck and Juarez 2017:9). Turning to the radiocarbon information, issues to be considered include laboratory processing, such as in the case of sample contamination, or something inherent to the sampled organism, such as suspected uptake of carbon from aquatic reservoirs (Taylor and Bar-Yosef 2014:148-149). The third and final component is the statistical information. This relates to the construction of the model itself—the statistical method and the code which organizes and processes the data.

As noted, models can be created for a single site, using primarily stratigraphic information to dictate the model, or regional models can be created to trace the beginning and ends of a phase of something (e.g., an artifact type or a technology or activity type) and to evaluate its tempo. Brown et al. succinctly explain the benefits of using Bayesian methods for determining phase starts and ends:

> While simply looking at the calibrated ages of individual dates to estimate the span of archaeological cultures is not necessarily incorrect, doing so tends to significantly overestimate the actual time span, as there is no way to tell which portions of the calibrated range are more or less likely to represent the archaeological phase in question. (Brown et al. 2019:475)

Regional models can be complex and rely heavily on the archaeologist's understanding of the archaeological problem. A danger in using Bayesian statistics for determining phases is that the archaeologist's assumptions may result in a model designed to reinforce their preconceived notions (Griffiths 2014:872).

The Bayesian approach has directed attention to two topics which are not new to radiocarbon dating but are essential to discussion of Bayesian statistics: 1) practical reporting and critical evaluation of radiocarbon data (Bayliss 2015), and 2) philosophical ramifications of how time is constructed (Griffiths 2017). In brief, reporting and critical evaluation of radiocarbon data are essential to appropriate interpretation and use of that data; a model is only as good as its information. This concept is discussed in more detail in the *Methods: Reporting Standards and Critical Evaluation* subsection below. Discussions of how time is constructed can be quite abstract. Griffiths (2017) contrasts the perspectives of processual archaeologists Colin Renfrew and David Clarke on the second radiocarbon revolution—calibration—and extrapolates their perspectives to the current Bayesian revolution. Griffith writes, "the seemingly benign sequences, which we seek to populate with data, are charged with interpretative value, they structure our thinking" (2017:1349). She challenges the archaeologist to consider how cultural historical constructs of time, considered to be long-gone, continue to direct how analytical units of time are conceived of, symbolized, and modeled.

Detractors harp on the subjectivity of the Bayesian method; proponents do not deny the methods' subjectivity. In the words of Bayliss and Bronk Ramsey, "one of the main problems in practice with the application of Bayesian statistics to archaeological chronology, is that absolute Bayesian rigour is almost impossible to achieve" (2004:35). Bayesian statistics, at least as applied to radiocarbon dating, uses qualitative data, and introduces an unquantifiable uncertainty to the equation. As noted, the structure of the model can be swayed by the maker's understanding of how archaeological time should be constructed (Griffiths 2014). The Bayesian approach to radiocarbon analysis is inherently "contextual and interpretative" (Whittle et al. 2011:20), and while this might seem problematic to some, others argue that radiocarbon data *should* be interpretive (Griffiths 2017:1355). In a final defense of Bayesian modeling, it is worth pointing out that Bayesian modeling's proclivity to revision is no different than other chronological models—incorporating new information into a model as it is available is the nature the process (Buck et al. 1991:811; Whittle et al. 2011:20).

The Bayesian revolution satisfies Bayliss' criteria for a radiocarbon revolution, which he believed AMS failed to meet—it is both a revolution in technology and theory (2009:125). Computer advancements have enabled the production of powerful statistical programs. Data are now "big," and archaeologists can access and share more information than ever before. These technological developments are changing the way radiocarbon data are analyzed, and archaeologists are again reevaluating their chronologies. Hand-in-hand with this current chronological upheaval is a revolution in archaeological theory which pushes archaeologists to reflect on how their concepts of time affect how the past is modeled and conceived.

### *Radiocarbon Methods and Data*

This section discusses radiocarbon methods as they pertain to the Lower Pecos Canyonlands radiocarbon data set. Reporting standards for radiocarbon data are discussed first, followed by a discussion of age corrections for isotopic fractionation and reservoir effects. Sample materials common in the Lower Pecos are then discussed, including sample pretreatment to remove contaminants and other considerations relevant to specific material types. Finally, the chapter culminates on the topic of critical evaluation of radiocarbon data.

#### *Reporting Standards*

Despite decades of discussion about radiocarbon reporting, radiocarbon data remain frequently under-reported. Radiocarbon reporting should consist of much more than the radiocarbon ages and calibrated dates—sample material descriptions, archaeological context, pretreatment methods, and $^{14}C$ measurement methods are also critical pieces of information, necessary to evaluate the relationship of the sample to the archaeological question it is intended to address. This section discusses what kinds of information should be reported and why.

Arguably, the most fundamental pieces of radiocarbon data to report are the radiocarbon lab number, the sample material type, and the radiocarbon age in radiocarbon years before present (RCYBP, also annotated as BP). The radiocarbon lab number is a unique number assigned by the lab, with a lab designation prefix (e.g., Beta- for Beta Analytic). This number makes the sample traceable, unlike specimen numbers assigned by the archaeologist. The sample material type is important to know for interpretive reasons. The material should be reported in as much detail as possible, including genus and species if known, and the part of the organism sampled. Other information, such as if it was burned, or whether it is a short or long-lived, can aid interpretation.

Radiocarbon ages can come in several forms. Standards published in 1977 by Stuiver and Polach, and widely agreed upon in the radiocarbon community, require that the conventional radiocarbon age be reported. There are several requirements that a radiocarbon age must meet in order to be considered conventional (Taylor and Bar-Yosef 2014:26-27).

1. Conventional ages must be calculated using the Libby half-life (5,568 years).
2. Conventional ages must be normalized for isotopic fractionation (discussed in the below section: *Age Corrections*). If available, the fractionation factor—the $\delta^{13}C$ value used to adjust the raw, measured age for difference in stable isotope ratios—should also be reported, and it should be indicated whether the $\delta^{13}C$ value was measured or estimated. There are two different $\delta^{13}C$ measurement types: that measured by isotope ratio mass spectrometer (IRMS) and reflective of the organism's natural isotopic fractionation, and that measured by AMS, which includes both fractionation introduced by the radiocarbon dating process and natural processes. IRMS $\delta^{13}C$ values are useful for dietary studies, and should be reported if they are measured. In contrast, AMS $\delta^{13}C$ values are typically not reported, but they *are* used to

calculate conventional ages. Variability in what data radiocarbon labs return to the archaeologist, and changing standards through time, can make $\delta^{13}C$ reporting confusing. Therefore, it is essential for the archaeologist to understand what is being reported to them by the lab, and make clear what kind of $\delta^{13}C$ data is being presented in their own reports (estimated or measured values, and if measured, IRMS or AMS $\delta^{13}C$). Radiocarbon measurements made before the late-1970s were normally neither measured for $\delta^{13}C$ nor adjusted for isotopic fractionation, despite fractionation being a known issue since the 1950s (Taylor and Bar-Yosef 2014:142). Despite this, estimated $\delta^{13}C$ values can be applied to legacy ages if the sample material type is known.

3. Another requirement of conventional age reporting is that a modern standard be processed along with the sample material for quality assurance. The modern standard must either be oxalic acid distributed by the National Institute of Standards and Technology (NIST) or a sample with a precisely measured relationship to NIST-distributed oxalic acids (Taylor and Bar-Yosef 2014:26).

The conventional radiocarbon age should be reported as an average and a measurement precision (also referred to as standard error). It is standard to report the measurement precision as $\pm 1\sigma$ (68% precision) (Stuiver and Polach 1977:357). Reservoir corrected ages, if applicable to the sample material, should not be factored into the conventional age, but reported separately (Stuiver and Polach 1977:357).

A calibrated radiocarbon date, in contrast to a radiocarbon age, is important for correlating the event of interest with our calendar system. However, the calibrated date is less important to future researchers because it, unlike the conventional age, cannot be recalibrated with updated calibration curves. Radiocarbon dates should be reported as cal BP, cal AD or cal BC. The calibration curve employed should also be reported. The radiocarbon date should, like the radiocarbon age, be reported with its measurement precision—either $\pm 1\sigma$ or $\pm 2\sigma$ may be reported so long as it is indicated which is being used. It is standard for radiocarbon dates to be reported as an age range, rather than a mean and standard error.

While the radiocarbon data discussed above—lab number, sample material, ages, dates, and calibration curves—are the most fundamental information to report, other methodological and contextual information are needed for interpreting how these data address the archaeological question of interest. This includes the method of measurement, pretreatment processes, and any information pertaining to sample condition. Contextual information to report should include a site identifier, intra-site provenience, associated stratum or feature, and when it was collected and submitted for radiocarbon dating and by whom. Additional information to report includes why that sample was chosen (i.e., rationale for selection and the targeted research question the sample was intended to address). Finally, information about the sample's contextual relationship to the research question should be discussed.

*Age Corrections*

Corrections commonly applied to radiocarbon ages include adjustment for isotopic fractionation (normalization), reservoir effects, and calibration. These topics were introduced in previous sections and are discussed in greater detail below.

Isotopic fractionation results from the discriminatory incorporation of isotopes of varying atomic weights during natural or laboratory processes. Isotopic fractionation is quantified as a $\delta^{13}C$ value, which is a ratio of $^{12}C$ to $^{13}C$ as compared to a known standard (the Pee Dee Belemnite limestone formation, or PDB), in parts per thousand (per mille) (Taylor and Bar-Yosef 2014:142-143). The more negative the $\delta^{13}C$, the greater abundance of $^{12}C$ compared to the heavier carbon isotopes (O'Leary 1988:328).

$$\delta^{13}C = \left[\left(\frac{\frac{^{13}C}{^{12}C}sample}{\frac{^{13}C}{^{12}C}standard}\right) - 1\right] x\ 1000$$

Fractionation occurs because lighter isotopes (e.g., $^{12}C$ and $^{13}C$) react more quickly in kinetic reactions compared to heavier isotopes ($^{14}C$), and because heavier isotopes cluster at stronger bonds in exchange reactions (Fry 2006:12). By measuring the relationship between the stable carbon isotopes, the relationship between $^{12}C$ and $^{14}C$ can then be more precisely quantified. In sum, isotopic fractionation causes the ratio of the carbon isotopes in a sample to differ from atmospheric carbon, and can be adjusted for after measuring the ratio of $^{12}C$ to $^{13}C$.

As noted, isotopic fractionation in radiocarbon dating takes two forms: fractionation due to natural processes and fractionation that occurs during sample pretreatment and measurement by AMS. Photosynthesis is the primary mechanism of natural fractionation of carbon isotopes. In photosynthesis, lighter carbon isotopes are differentially incorporated into the plant during respiration and internal chemical processes such as carboxylation (O'Leary 1988). As a result, plant carbon ratios are different than atmospheric carbon ratios. This effect is transferred up the food chain.

There are three photosynthetic pathways: $C_3$, $C_4$, and crassulacean acid metabolism (CAM). These have distinct effects on isotopic fractionation, which reflect plant adaptations for temperature, moisture, and atmospheric abundance of $CO_2$ (Ehleringer and Cerling 2002:1). $C_3$ plants are the most common plant type globally, (Drake 2014:29) and include trees and shrubs which prefer cooler, higher $CO_2$ environments (Ehleringer and Cerling 2002:1). $C_3$ plants typically have more negative, or lighter, $\delta^{13}C$ values compared to $C_4$ plants (O'Leary 1988:329). In the Lower Pecos, all woody plants are $C_3$ plants (Dering 2007:185), as is evergreen rosette sotol. $C_4$ plants include most grasses, such as corn and sugar cane, and make up an estimated 18% of plants globally (Drake 2014:30), and are adapted for hotter, lower $CO_2$ environments. CAM plants include most succulents, including cacti, euphorbia, and evergreen rosette plants such as agave and yucca. While CAM plants comprise the smallest percentage of plants globally, they are abundant in the Lower Pecos. Adapted to arid environments, CAM plants switch between photosynthetic pathways as environmental conditions dictate. During the daytime CAM plants generally employ a $C_3$ photosynthetic pathway, and at night employ a process similar to $C_4$ (O'Leary 1988:331). $\delta^{13}C$ values for CAM plants are generally similar to $C_4$ values.

As noted previously, fractionation resulting from natural processes is measured by IRMS, and the resulting $\delta^{13}C$ value can be used for dietary studies. However, $\delta^{13}C$ values measured during AMS are not useful for dietary studies because they account for both natural fractionation and fractionation that occurs during chemical pretreatment and in the spectrometer. AMS $\delta^{13}C$ values are typically not reported by the radiocarbon lab because archaeologists often erroneously apply it to dietary studies. However, it is this value that is used to calculate conventional ages. This is often referred to as "normalizing" the raw age (Taylor and Bar-Yosef 2014:143). If the $\delta^{13}C$ cannot or has not been measured, it can be estimated based on previous measurements made on samples of the same material type.

After normalizing the radiocarbon age, the conventional age may be adjusted for reservoir effects, such as marine or hardwater/freshwater effects. A fundamental assumption of radiocarbon dating is that carbon in biological life is in equilibrium with the atmosphere, but in reality, this assumption is violated when biota incorporate carbon from other sources, such as upwelling ocean water and carbon-bearing geological formations (e.g., limestone). Such reservoirs have "dead," or fossil, $^{14}C$. When fossil carbon is incorporated in the sample, the ratio of $^{14}C$ to the stable carbon isotopes becomes different than that found in the atmosphere. A $\Delta R$ (Delta R) value is used to adjust conventional ages for reservoir effects. The $\Delta R$ can be estimated by pairing associated samples of different material types (e.g., marine and terrestrial), by comparing dates on modern terrestrial and aquatic samples, or by dating correlated tephra deposits from terrestrial and marine environments (Taylor and Bar-Yosef 2014:150).

The Lower Pecos is distant from the ocean, and marine reservoir effects are not of concern here. However, freshwater, also called hardwater, reservoir effects are relevant. Dissolved carbonates in freshwater bodies can affect carbon isotope ratios in freshwater aquatic organisms, and animals that consume them. The hardwater reservoir effect can be difficult to adjust for, because carbon levels in rivers fluctuate seasonally, and lie anywhere between atmospheric and bedrock levels (Bronk Ramsey 2008:253). Hardwater reservoir effects have been shown to cause radiocarbon ages to be as much as 800 years too old (Olsen et al. 2010:642).

When considering hardwater reservoir effects in humans, one must consider how carbon fixing occurs in various parts of the body—does sample material reflect recent diet or cumulative diet? Keratin based materials such as hair and nails, for example, do not continue to exchange carbon after being produced and therefore reflect short-term diet. In contrast, collagen from dense cortical bone represents diet approximately 20 years before death, while non-compact (trabecular) bone represents the past 4 years or so of the individual's diet (Olsen et al. 2010:635-636). Further complicating the matter, collagen turnover rates vary depending on the age and sex of the individual (Hedges et al. 2007).

Hardwater reservoir effects have not yet been investigated in the Lower Pecos. However, riverine resources are found in the archaeological record and hardwater effects can be expected to bear on dating aquatic biota and the remains of people and animals who subsisted on them. Stable isotope studies on human bone from the region indicate elevated $\delta^{15}N$ values, which suggests fish were consumed in ancient Lower Pecos populations (Huebner 1991). A riverine diet is supported by fish macrofossils in human coprolites (Poinar et al. 2001), as well as butchered fish bones in archaeological assemblages (Jurgens 2008). However, it has been argued that xeric desert habitats may also contribute to elevated $\delta^{15}N$ levels (Huebner 1991:182; Van Strydonck 2017:1246).

Given that nomadic people likely drew their diet from several reservoirs, and that fossil carbon levels in the rivers likely fluctuated seasonally, establishing a baseline reservoir offset for the rivers of the Lower Pecos (Rio Grande, Pecos and Devil's) would not be practical. Quantifying hardwater reservoir effects in the Lower Pecos likely cannot be done with broad strokes, but instead on a case-by-case basis. This could be done using paired dates from contemporaneous aquatic and terrestrial samples, by estimating the percentage of riverine organisms in the diet of a given individual and adjusting the age accordingly, or by dating amino acids, which reflect a specific carbon reservoir.

Finally, while not technically a hardwater reservoir effect, it is worth mentioning here that the limestone bedrock ubiquitous in the Lower Pecos has been shown to effect terrestrial gastropod ages on the magnitude of hundreds of years (Goodfriend et al. 1999). This effect, and adjustments for it, is discussed in the *Samples* subsection below.

After age adjustments have been made to normalize carbon isotope ratios for isotopic fractionation, and after reservoir corrections are applied (if needed), the final age correction can be applied: calibration. Radiocarbon calibration serves to correlate radiocarbon time with our solar calendar by accounting for fluctuations in atmospheric carbon through time (Reimer et al. 2013b:1925). Calibrations curves are periodically published as more data is gathered on past atmospheric $^{14}C$ levels. Because of this, radiocarbon ages may need to be re-calibrated as calibration curves are updated and published (i.e., for new studies and analyses using older data).

Currently there three primary radiocarbon calibration curves: the Northern Hemisphere curve (IntCal13), the Southern Hemisphere curve (SHCal13), and a baseline global marine reservoir curve (Marine13). A single global curve does not exist because natural patterns such as winds, ocean upwelling, and land to water ratios effect global carbon distribution (Reimer et al. 2013b:1925). Even within these three curves there are geographic constraints on their application due to natural processes. For example, in both Southern and Northern Hemispheres the calibration curves are less reliable for samples from high latitudes or great altitude. Similarly, around the equator, atmospheric mixing due to winds at the Intertropical Convergence Zone cause carbon variability (Reimer et al. 2013b:1925). For these reasons, both hemisphere curves are most accurate for mid-latitudes. The Lower Pecos Canyonlands are situated in the mid-latitudes of the Northern Hemisphere—well above the Tropic of Cancer, distant from the Arctic, and at low elevation, and thus the Lower Pecos radiocarbon record is not saddled with these problems.

Sample materials used as proxies for past atmospheric records (also called "archives") include tree rings, terrestrial macrofossils, corals, foraminifera (single-celled animal plankton), and speleothems (mineral cave deposits) (Reimer et al. 2013b). Tree rings with known dates, determined through dendrochronology, were the first carbon archive used to construct calibrations curves. Dendrochronology remains the favored independent chronology for constructing calibration curves, especially when a given chronology is shown to be repeated across several trees. Replication of dendrochronologies ensures any missing or doubled annual growth rings are accounted for (Reimer et al. 2013b:1926). Dendrochronologies used in the IntCal13 curve include the US bristlecone pine chronology and several European oak chronologies (Reimer et al. 2013b: 1933-1934), as well as several "floating" European tree chronologies, which have been anchored by wiggle-matching (Reimer et al. 2013a:1872). These dendrochronologies comprise IntCal13 as far back as 13,900 cal BP (Reimer et al. 2013a:1870). Terrestrial macrofossils such as pollen grains and leaves from unmixed, varved (annually laminated) sediments can, like tree rings, be used to establish an independent carbon time scale. The IntCal13 curve uses macrofossils from varved sediments from Lake Suigetsu, Japan, to extend the radiocarbon time scale back to ca. 50,000 cal BP (Reimer et al. 2013a:1870).

Problematic areas of the curve, characterized by insufficient or contradictory data, are strengthened with chronologies from non-varved marine foraminifera, and uranium–thorium dated aragonitic corals and speleothems. Corals and foraminifera are reflective of the mixed marine layer, which incorporates both atmospheric and marine reservoir carbon sources. Speleothems incorporate fossil carbon, which is corrected for by comparing overlapping speleothem records with varved macro-fossil and dendrochronological records to ascertain a constant background value of this inert carbon (Reimer et al. 2013a:1872). In sum, radiocarbon calibration curve development is a patchwork of chronologies and is a work-in-progress (Reimer et al.2013a:1883), much like the archaeological chronologies that rely upon them.

*Samples*

Prior to $^{14}C$ measurement, a radiocarbon sample must be cleaned of carbon-bearing contaminates (pretreated) and converted to graphite. Contaminants can be removed by one of five methods: physical removal, acid extraction, base extraction, solvent extraction, or separation at the molecular level (Taylor and Bar-Yosef 2014:92). These methods may be used in combination. The kind of pretreatment employed depends both on the contaminant type and what methods the sample material can withstand.

In the Lower Pecos Canyonlands, the majority of radiocarbon sample materials are from plants. Wood charcoal, which preserves better than uncarbonized or more delicate plant materials, can be found at open (upland and terrace) sites as well as rockshelter sites, and account for approximately 60% of the assays (assuming materials listed as "charcoal" are from woody plants). Fiber artifacts and other plant remains preserved in dry rockshelters account for many approximately 35% of the assays. Dates on faunal remains, including bone, hair, human coprolites and intestinal contents, and snail shell, make up a minority, approximately 5%, of Lower Pecos radiocarbon data. This section describes sample material types of importance to the Lower Pecos.

*Wood and wood charcoal*: Wood and wood charcoal are considered a standard sample material, along with non-wood plant materials, marine and terrestrial shell, bone, and keratin-based tissues (Taylor and Bar-Yosef 2014:66-82). Of these, wood charcoal is the most commonly dated, in great part due to its durability in archaeological deposits relative to other materials. The cellular structure of wood is also favored for its ability to withstand rigorous pretreatment (Taylor and Bar-Yosef 2014:67).

A common contaminate of archaeological wood is post-depositional intrusion of rootlets into the sample; these can sometimes be removed mechanically. Strong chemical washes can also remove rootlets, though they can also reduce sample size by up to 40% (Taylor and Bar-Yosef 2014:69). Soil humics (humic and fulvic acids) are another common contaminant. Soil humics are the product of active soil horizons and can be incorporated into buried wood as the humics are transported by groundwater through soils (Taylor and Bar-Yosef 2014:69). Humic acids are soluble in base washes, and fulvic acids are soluble in acids and bases (Brock et al. 2018:104). Soil humics extracted from wood charcoal have been dated separately from wood, and age discrepancies between the two fractions have been found on the scale of centuries for Holocene-age wood, and millennia in Pleistocene-age wood. The amount of soil humic incorporated vary with depositional environments—organic-rich environments will result in higher levels of contamination.

Though wood charcoal is a common and well-studied radiocarbon sample material, there remain questions about how accurately charcoal dates reflect the targeted event. Problems with wood samples include the old wood effect, contextual/depositional issues (Potter and Reuther 2012), and legacy bulk charcoal dates. Before AMS, large sample sizes were needed to obtain a date, and bulk charcoal samples were often the only option available. Legacy dates derived from these samples are considered suspect because of the risk of wood material from different events being comingled. The old wood effect is problematic for radiocarbon dating because the inner rings of a long-lived tree can date to centuries earlier than the event of interest to the archaeologist. This problem can sometimes be mitigated by sampling from the outer-most rings or short-lived twigs. The tree species should be identified prior to dating so that the possible lifespan of the species can be determined. To mitigate post-depositional contamination, the cellulose fraction can be separated for what some believe will yield a more accurate date, though adequate pretreatment has been shown to remove contaminants in most cases (Taylor and Bar-Yosef 2014:70).

*Non-wood botanicals*: Plant materials other than wood are commonly found in Lower Pecos rockshelters; these include desert succulents such as prickly pear pads and evergreen rosette (e.g., agave, sotol) leaves and bloom stalks, grasses and sedges, and a variety of seeds. Shorter-lived than most trees, these plants provide excellent dating opportunities. However, many plants in the Lower Pecos have Crassulacean acid metabolism (CAM) photosynthetic pathways, which can result in variation of $^{14}C$ uptake. As a result, it can be difficult to accurately estimate $\delta^{13}C$ for CAM samples (when measured values are not available). Isotopic fractionation and photosynthetic pathways were discussed previously in the subsection *Age Corrections*.

Non-wood plant materials are pretreated with acid and base washes, much like wood, however, some non-wood plant materials disintegrate easily in chemical pretreatment. Partial or near-total loss of sample material is possible. This problem was encountered while pretreating persimmon seeds from Eagle Cave (41VV167) from the Ancient Southwest Texas Project's 2014-2016 excavations (Charles Koenig, personal communication 2019).

*Bone*: Like wood and wood charcoal, bone is a popular sample material for radiocarbon dating, no doubt a result of its abundance in the archaeological record. Bone is considered a good material for radiocarbon dating for contextual reasons; for example, bone often has a closer temporal relationship to the event of interest to the archaeologist than old wood (Potter and Reuther 2012: 72-73; Taylor and Bar-Yosef 2014:66). However, the history of pretreating bone for radiocarbon dating has been checkered. What follows is a brief overview of a multifaceted and much more extensive subject than can be covered here.

Bone is comprised of an organic carbon fraction and an inorganic fraction (Taylor and Bar-Yosef 2014:75). The organic fraction is comprised of proteins or lipids—chiefly collagen—and is the preferred fraction for radiocarbon dating. In contrast, the inorganic fraction (apatite mineral) is widely regarded as problematic due to contamination from carbonates in the depositional environment. Bone apatite is subject to diagenesis such as perimineralization and petrification—essentially, dissolved minerals seep into the bone and create crystals inside it (Ambrose and Krigbaum 2003:195).

Early in the history of radiocarbon dating, bone was considered an unreliable material to date (Taylor and Bar-Yosef 2014:75). The earliest assays used the whole bone, and lacked pretreatment—such dates are considered "grossly inaccurate" (Ambrose and Krigbaum 2003:195). In the mid-1960s, geochemist Harold Krueger pioneered methods of separating collagen from bone, but pretreatment methods proved insufficient to remove all contaminants in many instances. By the late 1980s, AMS and modern pretreatment methods, including dating of amino acids, enabled much more accurate bone dates (Ambrose and Krigbaum 2003:195). Currently, extracted collagen is the standard component to date. But even with AMS's small sample sizes, obtaining enough good quality collagen from a specimen, especially an old or fragile specimen, can preclude collagen dating. Most archaeological bone has little collagen that is unaltered, and the older the bone is, the more likely the collagen is to be affected by diagenesis (Taylor and Bar-Yosef 2014:81). Pleistocene age bones in particular require great attention to specifics of sample pretreatment because of low organic carbon content (Taylor and Bar-Yosef 2014:81-82).

Standard pretreatment of bone involves physical removal of contaminants such as rootlets from the bone surface and fractures (Taylor and Bar-Yosef 2014:76). This is followed with removal of the inorganic fraction with hydrochloric acid (Taylor and Bar-Yosef 2014:77). The organic fraction which remains can then be treated a number of different ways: sodium hydroxide can be used to remove humic acids and other base-soluble contaminants, and amino acids can be separated if desired. If amino acids are separated, further processing may include removal of trace humic and fulvic acids with a resin such as XAD (name trademarked by Dow, not a known acronym), or ultrafiltration to isolate the high molecular weight fraction. The high molecular weight fraction isolated during ultrafiltration is comprised of long-chain gelatins which are assumed to be higher-quality than the short-chain fraction, which contains broken amino acids and trace humates; this process can result in sample sizes too small to be dated (Lohse et al. 2014:99). In contrast, XAD-purification removes trace contaminants by passing the material through XAD resin, and retains both long and short-chain gelatin fractions, resulting in a larger sample size than would be possible with ultrafiltration. This makes XAD-purification well suited to obtaining accurate and precise dates on very old bone and bone with little collagen remaining (Lohse et al. 2014:99).

Reservoir effects are also a consideration when dating bone; if a significant portion of the animal's food (or the animal itself) was derived from an aquatic environment, then reservoir corrections need to be made. Stable isotope measurements can indicate how much of a diet was derived from aquatic life, but Van Strydonck warns, "a shift in $^{13}C$ can also be caused by the consumption of $C_4$ instead of $C_3$ plants and a high $^{15}N$ value can be caused by urea recycling due to the fact that this person lived in a very arid environment" (2017:1246, also see Ambrose and Krigbaum 2003:196). As mentioned, hardwater reservoir effects in the Lower Pecos is a topic that is unexplored in the region's literature.

*Keratin*: Keratin-based materials are relatively rare to find archaeologically, although they are present in the dry rockshelters and caves of the Lower Pecos. These materials include hair, skin and leather, fingernails, hooves, feathers, and derivatives of these (e.g., parchment). The relationship between the dates of keratin-based materials and the event of interest to the archaeologist is often even more closely related than bone, as keratin ceases exchanging carbon with the environment after it develops, and thus represent a shorter time period. For example, section of hair may represent a single season in an animal's life, while a dense bone fragment from the same animal may represent 20 years of carbon accumulation.

Pretreatment of keratin-based materials is similar to that of bone, though comparably little research has been done on it. Keratin-based materials are less subject to the diagenesis that causes collagen to be lost from bone (Taylor and Bar-Yosef 2014:82). Arguably, preservation conditions must be exceptional to find these materials archaeologically. Though the Lower Pecos has no previously dated keratin-based samples, one is reported in this thesis. Notably, Verostick has done stable isotope research on hair from a Lower Pecos mummy, though the hair itself was not dated (Verostick 2013, Verostick et al. 2019).

*Gastropods*: Although often well preserved at open sites, terrestrial gastropod shell is considered to be "among the *least* suitable samples for $^{14}C$ analysis in most archeological contexts," along with other terrestrial shell material (Taylor and Bar-Yosef 2014:74). Gastropods can incorporate fossil carbon from limestone into their shells; therefore, $^{14}C$ in shell material will not be in equilibrium with atmospheric carbon (Pigati et al. 2010:520). However, some researchers have found that terrestrial shell can be an acceptable material to date, though reliability may depend on environmental conditions and species (Pigati et al. 2010) and a correction may be required prior to calibration (Goodfriend et al. 1999). Goodfriend et al. found in sampling modern Texas *Rabdotus* that the whirl closest to the opening of the shell may provide more accurate dates than the upper whirls of a shell. The last whirl is the most recent whirl created, and Goodfriend et al. hypothesize that the shell growth reflects the snail's diet during various stages of life, with the majority of fossil carbon being taken in earlier in life (Goodfriend et al. 1999:152). This last whirl does still not return acceptable radiocarbon ages, and Goodfriend et al. suggest a correction to be applied prior to calibration. Even after this correction, the accuracy of the date still will not be better than ±200 years (Goodfriend et al. 1999:155). Pretreatment of gastropods is chiefly mechanical rather than chemical, and entails breaking apart the shell and discarding unwanted sections (such as the upper whirls, columella, and any areas found after microscopic examination to have contamination on the surface), cleaning in a sonicator, and etching with hydrochloric acid (Yates 1986:458). There is only one example of radiocarbon dated archaeological snail shell in the Lower Pecos, from Centipede Cave (Tamers et al. 1964).

Though they are not gastropods, mollusks such as freshwater mussels appear in Lower Pecos archaeological deposits. However, no one has radiocarbon dated mussel shell in the Lower Pecos. Dating mussels is problematic, from a carbon reservoir perspective, much the same as snail shell.

*Conservation Treatments*

Many archaeological collections contain artifacts which were treated for conservation with various glues, shellacs, and acetate-derived polymers. These products may contaminate artifacts with modern carbon. Conservation treatments are frequently problematic due to a lack of record of what treatments were applied (Brock et al.

2018:36). There are laboratory methods for detecting conservation treatments, but they are imperfect. In some instances, a conservation treatment is not detectable at all (e.g., fish-derived glue on bone). With time, conservation treatments may become unstable, causing them to react with pretreatment solutions or the artifact itself, differently than when they were first applied (Brock et al. 2018:36). In cases where polyvinyl acetate-derivatives or cellulose nitrate lacquers are known to have been applied, Brock et al. suggest isolating and dating amino acids, or sampling portions of the artifact which were not treated (2018:48). When a sample of the treatment is large enough to be removed from the artifact, that material can be dated itself, which may help address questions of when the material was applied, and the nature of the material. For example, a sample of shellac taken from the Skiles Mummy hair was dated to the 1930s, and therefore is believed to be made from the common ingredients for that time: ethyl alcohol and plant resin (Verostick 2013:48). Many artifacts from the Lower Pecos had conservation treatments applied. Information on conservation treatments applied to Lower Pecos artifacts can sometimes be found in primary records, if they are not found in reports. Lower Pecos materials with conservation treatments applied have been, and undoubtedly will continue to be, radiocarbon dated. In sum, when artifacts with conservation treatments are to be radiocarbon dated, the archaeologist should provide the pretreatment lab with as much detail regarding conservation treatment as possible, so that they can tailor their methods to ensure maximum removal of these contaminants.

### *Critical evaluation of Radiocarbon Data*

The recognition that "not all dates are equal" (Nolan 2012:187) was made during the AMS revolution, and has resulted in increased emphasis on the critical evaluation of radiocarbon data and the application of data hygiene to large data sets. The aim of data hygiene is to cull potentially unreliable and irrelevant dates from a data set in order to build more accurate and precise chronologies. There are several perspectives about how to critically evaluate radiocarbon data. Some archaeologists adopt strict data hygiene criteria, which can result in exclusion of the majority or a radiocarbon data set—upwards of 80% of dates are frequently rejected when these methods are employed (Nolan 2012:190). Others adopt less restrictive criteria in order to maximize the quantity of dates used in analysis. Ultimately, the criteria used should depend on the research question and on the chosen statistical method (Hamilton and Krus 2018:5).

To formulate the method by which I would implement data hygiene for this thesis, I reviewed different examples of data hygiene criteria selection. One approach is to score or rank the dates according to how well they satisfy the chosen criteria. Nolan scored the sample based on its material type, assigned an additional point if it was measured by AMS, and subtract points if the standard error was greater than 100 years or if it was measured before 1970 (Nolan 2012). Though a well-designed scoring system may be shown to be practicable, Hamilton and Krus warn against it, arguing the method “misses the importance of holistically understanding the sample, context, and date” (2018:7) and that “a high-ranking sample might have low utility for some questions” (2018:8). Hamilton and Krus developed their method of data evaluation with Bayesian analysis in mind; they eliminate dates that fail to meet basic reporting standards (i.e., description of sample material, lab methods used, and provenience description relating the sample to its archaeological context). In comparison with Nolan, Hamilton and Krus take a liberal perspective on the inclusion of legacy dates and those with large standard deviations;

discounting of dates with large standard deviations, they believe, is a hold-over from older methods of radiocarbon date analysis such as summed probability distributions (Hamilton and Krus 2018:5). Legacy dates, they argue, are not inherently unreliable, though considerable effort is often required to chase down all the pieces of information necessary to evaluate them. They suggest that legacy dates be evaluated on a case-by-case basis, and that if exclusion of a legacy date is determined necessary, the reasoning be made explicit by the analyst (Hamilton and Krus 2018:7). Hamilton and Krus also propose a workflow for integrating critical evaluation and sample selection into the Bayesian process: assess the existing data, consider the archaeological problem to be addressed, and then identify samples to be used in the statistical analysis.

For this thesis, I adopt the method of Hamilton and Krus because I find scoring to be unnecessarily abstract. Evaluating each radiocarbon assay as the qualitative data it is seems like a more prudent method for a novice radiocarbon analyst to employ. In keeping with the workflow of Hamilton and Krus noted previously, an initial assessment of the state of the Lower Pecos radiocarbon data set is presented in Chapter 2, and the archaeological questions to be addressed are outlined in Chapter 3. The following criteria for date inclusion for my analyses are:

1. Basic reporting standards must be met: a reported or calculated conventional age is essential, and material type and context are critical. Exceptions are made for poorly provenienced but otherwise well-reported Lower Pecos samples, which are useful for region-wide analyses.
2. Bulk charcoal samples are excluded, unless their context is believed to be unusually secure.

3. Samples with known or suspected contamination or laboratory problems are excluded (e.g., whole bone legacy dates, samples indicated as problematic by the reporter).
4. Non-archaeological samples (e.g., sediment, dates on modern materials) are excluded.
5. Pictograph assays are excluded, due to uncertainty of paint composition and difficulties in pretreatment, as discussed in Chapter 1.

After culling data based on these criteria, the data are evaluated for their application to each of my research questions. As such, any date which passed the criteria may be excluded for some analyses but included in others.

A final point regarding critical evaluation of radiocarbon data that has not yet been made in this thesis is the importance of replicating radiocarbon assays. Replication—that is, dating the event of interest more than once—is advised to check the accuracy of dates. Replication can be done by splitting samples and sending them to different labs, or using different pretreatment methods on a split sample, or by dating several different material types that are associated with the same event and context (Hamilton and Krus 2018:9). Replication can help identify mixed deposits, reservoir offsets (Hamilton and Krus 2018:9), variation due to pretreatment methods, interlaboratory error (Potter and Reuther 2012:75), and even curation or reuse of materials (Wright 2017). In addition, having multiple dates from the same single-use feature may allow a more precise date to be generated (Potter and Reuther 2012:93). As a rule of thumb, Hamilton and Krus recommend replicating approximately 10% of the data set. The Lower Pecos radiocarbon record has at least 22 instances of date replication using 53 assays, which account for approximately 11% of the radiocarbon assays in the region, though replicated events only account for 5% of the data set. Quantifying date replication is a little strange, because legacy assays were sometimes reported under one lab number but are an average of two assays and measurements reported as one, while other events may be dated using a dozen or more assays reported individually (e.g., Steelman et al. 2004).

# V. THESIS METHODS AND PRESENTATION OF DATA

In this chapter, data collection methods and data types are described. Subsequently, 100 previously unpublished radiocarbon assays submitted by the Ancient Southwest Texas Project (ASWT) are presented, including detailed descriptions of four radiocarbon samples selected for this thesis. My attempt to assay the lowest excavated feature at Arenosa Shelter—Pleistocene bison remains (Feature 19)—is also reported here, though the bone was found to be too poorly preserved to be reliably dated. Finally, I describe and discuss previously reported Lower Pecos assays (n=373), organized by assaying lab and archaeological site. The radiocarbon database itself contains much more detailed information than is presented in this chapter, and is available for digital download (Appendix A).

To gain an understanding of the radiocarbon dating process I took advantage of opportunities to learn from several experts: Over the course of several semesters, I learned pretreatment methods from Raymond Mauldin at the Center for Archaeological Research (CAR) at the University of Texas at San Antonio (UTSA). I toured DirectAMS' radiocarbon dating facilities in Washington in March 2018. In April 2018, I took a Bayesian modeling workshop at the Smithsonian Institution, instructed by Tony Krus and Derek Hamilton of the University of Glasgow. Some of these experiences are described in the following sections.

## *Data Collection*

Turpin's (1991) radiocarbon date list served as a starting point for data collection. I vetted and supplemented Turpin's data using archaeological reports, *Radiocarbon* journal date lists, and primary documents. However, some (n=33) of the assays reported in Turpin (1991) (n=268) and Turpin and Eling (2017) (n=376) are excluded from this thesis, as they fall outside the regional boundaries as they are defined here.

*Radiocarbon* began publishing date lists in 1959 and served as my go-to source for basic radiocarbon data when researching legacy dates. In the early 1970s *Radiocarbon* stopped reporting exhaustive date lists. Archaeological publications from the 1960s and 1970s often excluded radiocarbon data considered essential today, making it difficult to find the desired information. Records from the Texas Archeological Research Lab (TARL) were referenced to ameliorate this problem, though exhaustive primary-record searching was not undertaken for all of the legacy assays. Assaying labs were also contacted directly in attempts to fill the data gaps.

Assays published after Turpin's 1991 list were compiled primarily from archaeological publications. Original lab reports were referenced when they were attached as report appendices. In some instances where data or clarification was needed, I strove to communicate directly with the reporting archaeologist. Previously unpublished radiocarbon dates from ASWT projects were compiled from radiocarbon laboratory reports, field records and databases, and data provided by Raymond Mauldin (on file at CAR).

As previously mentioned, radiocarbon assays on non-archaeological materials and on pictographs are excluded from the database, with the exception of a few new ASWT sediment assays which are reported but not used in my analyses. Assays not included in the database include those reported in Kochel and Baker's (1982) paleoflood hydrology, and sediment and travertine dates from Seminole Sink (Bement and Turpin 1988).

Pictograph assays were excluded because they are too experimental at this juncture, as discussed in Chapter 1. Data from sites located outside the Lower Pecos boundary, as it is defined in this thesis, are also excluded, though some of the assays from these sites are undoubtedly relevant to my research questions. Their exclusion is a regrettable result of the practicality of drawing the line somewhere. Sites near the Lower Pecos boundary which are excluded include 41VV1892 and 41VV1893 (Cliff et al. 2003), 41VV1751 (Johnson and Johnson 2008), and sites just outside the poorly defined Lower Pecos boundary in Mexico—those from Cueva Pilote and Cueva Encantada. Ultimately, no sites from Mexico are included in the database.

I elected to use the database template developed by the Canadian Archaeological Radiocarbon Database (CARD) to organize the Lower Pecos data; the data will ultimately be submitted to CARD. I added several fields, including site type, calibrated dates, and critical evaluation information related to my research questions. The data fields in the database are discussed below.

*Laboratory Number*: Lab numbers are unique numbers assigned by the assaying lab. CARD stipulates that they be submitted using the exact format used by the lab. A periodically updated list of lab prefixes is available from *Radiocarbon*. Some lab codes reported in Turpin (1991) were changed to conform to this criterion (i.e., Beta-# instead of B#).

*Field Number* and *Other Numbers*: The Field Number is the number assigned to a sample by the field archaeologist. Other Numbers include those assigned during sample selection, pretreatment, or during analysis.

*Site Identifier* and *Site Name*: The Site Identifier is the site's trinomial. The Site Name is the name used by the reporting archaeologist. Where two names are given, both are listed. For sites without a name, the trinomial is listed.

*Site Type*: This field is not in the CARD template, but it is useful for identifying sampling biases and investigating taphonomy or preservation issues. Site Types I use for describing Lower Pecos site landforms are upland, rockshelter, and terrace. Publications and site records in the Texas Archeological Sites Atlas were used to determine type. If the type of site was not clear, I used my best judgement based on aerial imagery and location description. In the event a site bridges two or more types, I attempted to determine which part of the site a sample was taken from.

*Taxa Dated*: The Taxa Dated is the scientific name; genus and species is the preferred level of identification. Where a specimen was not identifiable at the species level, genus or family names are given. For materials reported as a common name rather than scientific, I looked up the scientific name, except for cases where more than one family was represented (i.e., "sotol, agave, and yucca-type"). If no attempt was made to identify the taxa, the field is left blank. If identification was attempted, but could not be determined, "indeterminate" is listed.

*Material Dated*: Here I generally use the material indicated by the reporting archaeologist, in their terms, be it the sample material type or the artifact type (e.g., sandal). Where "charcoal" is the only information reported, it may be safe to assume that the reporter means wood charcoal, but it is up to the radiocarbon analyst to determine how comfortable they are making that assumption; I do this on a case-by-case basis.

*Measured Age and Sigma*: This is the raw $^{14}C$ measurement reported by the radiocarbon lab in RCYBP. The standard error is given to one sigma. Determining whether a radiocarbon age given in a publication is measured or conventional (normalized) was often difficult, especially for assays from the University of Texas lab. After much back-and-forth, I verified that pre-1978 UT assays were measured by reviewing archived lab records. For legacy data from other labs, I assume that the measured age was reported unless noted otherwise.

In recent decades, how labs report radiocarbon ages have changed. DirectAMS, for example, does not report measured ages and only provides conventional (normalized) ages. Beta Analytic, however, continues to report measured ages in addition to conventional/normalized ages. When the age type is not made clear in a report, I contacted the assaying lab to inquire about how their data was reported through time, which sometimes proved helpful, and sometimes not.

*Normalized Age* and *Sigma*: This is the conventional age given in RCYBP, with the standard error given to one sigma. As discussed in previous chapters, the conventional age is normalized for isotopic fractionation and must meet other standards outlined in Stuiver and Polach (1977). For legacy data, where only the measured age was given, the normalized age is calculated using estimated $\delta^{13}C$ values based on the material type using Stuiver and Reimer's (2016) methods.

*Delta $^{13}C$* and *Delta $^{13}C$ Source*: As described in previous chapters, the $\delta^{13}C$ is the ratio of $^{13}C$ to $^{12}C$ used to correct measured radiocarbon ages to account for isotopic fractionation. The value is given in parts per thousand (per mille). The Delta $^{13}C$ Source can be either estimated or measured. For measured values, I indicate whether the measurement is AMS and IRMS when it is known.

*Additional Information*: Additional information about sample measurement and pretreatment are listed here. This includes measurement method and method of pretreatment.

*Stratigraphic Component*: Listed here is the name of the stratigraphic unit from which the sample was taken, and other intra-site provenience, such as unit, level, or depth.

*Context*: Listed here are feature numbers and types. In instances where the term "hearth" was used by the reporter, I referred to other contextual information to determine whether the feature likely represented an earth oven heating element, burned rock midden, or some other discreet thermal feature.

*Associated Taxa*: Other botanical and faunal remains associated with the date may be listed here. For example, if a dated sandal footbed it made of sotol fibers, but the tie strings have been identified as yucca, yucca will be listed as an associated taxa. For publications with detailed botanical analyses, often much more information is listed in the publication than in this database.

*Collector* and *Date Collected*: The collector, in the strict sense, is the person who collected the sample in the field. Undoubtedly, the collector was sometimes reported as the field director or principle investigator by the journal *Radiocarbon*. For this database, whomever was published as the collector was listed, though it may not be the person who physically excavated the sample material. The Date Collected is either the specific date on which the sample material was excavated, or a year or range of years the excavation was underway. The exact date collected was sometimes found in original field notes, though tracking down these data was not a priority.

*Submitter* and *Date Submitted*: When original lab records were available, I listed the name of the person to whom the lab report was addressed as the Submitter. In other cases, I assumed that the submitter was the same person who directed and reported the excavation. The exact date submitted proved to be nearly impossible to pin down, so I simplified it to the year submitted. When this could not be deduced, I listed a range of possible years based on the time between collection and publication.

The database also includes the *Date Type* (i.e., archaeological, geological, or paleontological), *References*, and *Comments*. The CARD template also has fields for site location information (i.e., UTM coordinates), which is restricted information so is not reported in this thesis. The calibrated date ranges (cal BP at 2σ) are presented in the database as well. Conventional (normalized) ages were calibrated using OxCal v4.3 (Bronk Ramsey 2009) and the IntCal13 calibration curve (Reimer et al. 2013).

### *Ancient Southwest Texas Project Assays*

Four assays were made for this thesis—two from Eagle Cave, one from Kelley Cave, and a single unprovinienced assay, possibly from an unrecorded site referred to as Guy Skiles' Storage Shelter (Stephen Black, personal communication 2017). In addition, one sample was selected from curated NPS collections from Arenosa Shelter excavation; this assay did not yield a date. Nonetheless, the sample is discussed here. The four successful samples were pretreated at CAR and assayed at DirectAMS.

New assays (n=100) from recent (2011-2019) Ancient Southwest Texas Project excavations are reported here. These are from excavations at Eagle Cave, Bonfire Shelter, Kelley Cave, Tractor Terrace Midden, Rancid Cactus Midden, Hibiscus (or Spool) Shelter, and Horse Trail Shelter, as well as assays from Skiles Shelter (Bryan Heisinger's 2019 thesis, concurrently published). New ASWT assays are not reported in depth, other than those made for this thesis, because analysis is ongoing. Contextual elaboration and interpretation for these ASWT assays will be presented in future publications. The five assays made for this thesis are presented in Table 2, and all newly reported ASWT assays are presented in Table 3, as well as in Appendix A.

Previously reported ASWT assays from Skiles Shelter and Kelley Cave (Rodriguez 2015), Eagle Cave (Nielsen 2017), Sayles Adobe (Pagano 2019), Little Sotol (Knapp 2015), and Torres Ranch House and the Lone Star Bridge Site (Basham 2015) are listed in the database, and are not included in Table 3. However, important changes to many of these previously reported ASWT assays include the conventional ages, which were originally mis-calculated using estimated $\delta^{13}C$ values.

Table 2. Assays made for this thesis.

| Sample Number | Other ID | Material | $^{14}C$ Age (RCYBP) | cal BP (2σ) | Provenience | Site |
|---|---|---|---|---|---|---|
| DAMS-027494 | FN32829/ CAR-613 | *Prosopis* sp. (mesquite) charcoal | 4081 ± 27 | 4805-4446 | PS020, Strat 238 | Eagle Cave |
| DAMS-027495 | FN33250/ CAR-614 | Charred *Agave lechuguilla* | 3523 ± 27 | 3877-3709 | PS020, Strat 358 | Eagle Cave |
| DAMS-027496 | FN10509 | *Agave lechuguilla* in fiber bundle | 506 ± 23 | 546-507 | Feature 4 area | Kelley Cave |
| DAMS-027497 | SCP-268 | Bison hair | 361 ± 21 | 495-319 | N/A | Skiles Collection |
| N/A | AMIS-24346 | *Bison* cf. *antiquus* radius | No date | | Feature 19, Strat 42, Silt Zone 4 | Arenosa Shelter |

*Thesis Assays: Eagle Cave (DAMS-027494 and DAMS-027495)*

Eagle Cave is a large dry rockshelter located in Eagle Nest Canyon with well-preserved organic artifacts and substantial earth oven facilities, investigated by ASWT 2013-2017. I collected the sample material for these two Eagle Cave assays (DAMS-027494 and DAMS-027495) during ASWT excavations in 2016. The sample taxa were identified by Kevin Hanselka. In 2017, the samples were pretreated by Raymond Mauldin and I, and in 2018, assayed at DirectAMS. I followed these samples through most of the radiocarbon dating process, from collection in the field and pretreatment, to delivery to DirectAMS, where I witnessed the first steps of the assay process.

The two Eagle Cave samples were chosen to better understand the timing and use-life of a small, fiber lined pit (Figure 3) encountered during excavation of sampling column Unit 84, which removed a portion of Profile Section 20 (PS020). The pit feature (no feature number has been assigned) was not visible in PS020, until it was revealed by excavation of the sampling column. Radiocarbon samples were taken from the profile after the sampling column was removed.

A radiocarbon sample (FN33250) was taken from the pit fill stratigraphic unit (hereafter, "strat") 358 (S0358) directly from the profile. In the field, S0358 was described as "loose, silty, botanic-rich, charcoal flecked sediment overlaying intact plant remains, which line the pit," and was characterized as anthropogenically mixed. The pit fill did not appear to be disturbed by rodent burrows. Materials found in S0358 included debitage, uncharred botanical remains, charcoal, fire cracked rock, and a coprolite. Charred lechuguilla from the pit fill (DAMS-027495) dates to 3877-3709 cal BP (3523 ± 27 RCYBP).


Figure 3. Fiber lined pit in corner of Unit 84, in profile.

The plant-matter lining the pit (S0373) was also sampled from the profile after excavation of Unit 84. Though cf. *Condalia viridis* leaves comprised the bulk of the pit lining, a *Yucca torreyi* seed was also collected, and selected for radiocarbon assay (DAMS-018144) by Charles Koenig and Steve Black. The seed returned a date of 3064-2885 cal BP (2861 ± 24 RCYBP), incongruously younger than the pit fill. The incongruities of the dates may point to rodent burrowing or mixing, or simply gravity as refuse fell into the pit. In hindsight, the selection of the leaves, versus the seed, would have been a better choice for dating the pit lining.

Assay DAMS-027494 was a sample of mesquite (*Prosopis* sp.) wood charcoal (FN32829), collected directly from PS020, Strat 238, which overlies the pit feature. This strat was identified in the eastern part of the profile prior to excavation of the sampling column. It was described as sloping and fiber-rich, with flecked charcoal, small rocks, and scattered fire cracked rock. It did not appear mixed, evidenced by large, delicate, horizontally-bedded cut leaf bases. However, the strat was surrounded by krotovinas to the "east, west, and above, and through middle." The strat was described again during excavation of Unit 84. Though krotovinas were encountered during unit excavation, they were easily separated from intact material. Artifacts found in the strat include faunal bone, lithic debitage, uncharred botanical remains, and possible coprolitic material. The mesquite charcoal sample (DAMS-027494) returned a date of 4805-4446 cal BP (4081 ± 27 RCYBP). This date is unexpectedly early compared to the date returned on the pit fill. This could be attributed to old wood effects. However, old wood effects alone cannot explain the age discrepancy between the pit fill and the charcoal sampled from the overlying strat. Throughout the Eagle Cave excavations, pains were taken to collect radiocarbon samples from the most secure portions of the deposit. However, unrecognized mixing is the most likely explanation for this anomalously early age. The seeming defiance of the law of superposition encountered in this small pit feature is an example of the stratigraphic complexity encountered in dry rockshelters.

Pretreatment for both of the Eagle Cave radiocarbon samples (DAMS-027494 and DAMS-027495) was done at CAR in November 2017. Unused portions of the sample material are curated at Texas State University. Acid-base-acid pretreatments were undertaken for both samples; the acid solution removes carbonates introduced by ground water or sediments, and the base removes soil humics (Taylor and Bar-Yosef 2014:93). The final round of acid removes any $CO_2$ that is incorporated during base treatment. A balance must be struck in thoroughly removing contaminants, yet not destroying the sample material in the process. My notes on pretreating these samples are below, in gross detail for the benefit of the curious reader.

For DAMS-027494, Mauldin selected the largest fragment of wood charcoal. We began pretreatment by putting the charcoal in 6N HCl acid on heat for 15 minutes, which caused the acid to become darker and yellowish in color. This dirty acid was poured off, and the test tube was refilled with more 6N HCl and heated for another 15 minutes. After this second round, the acid was clear. It was poured off, and the charcoal was rinsed with Type 1 water (hereafter referred to as water) three times. The sample then was treated with 0.02 NaOH. The sample did not react to this base solution, so this was poured off and a stronger base (0.1 NaOH) was added and returned to heat for 20 minutes. This step was repeated twice. The base was then poured off, the sample rinsed once in water, and then set in water on heat for a few minutes before being rinsed again. Finally, the sample was treated with 0.5 HCl for 40 minutes on heat, before being rinsed with water and dried. The sample weight was 36.2 mg after pretreatment.

In pretreatment, the *Agave lechuguilla* sample (DAMS-027495) proved to be more reactive and finicky than the wood charcoal sample. Mauldin and I began by separating the sample into three aliquots (CAR-614 A, B, and C). The acid treatment began with 6N HCl for 15 minutes, on heat. Before heating, the lechuguilla fizzed in the acid; the fizzing was reduced when put on heat but some lechuguilla became suspended in the foam and got stuck to the side of the test tube—a clean stir stick was used to poke it down. After heating, it was set aside to cool in the hopes the stringy plant fibers would settle to the bottom, allowing the acid to more easily be poured off. At this stage, the acid was dark and opaque (Figure 4).

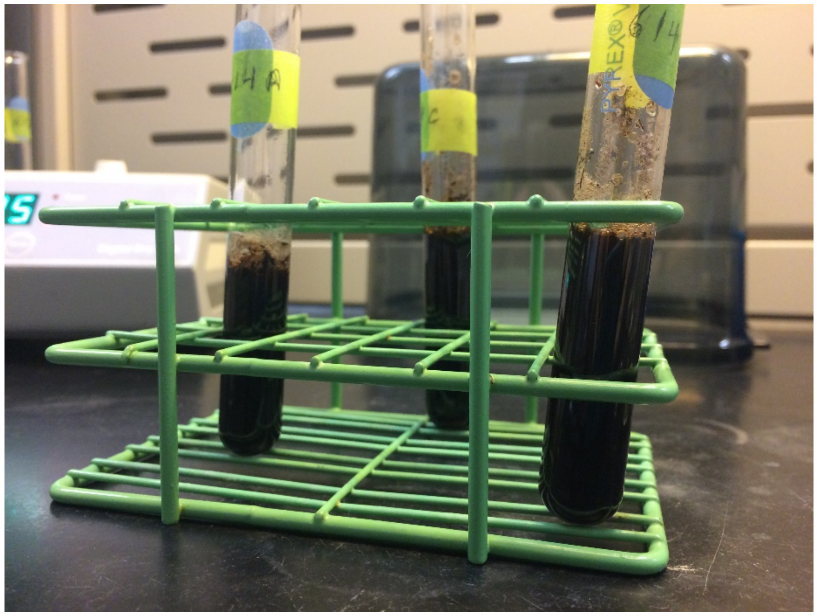

Figure 4. Pretreatment of DAMS-027495, first acid step.

After pouring off the dirty acid, the acid step was repeated. After the second round of acid, aliquot B was dark but mostly clear, C was dark and opaque, and A fell somewhere between these. The acid step was repeated for a third time. Aliquots A and B were transparent and brown and C was very dark but no longer opaque. Aliquot C was given a fourth round of acid while A and B were rinsed with water, centrifuged, and poured off. Aliquot C was then rinsed and centrifuged as well. Then all three aliquots underwent another round of acid and heat for 15 minutes, followed by three water rinses. The lechuguilla fibers were then treated with base (0.02 NaOH) diluted with water, and heated for 20 minutes. However, aliquot C didn't react to the base, so the strength was increased to 0.1 NaOH for aliquot C, which caused the solution to discolor; a little water was added to dilute the NaOH. The base step was repeated, with approximately five parts 0.02 NaOH diluted with one-part water. After base treatment, the aliquots were poured off, rinsed, and put in water on the heater for a few minutes. They were then rinsed four more times. The base was then repeated for a final round, using 0.02 NaOH. Aliquot C continued to color the base, while A and B did not (Figure 5). They were then rinsed five more times. I was not present for the final pretreatment steps of these samples, which were completed by Raymond Mauldin. After drying, the aliquots were recombined into one sample. The sample weight was 22.2 mg after pretreatment.

Figure 5. DAMS-027495, lechuguilla fibers, after base treatment.

*Thesis Assay: Kelley Cave (DAMS-027496)*

Kelley Cave is a dry rockshelter in Eagle Nest Canyon, protected from rain and all but the most extreme flooding, which has not occurred in recorded history. For this thesis, a single assay was made on a sample of lechuguilla leaf (DAMS-027496) extending from a prickly pear pad pouch (FN10509) bound with fiber cordage (undoubtedly made from an evergreen rosette fiber) (Figure 6). This sample was selected for radiocarbon assay by Stephen Black. It is relevant to my research question regarding the use of evergreen rosettes for fiber goods.


Figure 6. Fiber bundle (FN10509) from Kelley Cave, sampled for radiocarbon dating (DAMS-027496).

In 2014, this fiber pouch was excavated by Kevin Hanselka in Layer 3, north of Profile Cut 4A, at the top of a Rio Grande flood drape (Layer 4) (see figures in Rodriguez 2015:132, 136). The pouch was CT scanned to investigate its contents without damaging the artifact; it was found to contain an apical *Agave lechuguilla* stem with attached leaves. The sample returned a date of 546-507 cal BP (506 ± 23 RCYBP). This date agrees with the stratigraphy; two radiocarbon assays from Sub-layer 3C (FN1600; DAMS-005233 and DAMS-005234, in Rodriguez 2015), when averaged and calibrated using OxCal's R_Combine tool, return a 2σ date range of 636-540 cal BP. The fiber pouch dates overlap with the Sub-layer 3C dates at 2σ, suggesting contemporaneity.

The lechuguilla leaf sample (DAMS-027496) was pretreated at CAR. Mauldin divided the sample into three aliquots, saving one to the side. I cut the two samples to be pretreated with a scalpel to create more surface area, for more thorough cleaning. The two aliquots were covered in 6N HCl and put on heat for 11 minutes. The dark yellow-brown acid was poured off and refilled with clean acid and returned to heat for five minutes. After this second round, the acid was pale yellow. The acid was again replaced and returned to heat for eight minutes; this step was repeated twice, after which the acid did not color. The aliquots were rinsed four times in water, and then put in 0.02N NaOH for 15 minutes. After ten minutes, the base was diluted with a little water because it was coloring darkly. This base step was repeated two more times, each time with decreasing dilution. It was then rinsed and immersed in water, on heat, for 11 minutes. This was repeated twice. Two more rounds of base extraction followed (0.02N NaOH for 15 minutes, and 0.1N NaOH for 15 minutes). The aliquots were then rinsed in water four times. A final acid extraction (N/2 HCl for 40 minutes) was followed with four rinses with water. The specimen was then set to dry.

*Thesis Assay: Unprovinienced Bison Hair (DAMS-027497)*

A sample of bison hair was selected for radiocarbon dating by Stephen Black. The assay applies to my research question regarding the timing of bison in the region. The sample was purportedly removed several decades ago from a small, unrecorded rockshelter overlooking Eagle Nest Canyon, referred to as Guy Skiles Storage Shelter. The sample comes from the Skiles family collection, currently on loan to the Center for Archaeological Studies, where more of the hair is cataloged as SCP-268. The sample (Figure 7) was given to Black for radiocarbon dating by Jack Skiles, prior to the collection coming to the university. Bison rancher Zach Peoples recognized it as seasonally shed winter coat (personal communication 2017). However, the taxon has not been confirmed with microscopic analysis. The hair was dated to 495-319 cal BP.


Figure 7. Bison hair, prior to pretreatment for radiocarbon dating (DAMS-027497).

Archaeological hair samples are unusual materials to pretreat, so I researched methods for pretreating other keratin-based materials, and Mauldin and I did a practice run on modern bison hair given to us by Hugh Fitzsimons at Thunder Heart Bison. Articles referenced to help us formulate our pretreatment method include these: for pretreating skin, parchment and leather (Brock et al. 2010), parchment (Brock 2013), and bone collagen, silk, wool, and hair (Boudin et al. 2013). Based on best practices established in these publications, Mauldin and I followed an acid-base-acid protocol.

The archaeological specimen was pretreated in February 2018 over the course of a week. Mauldin began pretreatment by cleaning the sample in water and placing it in a sonicator to gently agitate the specimen, removing sediments clinging to the hair. It was pretreated with NaOH, and the strength of the acid was adjusted as necessary. Afterwards, it was rinsed in water. A week later I began the base treatment. After dividing the sample into four aliquots, I took the smallest and put it in 0.02 NaOH at 80°C for ten minutes. After five minutes the hair became slightly translucent. Water was added to the base, and the aliquot was centrifuged in get the hair to settle at the bottom of the test tube, to make pouring off the solution easier. Ultimately, the solution was removed with a pipette before pouring off, to mitigate loss of sample material during pouring. Rinsing and centrifuging was undertaken four times. The following acid treatment (N/2 HCl) caused the hair to clump together; this acid was immediately poured off, and the test tube refilled with acid and put on heat at 80°C for 20 minutes. It was then rinsed four times and dried. Having shown this method worked for the archaeological specimen, as well as the modern one, the final three aliquots were treated in the same manner. After drying, the samples were recombined and apportioned for radiocarbon assay; 0.0112 g of hair went to DirectAMS for measurement.

*Assay and Measurement at DirectAMS*

In March 2018, I traveled to the DirectAMS facilities in Bothell and Seattle, Washington. In Bothell, Director of Laboratory Operations Alyssa Tate and Director of Archaeological Services Brittany Hundman gave me a tour of the pretreatment and graphitization laboratories, describing the steps they take in sequence to clean and reduce whole, chemically complex sample materials to elemental carbon (graphite) for measurement by the accelerator mass spectrometer (AMS). When samples are received, they are photographed, apportioned, and pretreated. My three botanical samples, already pretreated, were apportioned for combustion. Approximately 0.002 g of the wood charcoal, 0.003 g of the charred lechuguilla, and 0.005 g of the uncharred lechuguilla were apportioned for combustion; the more carbonized the material, the less needed. Combustion entailed $CO_2$ being released from the sample and trapped. The samples then underwent gas transfer, and finally reduction to graphite on a heat block. The graphite was then pressed into instrument-specific aluminum cathodes and transferred to the Seattle lab for measurement.

In Seattle, I was given a tour of the AMS facility by Jonathan Heile, Director of AMS Operations. The lab operates a National Electrostatics Corporation 1.5 SDH Compact Pelletron Accelerator Mass Spectrometer. The graphite-filled cathodes are loaded into a wheel, along with control cathodes. Controls include blanks that accompanied the unknown samples for measuring background contamination and quantifying fractionation that could occur in chemical pretreatment and handling, "dead" graphite to measure any background contamination and fractionation in the accelerator, and reference standards, such as C7 and C2, which contain known levels of carbon. The wheel into which the cathodes were loaded can fit up to 134 cathodes, though the lab routinely measures smaller subsections than this because a full wheel takes several days to measure, during which accelerator may be influenced by minor environmental changes. The wheel is loaded into the ion source, where it is bombarded by a beam of cesium ions under vacuum. The liberated carbon isotopes then travel down the beamlines and into the mass analyzer, which splits the ion beam into $^{12}C$, $^{13}C$, and $^{14}C$. The carbon isotope currents are then measured in faraday cups. Each cathode is measured multiple times and a weighted average is taken. The ratio of carbon isotopes is used to calculate the fraction of modern carbon and the radiocarbon age. Measurements taken on the control cathodes are used to normalize the raw, measured isotope ratios. DirectAMS reports the fraction of modern carbon in percent Modern Carbon (pMC) and conventional (normalized) age in RCYBP (Scott et al. 2007; Stenström et al. 2011). DirectAMS does not routinely provide the $\delta^{13}C$ as measured on the sample graphite by the AMS during measurement, as it is too often confused by archaeologists as equivalent to an IRMS $\delta^{13}C$ measurement taken on the unprocessed original sample material. However, upon request, they supplied ASWT with the AMS $\delta^{13}C$.

*Unsuccessful Thesis Assay: Arenosa Shelter Bison Bone*

While the four radiocarbon samples discussed thus far were not wholly my choosing, this sample was. I was interested in radiocarbon dating bison from Arenosa Shelter, a well stratified terrace site now inundated by Amistad Reservoir, for several reasons. Foremost, it applies to my research question regarding the timing of bison presence, and is timely given new work being undertaken at Bonfire Shelter, the legendary bison jump site. Second, it makes use of the extensive collections of curated material from the Amistad salvage era. Third, it answers Dering's call for more radiocarbon sampling from well-stratified Lower Pecos deposits (2002:6.11).

Potential samples were selected by faunal analyst Christopher Jurgens and I. Initially, I proposed sampling two specimens from the Arenosa Shelter's oldest excavated features: a *Bison antiquus* maxilla fragment (AMIS#16066 VP#3264) from Feature 18 and a *Bison antiquus* radius fragment (AMIS#24346 VP#3266) from Feature 19. Ultimately, only the Feature 19 specimen was submitted for radiocarbon dating, though a date was not obtained due to poor collagen returns. Nonetheless, the steps taken in pursuit of these assays are described below.

Arenosa Shelter was excavated in the middle and late 1960s by the Texas Archeological Salvage Project during the NPS-funded archaeological salvage in advance of Amistad Reservoir (Dibble 1967). Arguably, Arenosa Shelter is best known for having remarkably deep and stratified flood and cultural deposits, which have yielded information on regional Holocene hydrogeologic patterns (Patton and Dibble 1982), lithic technologies (Collins 1974) and use of animals for food and tools (Jurgens 2005). The proposed samples came from Features 18 and 19, which are in the lowest excavated strata of the site, stratigraphically below the lowest extant radiocarbon assay (Tx-668, 9550±190 RCYBP). Feature 18 was comprised of the disarticulated anterior portion of a young adult male *Bison antiquus* carcass, found in association with a limestone cobble and small limestone slab (Jurgens 2005:267-274). No definite cultural materials were found in association with the bison, though the limestone cobble and slab are anomalous in the otherwise fine-grained sand matrix (Jurgens 2005:309), possibly indicating human activity. Feature 19 was comprised of *Bison antiquus* longbone fragments. Other Pleistocene fauna were present in the same layer. It is unclear if people were involved in butchery of Feature 19, due to a lack of associated cultural materials (Jurgens 2005:15). Some of the bone from Feature 19 exhibits carnivore damage, however, Jurgens also identified a possible cultural cut mark in his analysis (Jurgens, unpublished dissertation data).

Permission from the National Park Service and the Texas Archeological Research Lab (TARL) were secured to date these specimens. As a requirement of dating these irreplaceable bones, high resolution 3D models were generated via CT scan by Deborah Cunningham at Texas State University's Grady Early Forensic Anthropology Laboratory (GEFARL). Both surface and slice data were generated. However, the surface data was too high resolution to be 3D-printed at the University of Texas at Austin's facilities, so lower resolution surfaces were generated by Devora Gleiber (at GEFARL) for this purpose. Both surface and slice data are on file at TARL and GEFARL. As of this writing, no 3D prints have been made.

Due to technical difficulties with the 3D models and the crunch of thesis deadlines, the decision was made to assay only the Feature 19 specimen (AMIS-24346). The specimen had been consolidated with Elmer's glue in the field in the 1960s. However, Jurgens believes the glue did not permeate the bone due to moisture in the bone. In 2000, Jurgens consolidated the bone with Gelva/polyvinyl acetate (PVA). Because only a portion of the bone was to be sent for sampling, the specimen needed to be taken apart (unconsolidated). After consulting with Penn State University's AMS Radiocarbon Facility (Penn State), where the specimen would be sent for assay, I immersed the bone in reagent grade acetone for approximately 5 mins; the bone came apart easily. Undoubtedly, PVA remained on the bone, to be removed during pretreatment at Penn State. The bone fragment with possible cut marks was separated from the remainder of the specimen and returned to TARL, along with some small crumbles of bone which had not been immersed in acetone.

After pretreatment at Penn State, the sample was processed with XAD purification. The XAD method isolates amino acids and provides more confident measurements (see Lohse et al. 2014). Penn State lab analyst Maggie Davis first sampled 1g of dense cortical bone for XAD purification, with poor results. Davis wrote, "a normal XAD sample produces a sticky amino acid liquid that looks something like maple syrup, whereas your sample looked more like dry table salt" (Margaret Davis, personal communication 2019). This sample was sent for stable carbon and nitrogen isotope ratios to confirm whether this amino acid extraction is indeed too poorly degraded for radiocarbon measurement. In the meantime, Davis repeated the XAD process with a 2g sample of the bone. Davis wrote, "When I tried to combust the XAD purified amino acids from your bone to create $CO_2$ for graphitization, almost no $CO_2$ gas was produced. This tells me that there isn't enough organic carbon in this bone to radiocarbon date."

If this project had succeeded, the Arenosa Shelter assay would be the first published Paleoindian assay on bison bone in the Lower Pecos. Published Paleoindian dates in association with bison (that is, not on the bone itself) are those from Bonfire Shelter and Cueva Quebrada. However, associated dates such as these are regarded by some as imprecise (e.g., Lohse et al. 2014:114). The Arenosa assay would have complemented other current projects in the Lower Pecos, such as Bonfire Shelter excavations and the recently completed excavations at Eagle Cave by ASWT, which are expected to contribute to our understanding of bison presence, the environment, and human behavior in the Lower Pecos, as well as in inter-regional bison studies.

*New ASWT Assays*

One hundred previously unpublished ASWT assays submitted by or on behalf of Stephen Black, and assays from Bonfire Shelter submitted by James David Kilby, are presented in Table 3. Assays are from Eagle Cave (n=26), Bonfire Shelter (n=18), Kelley Cave (n=14), Rancid Cactus Midden (n=10), Hibiscus (or Spool) Shelter (n=10), Tractor Terrace Midden (n=9), Skiles Shelter (n=10; concurrently published in Heisinger 2019), and Horse Trail Shelter (n=2), plus the unprovenienced bison hair assay reported in this thesis. See the database (Appendix A) for more data related to these assays. See Appendix B for lab reports for all ASWT assays except those from Bonfire Shelter.

Botanical identifications of the ASWT assays are by Phil Dering, Leslie Bush, and Kevin Hanselka. Jim Mead identified the sheep dung assay from Eagle Cave. Raymond Mauldin pretreated the majority of the samples, except those from Bonfire Shelter and the four Beta Analytic assays from Eagle Cave and Horse Trail Shelter. Contextual information was obtained from field records and project-specific databases, as well as personal communication with Charles Koenig, Bryan Heisinger, Stephen Black, Amanda Castañeda, and David Kilby. Analyses of these sites are still underway, and interpretations of contextual data may change after further analyses are completed.

All assays were measured by AMS. Ages given (RCYBP) meet conventional standards described in Stuiver and Polach (1977), and are presented as a median and standard error given to 1σ. Calibrated dates (cal BP) were calculated using OxCal v4.3 (Bronk Ramsey 2009) and the IntCal13 calibration curve (Reimer et al. 2013), and are presented as a 2σ range.

Table 3. New ASWT Radiocarbon Assays.

| Site Name | Lab No. | Sample ID | Material Dated | Sample Taxa | $^{14}C$ Age (RCYBP) | Cal BP ($2\sigma$) |
|---|---|---|---|---|---|---|
| Eagle Cave | Beta-445875 | FN34781 | mesquite wood charcoal | *Prosopis* sp. | 8270±30 | 9402-9134 |
| Eagle Cave | Beta-445876 | FN35575 | decomposed fiber and sediment | | 11200±40 | 13141-12997 |
| Eagle Cave | Beta-516053 | FN35784/ 35793 | sheep dung | | 10500±40 | 12590-12236 |
| Eagle Cave | DAMS-013530 | FN32514 | uncarbonized lechuguilla leaf | *Agave lechuguilla* | 6043±31 | 6971-6795 |
| Eagle Cave | DAMS-013532 | FN32520 | carbonized Texas Persimmon seed | *Diospyros texana* | 5762±30 | 6651-6487 |
| Eagle Cave | DAMS-013533 | FN32523 | wood charcoal, ring-porous hardwood | indeterminate | 2230±24 | 2330-2154 |
| Eagle Cave | DAMS-013534 | FN32525 | acacia wood charcoal, ca. 9 rings | *Acacia* sp. | 2226±24 | 2329-2153 |
| Eagle Cave | DAMS-013536 | FN32519 | carbonized prickly pear seed | *Opuntia* sp. | 2272±23 | 2349-2180 |
| Eagle Cave | DAMS-013537 | FN32522 | mesquite wood charcoal, ca. 12 rings | *Prosopis* sp. | 2902±27 | 3156-2955 |
| Eagle Cave | DAMS-013538 | FN32516 | uncarbonized sotol leaf | *Dasylirion texanum* | 4482±27 | 5290-4983 |
| Eagle Cave | DAMS-013539 | FN32517 | mesquite/acacia wood charcoal, ca. 8 rings | *Acacia* or *Prosopis* sp. | 6465±31 | 7432-7319 |
| Eagle Cave | DAMS-013541 | FN32524 | charred prickly pear seed | *Opuntia* sp. | 2343±25 | 2433-2325 |
| Eagle Cave | DAMS-018135 | FN33340 | blackbrush wood charcoal, 15-20 rings | *Acacia* cf. *rigidula* | 9024±52 | 10263-9935 |
| Eagle Cave | DAMS-018136 | FN34274 | guajillo wood charcoal, ca. 10 rings | *Acacia* cf. *berlandieri* | 5058±33 | 5905-5730 |
| Eagle Cave | DAMS-018137 | FN34555 | uncarbonized dropseed grass stem | cf. *Sporobolus* | 3728±28 | 4151-3985 |
| Eagle Cave | DAMS-018138 | FN34632 | semi-carbonized prickly pear seed | *Opuntia* sp. | 2038±22 | 2101-1927 |
| Eagle Cave | DAMS-018139 | FN34562 | acacia wood charcoal, 2 rings | *Acacia* sp. | 4450±41 | 5288-4882 |
| Eagle Cave | DAMS-018140 | FN34393 | agarita wood charcoal, ca. 5 rings | *Mahonia trifoliata* | 5808±41 | 6719-6496 |
| Eagle Cave | DAMS-018141 | FN34569 | carbonized honey mesquite endocarp | *Prosopis glandulosa* | 9305±49 | 10655-10298 |

Table 3. Continued

| Site Name | Lab No. | Sample ID | Material Dated | Sample Taxa | $^{14}C$ Age (RCYBP) | Cal BP (2σ) |
|---|---|---|---|---|---|---|
| Eagle Cave | DAMS-018142 | FN34219 | carbonized stem or rhizome | | 4468±27 | 5286-4975 |
| Eagle Cave | DAMS-018143 | FN34292 | uncarbonized spiny hackberry leaves | *Celtis ehrenbergiana* | 9121±33 | 10388-10221 |
| Eagle Cave | DAMS-018144 | FN33249 | uncarbonized yucca seed | *Yucca torreyi* | 2861±24 | 3064-2885 |
| Eagle Cave | DAMS-018145 | FN34600 | carbonized honey mesquite pod with endocarp | *Prosopis glandulosa* | 9168±30 | 10413-10241 |
| Eagle Cave | DAMS-018146 | FN33341 | carbonized honey mesquite endocarp and seed fragments | *Prosopis glandulosa* | 9026±32 | 10239-10177 |
| Eagle Cave | DAMS-027494 | FN32829 | mesquite wood charcoal | *Prosopis* sp. | 4081±27 | 4805-4446 |
| Eagle Cave | DAMS-027495 | FN33250 | charred lechuguilla fiber | *Agave lechuguilla* | 3523±27 | 3877-3709 |
| Bonfire Shelter | DAMS-027366 | FN60052a | charcoal | | 3111±38 | 3438-3218 |
| Bonfire Shelter | DAMS-027372 | FN60178 | bone (charred) | *Bison bison* | 2516±24 | 2740-2492 |
| Bonfire Shelter | DAMS-031257 | FN60242a | wood charcoal, twig | indeterminate | 6034±36 | 6980-6785 |
| Bonfire Shelter | DAMS-031258 | FN60242b | wood charcoal, twig | indeterminate | 5950±42 | 6885-6674 |
| Bonfire Shelter | DAMS-034547 | FN60295 | Hackberry seed | *Celtis* sp. | 12112±69 | 14145-13770 |
| Bonfire Shelter | DAMS-034548 | FN60312 | charcoal | | 12189±48 | 14240-13925 |
| Bonfire Shelter | DAMS-034549 | FN60329 | sediment | | 9834±46 | 11325-11184 |
| Bonfire Shelter | DAMS-031261 | FN60501a | wood charcoal | indeterminate | 4458±32 | 5288-4966 |
| Bonfire Shelter | DAMS-031262 | FN60501b | wood charcoal | indeterminate | 4359±36 | 5038-4849 |
| Bonfire Shelter | DAMS-031259 | FN60547 | wood charcoal, twig | indeterminate | 6034±36 | 6980-6785 |
| Bonfire Shelter | DAMS-034550 | FN60589 | charcoal/burnt matrix | | 9831±36 | 11291-11195 |
| Bonfire Shelter | DAMS-031260 | FN60591a | wood charcoal, twig | indeterminate | 4327±36 | 5027-4837 |
| Bonfire Shelter | DAMS-034551 | FN60593 | hickory wood charcoal | *Carya* sp. | 8579±35 | 9599-9491 |
| Bonfire Shelter | DAMS-034552 | FN60594 | juniper wood charcoal | *Juniperus* sp. | 9026±35 | 10242-10175 |
| Bonfire Shelter | DAMS-034553 | FN60600 | ashy sediment | | 7638±35 | 8537-8381 |

Table 3. Continued

| Site Name | Lab No. | Sample ID | Material Dated | Sample Taxa | $^{14}C$ Age (RCYBP) | Cal BP (2σ) |
|---|---|---|---|---|---|---|
| Bonfire Shelter | DAMS-034554 | FN60643 | burnt matrix | | 8843±41 | 10157-9738 |
| Bonfire Shelter | DAMS-034555 | FN60648 | charcoal | | 10115±51 | 11999-11405 |
| Bonfire Shelter | DAMS-034556 | FN60665 | charcoal | | 6830±36 | 7728-7590 |
| Kelley Cave | DAMS-010256 | FN10016 | acacia wood charcoal | *Acacia* sp. | 6530±33 | 7554-7335 |
| Kelley Cave | DAMS-010255 | FN10043 | wood charcoal | indeterminate | 10000±45 | 11705-11270 |
| Kelley Cave | DAMS-011114 | FN10043 | wood charcoal | indeterminate | 10025±34 | 11710-11331 |
| Kelley Cave | DAMS-027496 | FN10509 | plant fiber pouch contents | *Agave lechuguilla* | 506±23 | 546-507 |
| Kelley Cave | DAMS-011116 | FN10613 | uncarbonized yucca leaf | *Yucca* sp. | 540±26 | 632-516 |
| Kelley Cave | DAMS-010251 | FN10614 | uncarbonized wood bark | indeterminate | 753±27 | 728-666 |
| Kelley Cave | DAMS-011119 | FN10615 | uncarbonized yucca leaf | *Yucca* sp. | 564±29 | 644-525 |
| Kelley Cave | DAMS-010252 | FN10616 | uncarbonized wood bark | indeterminate | 583±19 | 642-540 |
| Kelley Cave | DAMS-011118 | FN10617 | carbonized sotol leaf base | *Dasylirion texanum* | 596±25 | 652-541 |
| Kelley Cave | DAMS-010253 | FN10618 | semi-carbonized sotol leaf base | *Dasylirion texanum* | 649±22 | 667-559 |
| Kelley Cave | DAMS-010254 | FN10621 | uncarbonized onion bulb cloak | *Allium drummondii* | 966±32 | 933-795 |
| Kelley Cave | DAMS-010249 | FN10625 | uncarbonized leaf epidermis | indeterminate | 746±29 | 727-662 |
| Kelley Cave | DAMS-010250 | FN10626 | uncarbonized agave leaf epidermis | *Agave lechuguilla* | 937±31 | 925-789 |
| Kelley Cave | DAMS-011115 | FN10626 | uncarbonized agave leaf epidermis | *Agave lechuguilla* | 1019±27 | 979-831 |
| Rancid Cactus Midden | DAMS-003362 | CS-11 | carbonized leaf | Agave, sotol, Yucca-type | 921±27 | 922-782 |
| Rancid Cactus Midden | DAMS-003363 | CS-12 | shin-oak wood charcoal | *Quercus sinuata* | 1035±26 | 1043-918 |
| Rancid Cactus Midden | DAMS-003364 | CS-13 | Texas persimmon wood charcoal | *Diospyros texana* | 1115±26 | 1070-958 |
| Rancid Cactus Midden | DAMS-003365 | CS-14 | sumac wood charcoal | *Rhus* sp. | 965±27 | 932-796 |
| Rancid Cactus Midden | DAMS-003366 | CS-15 | mesquite/acacia wood charcoal | *Acacia* or *Prosopis* sp. | 1193±27 | 1225-1011 |
| Rancid Cactus Midden | DAMS-003367 | CS-16 | desert olive wood charcoal | *Forestiera pubescens* | 933±27 | 921-791 |

Table 3. Continued

| Site Name | Lab No. | Sample ID | Material Dated | Sample Taxa | $^{14}C$ Age (RCYBP) | Cal BP (2σ) |
|---|---|---|---|---|---|---|
| Rancid Cactus Midden | DAMS-003368 | CS-17 | algerita wood charcoal | *Berberis trifoliata* | 1031±24 | 976-920 |
| Rancid Cactus Midden | DAMS-003555 | CS-18 | carbonized leaf | Agave, sotol, Yucca-type | 638±28 | 666-554 |
| Rancid Cactus Midden | DAMS-003556 | CS-19 | carbonized leaf | Agave, sotol, Yucca-type | 1007±22 | 965-831 |
| Rancid Cactus Midden | DAMS-003494 | CS-20 | carbonized "heart" | Agave, sotol, Yucca-type | 907±23 | 913-763 |
| Hibiscus Shelter | DAMS-003550 | CS-1 | carbonized leaf | Agave, sotol, Yucca-type | 730±24 | 702-655 |
| Hibiscus Shelter | DAMS-003493 | CS-10 | carbonized fibers | Agave, sotol, Yucca-type | 651±26 | 669-557 |
| Hibiscus Shelter | DAMS-003551 | CS-2 | carbonized leaf, fiber | Agave, sotol, Yucca-type | 1058±25 | 1050-927 |
| Hibiscus Shelter | DAMS-003552 | CS-3 | carbonized leaf | Agave, sotol, Yucca-type | 524±24 | 623-511 |
| Hibiscus Shelter | DAMS-003490 | CS-4 | carbonized prickly pear seed/achene | *Opuntia* sp. | 1847±27 | 1865-1713 |
| Hibiscus Shelter | DAMS-003553 | CS-5 | carbonized leaf, "heart" | Agave, sotol, Yucca-type | 4310±26 | 4960-4836 |
| Hibiscus Shelter | DAMS-003491 | CS-6 | carbonized fibers | Agave, sotol, Yucca-type | 1597±25 | 1544-1413 |
| Hibiscus Shelter | DAMS-003554 | CS-7 | carbonized fibers | Agave, sotol, Yucca-type | 1324±22 | 1297-1186 |
| Hibiscus Shelter | DAMS-003361 | CS-8 | fiber | Agave, sotol, Yucca-type | 1921±27 | 1930-1817 |
| Hibiscus Shelter | DAMS-003492 | CS-9 | desert olive wood charcoal | *Forestiera* sp. | 897±28 | 911-738 |
| Tractor Terrace Midden | DAMS-003369 | CS-26 | leaf | Agave, sotol, Yucca-type | 5065±28 | 5901-5745 |
| Tractor Terrace Midden | DAMS-003495 | CS-21 | fiber | Agave, sotol, Yucca-type | 1456±29 | 1394-1301 |
| Tractor Terrace Midden | DAMS-003496 | CS-23 | leaf | Agave, sotol, Yucca-type | 4874±31 | 5658-5583 |
| Tractor Terrace Midden | DAMS-003497 | CS-25 | leaf | Agave, sotol, Yucca-type | 1513±23 | 1519-1341 |
| Tractor Terrace Midden | DAMS-003498 | CS-30 | shin-oak wood | *Quercus sinuata* | 1763±26 | 1776-1571 |
| Tractor Terrace Midden | DAMS-003557 | CS-22 | leaf | Agave, sotol, Yucca-type | 2014±28 | 2041-1891 |
| Tractor Terrace | DAMS-003558 | CS-24 | leaf | Agave, sotol, Yucca-type | 1345±31 | 1310-1185 |

Table 3. Continued

| Site Name | Lab No. | Sample ID | Material Dated | Sample Taxa | $^{14}C$ Age (RCYBP) | Cal BP (2σ) |
|---|---|---|---|---|---|---|
| Tractor Terrace Midden | DAMS-003559 | CS-27 | fiber | Agave, sotol, Yucca-type | 1916±22 | 1922-1820 |
| Tractor Terrace Midden | DAMS-003560 | CS-28 | "heart" | Agave, sotol, Yucca-type | 4172±27 | 4830-4615 |
| Skiles Shelter | DAMS-010262 | FN20130 | carbonized leaf base | probably *Dasylirion* | 6500±36 | 7477-7323 |
| Skiles Shelter | DAMS-010263 | FN20153 | carbonized sotol leaf base | *Dasylirion texanum* | 858±26 | 898-696 |
| Skiles Shelter | DAMS-010264 | FN20164 | carbonized mesquite | *Prosopis* sp. | 715±26 | 692-570 |
| Skiles Shelter | DAMS-011120 | FN20163 | carbonized mesquite | *Prosopis* sp. | 707±23 | 687-570 |
| Skiles Shelter | DAMS-031626 | FN20070 | lechuguilla leaf fragment | *Agave lechuguilla* | 619±23 | 657-552 |
| Skiles Shelter | DAMS-031627 | FN20092 | mesquite wood charcoal (twig) | *Prosopis* sp. | 691±26 | 683-564 |
| Skiles Shelter | DAMS-031628 | FN20094 | carbonized lechuguilla leaf fragment | *Agave lechuguilla* | 796±27 | 759-675 |
| Skiles Shelter | DAMS-031629 | FN20129 | carbonized lechuguilla leaf fragment | *Agave lechuguilla* | 3460±31 | 3830-3641 |
| Skiles Shelter | DAMS-031630 | FN20148 | carbonized lechuguilla leaf fragment | *Agave lechuguilla* | 1067±28 | 1053-929 |
| Skiles Shelter | DAMS-031631 | FN20152 | acacia wood charcoal | *Acacia* sp. | 1079±31 | 1057-932 |
| Horse Trail Shelter | Beta-448091 | 41VV166H205 | bone collagen | *Homo sapien* | 1730±30 | 1708-1564 |
| Horse Trail Shelter | DAMS-018387 | 41VV166H205 | bone collagen | *Homo sapien* | 1789±18 | 1812-1625 |
| Unprovinienced | DAMS-027497 | SCP-268 | bison hair | *Bison* sp. | 361±21 | 495-319 |

### ***Discussion of Lower Pecos Canyonlands Data Set by Laboratory***

Below is an overview of the complete Lower Pecos data set, organized by assaying laboratory. It is helpful, when swimming in a sea of archaeological publications, to grasp the histories of the lab and the period in which the assays were made in order to more readily understand how things were reported. Some critiques of the Lower Pecos data set are presented here, but comments on specific dates are in the database (Appendix A). The lab number prefix is given next to the lab name, in parentheses.

#### *Humble Oil and Refining Company (O)*

The first assay made on Lower Pecos materials was measured at this lab in Humble, Texas. Humble Oil and Refining Co. was eventually subsumed by Exxon. The radiocarbon lab was in operation by 1957; the only two available radiocarbon date lists from this lab were published in 1957 editions of *Science*. The lab was used for geological assays as well as archaeological. Measurements were made by proportional counting of carbon dioxide. Based on scant references to the lab, it seems to have been short lived. The dates reported by Humble Oil are likely measured values. The single Lower Pecos assay made at the Humble lab, from Eagle Cave, is problematic because it is a composite sample, and is therefore excluded from my analyses.

#### *University of Texas (Tx)*

One-hundred and forty-four Lower Pecos assays were made by the University of Texas (UT) radiocarbon laboratory in Austin. This radiocarbon lab was in operation from 1960-1988 (Jackson School of Geosciences, the University of Texas at Austin 2019).

Radiocarbon measurements were made by liquid scintillation counting of benzene. The lab reported measured ages to 1σ, unless otherwise noted. Measurement results were published in *Radiocarbon* until 1988, albeit not exhaustively, and often included comments made by the submitters.

Sites represented in the UT assays include Arenosa Shelter (n=22), Baker Cave (n=8), Bonfire Shelter (n=15), Cammack Sotol Pit (n=2), Centipede Cave (n=5), Conejo Shelter (n=11), Coontail Spin (n=6), Devils Mouth (n=3), Devil's Rockshelter (n=1), Eagle Cave (n=15), Fate Bell (n=3), Hidden Shelter (n=2), Hinds Cave (n=30); Hodge Site (or Dead Goats Site; n=1), Mummy Shelter (n=1), Nopal Terrace (n=1), Perry Calk (n=3), Piedra del Diablo (n=1), Skyline Shelter (n=11), Techo Bajo (n=2), and one unprovenienced Lower Pecos assay.

Most of the UT assays are considered legacy data, meaning assay and reporting standards were different than current standards; the material type is generally poorly reported, and it is often unclear whether assays are bulk (composite) samples from across a large area. Additionally, association of the assay with various projectile point types was more robustly reported than the sample context, in many instances.

A major problem encountered with the UT data was uncertainty about whether correction for isotopic fractionation was undertaken. In 1972, UT began prefacing their *Radiocarbon* date lists with the statement, "Except where noted, C12 /C13 measurements have not been made, and results are not corrected for C13 fractionation" (Valastro et al. 1972:461). This continued until 1978. In 1979, the lab began prefacing the list with a slightly different statement: "Unless noted, 12C/13C measurements were not made and results are not corrected for 13C fractionation (assumed ratio= -25‰ WRT PDB)"

(Valastro et al. 1979). In this publication, one can find reported assays with measured $\delta^{13}C$ values (e.g., 1979:264). This modified statement continued until their final date list was published in 1988. At the outset, it was not clear to me whether corrections were being made using an estimated value of -25‰ starting from ca. 1979 onward, or if estimated corrections began in 1972, or if the -25‰ correction was only being applied when noted.

To unravel this problem, I attempted to contact several past employees of the lab including Murry Tamers, a chemist affiliated with the UT lab who went on to found Beta Analytic, and Ernest Lundelius, also affiliated with the UT lab. Ultimately, the most fruitful correspondence was with the collection's manager for the archived lab documents at UT, Chris Sagebiel. After reviewing a handful of lab records, I believe that the UT assays were not corrected for $\delta^{13}C$ (either estimated or measured) at any point in time, unless explicitly noted. Uncertainty lingers, however, around why the *Radiocarbon* date lists indicated an estimated $\delta^{13}C$ of -25‰ beginning in 1979. If the estimated value of -25‰ was applied without indication of such, this is problematic not only because I am assuming they have not been previously corrected for isotopic fractionation and am correcting these ages myself, but also because this value of -25‰ is likely incorrect for faunal remains and for botanical materials other than wood.

*Geochron Laboratories (GX)*

Geochron Laboratories, A Division of Krueger Enterprises, Inc. is based in Cambridge, Massachusetts (Geochron Laboratories 2019a). It was founded in 1960 and continues to operate. The lab offers measurement by gas proportional counting and liquid scintillation, and they contract with other facilities to offer AMS measurement (Geochron Laboratories 2019b). Just one radiocarbon assay in the Lower Pecos data set was made at Geochron—a sample from Conejo Shelter on roasted juvenile lechuguilla leaves. I emailed the lab for details on their measurement and reporting routine ca. 1990, when the Conejo assay was made, and was told older records have been discarded and such information is not available (Robert Yriart, personal communication 2019).

*Smithsonian Institution (SI)*

Fourteen Lower Pecos assays were made by the radiocarbon lab at the Smithsonian Institution Radiocarbon Laboratory (SIRL) in Rockville, Maryland. The lab was associated with the Division of Radiation and Organisms, Astrophysical Observatory, and the Smithsonian Environmental Research Center (Smithsonian Institution 2019). SIRL was in operation from 1962-1986; in 1986 the lab was closed and the equipment, as well as some of the staff, moved to the University of Pittsburg. Radiocarbon measurements were made using gas proportional counters. Based on examples from their lab archives, it appears to me that SIRL reported measured ages, at least in the early 1970s. They ceased publishing date lists in *Radiocarbon* after 1973.

Sites represented in the SIRL assays are Arenosa Shelter (n=10), Goat Cave (n=2) and Moorehead Cave (n=2), all assayed between 1972 and 1973. These assays were not reported in *Radiocarbon* and were generally poorly reported in excavation reports. In hopes of filling the data gaps I contacted the Smithsonian Institution, and an archivist provided scans of the lab notes for these assays (Smithsonian Institution 1972-1973: Laboratory Notebooks). These lab notes were useful for confirming the age and discovering the date of assay but otherwise did not contain the data I sought. Two of the assays from Arenosa were considered anomalous by the reporters. The remaining are marginally useful (given they are poorly reported legacy data) for addressing the timing of earth oven use, fiber artifacts, or for population studies.

A single assay reported by Turpin (2018) from Shumla Caves as a SIRL assay proves problematic because the lab number ascribed to it is published in *Radiocarbon* as coming from a site in Iowa (Long and Mielke 1966). This assay is presented in the database but excluded from analyses.

*Radiocarbon, Ltd. (RL)*

Two Lower Pecos radiocarbon assays were measured at this lab, which was founded in 1969 in Spring Valley, New York and moved to Lampasas, Texas in 1974 (Tucek 1977). The lab is no longer in operation. Measurements were made using proportional counters measuring $CO_2$ and later benzene as well. Measurements were reported in *Radiocarbon* in 1971 and 1977, though the Lower Pecos assays, both from Baker Cave, post-date these lists. I could not determine whether Radiocarbon, Ltd. reported conventional or measured ages. The lab also reported MASCA-corrected dates to the submitters (e.g., Chadderon 1983:22; Hester 1983:104). MASCA is a now-defunct date calibration system. Due to the uncertainty of the type of age reported, these two assays are excluded from my analyses.

*University of California, Riverside (UCR)*

Two Lower Pecos assays were made at this lab, both from Shumla Caves. This lab was operated by the Department of Anthropology and Institute of Geophysics and Planetary Physics at the University of California, Riverside. The lab was built between 1970 and 1973 and began publishing *Radiocarbon* date lists in 1974. At that time, the lab operated a proportional gas counter. The lab closed in the early 2000s, and their equipment was relocated to other University of California labs (Anon 2003). Both Shumla Caves assays are excluded from the database due to inadequate reporting.

*Beta Analytic Testing Laboratory (Beta)*

Sixty-five Lower Pecos radiocarbon assays were made at the Beta Analytic Testing Laboratory (Beta Analytic) in Miami, Florida. Beta Analytic is a commercial lab founded in 1979 by Murry Tamers and Jerry Stipp (Beta Analytic 2019), both of whom were previously affiliated with the University of Texas radiocarbon lab. Beta Analytic is still in operation. The lab has both AMS and liquid scintillation counters (LSC). The lab reported both measured ages and conventional ages. IRMS $\delta^{13}C$ has been reported throughout the duration of Beta Analytic's operation, unless a given sample is too small to be measured with IRMS. However, until the early 1990s, IRMS measurement incurred an additional fee at Beta Analytic and many archaeologists chose to skip this analysis (Britt Bousman, personal communication 2019).

Lower Pecos assays from Beta Analytic include those from Baker Cave (n=3), Bonfire Shelter (n=4), Eagle Cave (n=3), Fate Bell (n=4) High and Dry Cave (n=2), Hinds Cave (n=3), Horseshoe Caves (also called Horseshoe Ranch Caves; n=5), Horse

Trail Shelter (n=1), Leaping Panthers (n=1), Lost Midden Site (n=9), Mummy Shelter (n=1), Seminole Sink (n=1), Shumla Cave (n=3), 41VV48 (n=1), 41VV661 (n=3), 41VV837 (n=1), 41VV1207 (n=2), 41VV1895 (n=4), 41VV1897 (n=5), 41VV2120 (n=1), 41VV2139 (n=1), 41VV2205 (n=1), 41VV2225 (n=1), and five samples from unknown provenience. The majority of these measurements are AMS, though there are a few LSC.

With the exception of the Shumla Caves and Fate Bell assays, the Lower Pecos samples assayed by Beta are problem-free. The Shumla Caves and Fate Bell assays are poorly reported (Turpin 2018), and thus excluded from my analyses. Three of the remaining assays are excluded from my analyses, including one (Beta-300561) reported with different ages and materials in two different publications, one new bulk sediment assay from Eagle Cave, and the Eagle Cave sheep dung assay. The dung assay is useful for certain discussions and analyses, but not those I am undertaking—it more likely dates a period of abandonment of the site, rather than a human activity relevant to my research questions.

Several of the Beta assays are on artifacts associated with bundled burials which include fiber artifacts (i.e., Turpin 2012a). Most of these came from uncontrolled excavations and are therefore poorly provenienced, however, the assays are useful for addressing the timing of the use of evergreen rosettes for fiber goods. A potential issue with fiber artifacts from legacy collections, however, is the application of conservation treatments. Without clear reporting of conservation treatments and the pretreatment methods used to remove them, discussion about whether these particular samples were contaminated by conservation treatments is conjectural.

*University of Arizona AMS Laboratory (A and AA)*

Seven Lower Pecos assays are from the University of Arizona AMS Laboratory, located in Tucson. This lab was founded in 1982. They are exclusively an AMS lab today, though at one point a conventional scintillation counting lab was present at the facility as well. Assays measured by AMS are given the prefix “AA,” and those counted by conventional scintillation are prefixed with “A.” Currently, the lab reports the conventional age and IRMS $\delta^{13}C$ (Gregory Hodgins, personal communication 2019).

The Lower Pecos samples assayed at the University of Arizona are from Seminole Sink (n=5) and Bonfire Shelter (n=2). Of the Seminole Sink assays, four are AMS and one was measured with scintillation counting. All assays from Seminole Sink are on human bone or cremated remains. The potential need for reservoir corrections for these bone assays has not been investigated. One of the AMS assays is considered problematic by Bement and Turpin, who note the date is incongruous based on the stratigraphy (1988:33).

The two Bonfire Shelter assays are from the 1980s, and though they are reported with the “AA” lab code, I am not absolutely sure whether or not they were measured by AMS (The scintillation assay from Seminole Sink was also reported with “AA” in the literature). In addition, the event that they are dating is uncertain, and it sounds like they may be bulk charcoal samples, precluding their inclusion in my analyses.

*Center for Accelerator Mass Spectrometry (CAMS)*

Twenty-two assays were measured at the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory, in Livermore, California. The lab has been in operation since 1987 (Lawrence Livermore National Laboratory 2019). As the name suggests, it is an AMS lab. The lab reports conventional radiocarbon ages. They do not standardly report $\delta^{13}C$, but if it is reported it is measured by AMS, not IRMS (Tom Brown, personal communication 2019).

Lower Pecos samples assayed at CAMS are from Hinds Cave (n=19) and Shumla Caves (n=3), all of which were assayed in the early-mid 2000s. These are well reported, replicated assays—a boon to this data set. The Hinds Cave materials, all associated with a bundle burial, were sampled by plasma oxidization at Texas A&M University followed by measurement at the Center for Accelerator Mass Spectrometry. The three Shumla Cave assays are on peyote effigies.

*W.M. Keck Carbon Cycle Accelerator Mass Spectrometer (UCIAMS)*

Forty-two Lower Pecos radiocarbon assays were made by this AMS lab, located at the University of California, Irvine. The Keck lab was established in 2002, and offers AMS services, as well as IRMS, and sample pretreatment (W.M. Keck Carbon Cycle Accelerator Mass Spectrometer 2019). The lab routinely reports the conventional radiocarbon ages. Twelve assays are from Little Sotol and thirty assays are recently dated from Conejo Shelter collections, all on sandals and coprolites. The Little Sotol assays are useful for addressing my research questions pertaining to timing of earth ovens and population fluctuations. The Conejo Shelter sandal assays substantially increase the sample size for addressing the manufacture of fiber artifact from evergreen rosette fibers.

*DirectAMS (DAMS or D-AMS)*

One-hundred and sixty-nine Lower Pecos radiocarbon assays were made by DirectAMS in Bothell and Seattle, Washington. Pretreatment and assay of archaeological samples are done at the Bothell lab, and measurement is done at the Seattle lab. DirectAMS was founded in 2006 (DirectAMS 2019), and like Beta Analytic, is one of the primary commercial radiocarbon labs in the country. As the name suggests, this lab specializes in AMS and does not offer conventional assay measurement. DirectAMS reports conventional radiocarbon ages. They do not report AMS $\delta^{13}C$ unless it is specifically requested. Unlike Beta Analytic, the lab accepts samples that are pretreated elsewhere.

Sites represented in assays from DirectAMS include Baker Cave (n=7), Bonfire Shelter (n=18), Eagle Cave (n=41), Hibiscus (or Spool) Shelter (n=10), Horse Trail Shelter (n=1), Kelley Cave (n=29), Little Sotol (n=3), Lone Star Bridge Site (n=4), Rancid Cactus Midden (n=10), Sayles Adobe (n=10), Skiles Shelter (n=15), Torres Ranch House Site (n=11), and Tractor Terrace Midden (n=9), as well as one sample from the Skiles' family private collection, which is likely from an unrecorded site colloquially referred to as "Guy Skiles' Storage Shelter." All these assays, other than the Baker Cave assays, were submitted on behalf of the ASWT Project by Raymond Mauldin. By and large, ASWT assays reported thus far are reported fairly well by the archaeologist, though inconsistencies exist, and some critical data are missing. Additionally, some previously reported ASWT assay ages were incorrectly reported using experimental age adjustments, rather than the conventional ages reported by the lab. These problems are remedied in the database.

*Tandem Laboratory/Uppsala AMS (Ua)*

Three radiocarbon assays were measured at the Tandem Laboratory, also referred to as Uppsala AMS, located at Uppsala University in Sweden. The university has hosted an AMS lab since at least the late 1980s (Possnert 1990). All three assays are AMS and were made on paleofeces from Hinds Cave. It is not clear whether the ages reported are conventional or measured, but given that they are relatively recent AMS assays, I assume the ages reported are conventional. My email inquiry for more information about the lab yielded no reply.

### ***Data Selection and Critical Evaluation***

After compiling the data, I evaluated the acceptability of the assays for inclusion in my analyses. To review, the criteria, discussed in Chapter 5, are that the sample must be archaeological, and that age, material type and context must be identified. Also, bulk (composite) samples, pictograph assays, and contaminated samples are excluded. Exceptions to the context criterion are made for poorly provenienced, but otherwise well-reported, samples and well-reported bulk samples from secure contexts. After vetting the data, they were sorted for applicability to my research questions.

While parsing the assays, I frequently ran into the problem of "gray areas" in the data—information which was not reported clearly, but that one could make educated assumptions about. Excluding such assays limits the data set, yet including them increases the uncertainty of the results. Ultimately, I decided I would run the earth oven models twice—once with the rigorously vetted data, and again with the inclusion of these lower confidence assays. The decision to include or exclude an assay was also contingent on the research question and method of analysis, described below.

*Population Fluctuations*

All Lower Pecos assays that met the basic criteria could be applied to population analyses using summed probability distributions (SPDs) of calibrated radiocarbon dates. Even context is not a concern for this analysis, so long as the assay is archaeological. However, factors stemming from the statistical method itself, discussed below, require consideration.

SPD analyses for evaluating relative population fluctuations rests on the assumption that the number of radiocarbon dates are reflective of the number of people inhabiting a place (i.e., more people = more archaeological deposits = more $^{14}C$ dates) (Rick 1987:55-56; Riris 2018:68-69). Rick (1987) was the first to apply radiocarbon dates to investigations of population change. He found apparent differences in pre-ceramic population trajectories, between highland and coastal Peru. Though the results of Rick's study have not stood the test of time, Rick pioneered a method of using large radiocarbon data sets to quantitatively investigate demographic changes in prehistory (Riris 2018:67). In the intervening decades, SPDs for investigating population change and other archaeological trends have been widely adopted (Williams 2012:578; Riris 2018:67). It has also been argued that the quantity of archaeological deposits correlates with energy expenditure, which may be related to economic complexity (Freeman et al. 2018:1). I argue that increased economic complexity also often correlates with population size (our own society is a good example).

Since the inception of SPDs using radiocarbon dates, problems and biases of the method have been recognized. Rick (1987) identified three points at which biases may be introduced into the SPD: difference between magnitude of occupation and deposition (e.g., different activity types will yield different deposits), difference between the original carbon deposit and archaeological deposit (i.e., preservation), and sampling bias introduced by the archaeologist (1987:57). Despite these, Rick argued that a large data set representing numerous sites across a region and sampled by several different investigators, should minimize biases and yield generalized population trends (1987:58).

Since Rick's 1987 publication, biases in SPDs have been investigated in greater depth. Surovell et al. (2009) investigated the complexities of organic preservation biases as a result of taphonomic processes. The authors found that a constant rate of site loss though time is very unlikely to accurately model taphonomic bias (Surovell et al. 2009:1716) and proposed that models based on terrestrial geologic deposits may be used to correct for taphonomic loss (2009:1723). Using terrestrial volcanic deposits as a proxy for open archaeological sites, Surovell et al. developed a global model for estimating taphonomic loss. They tested their model by comparing corrected open sites to uncorrected rockshelter sites (assumed to be negligibly affected by taphonomic loss) and found excellent correlation for the majority of the distributions (Surovell et al. 2009:1719). In the Lower Pecos, the problem of taphonomy can be circumvented by using only assays from rockshelter sites for constructing SPDs. That said, rockshelters also suffer from taphonomic processes, albeit to a much lesser extent than upland or terrace settings. Further, as demonstrated at Skiles Shelter (Heisinger 2019), temporal biases can be introduced into the archaeological record by earth oven pit construction, found in all large Lower Pecos rockshelters, which can destroy or displaces earlier deposits.

In 2018, Rick's study of coastal and highland Peru was revisited with a much larger data set and more sophisticated methods (i.e., Riris 2018). Riris compared highland and coastal SPDs with an exponential growth model and concluded that population trajectories in both data sets were similar (2018:74). Riris then compared the SPDs with environmental proxy data, and found that the trajectories sometimes, but not always, correlated with environmental change. Riris emphasized the importance of using model-testing to evaluate the statistical significance of the SPD, rather than simple visual inspection.

The usefulness of an SPD for accurately reflecting population change is dependent on the interrelated factors of sample size and median standard error of the data set. For example, an average standard error of 115 years for an entire data set is acceptable if the sample size is 780 assays (Williams 2012:580-581). The number of assays in the Lower Pecos data set is smaller than preferred for SPD analysis, and when restricted to those only from rockshelters, is further diminished. However, the average standard error of the rockshelter-only data set is small, approximately 60 years, so I elected to include all rockshelter assays (that meet the criteria; n=293) regardless of the size of the standard error.

Whether or not poorly reported legacy data should be included in the Lower Pecos SPD remains a conundrum. For many legacy assays it is not clear if they are bulk samples or not. Additionally, material type is often not listed beyond "charcoal." While it might be safe to assume most of these are wood charcoal samples, the question lingers unresolved. Ultimately, I opted to include these assays and noted in my evaluation section of the database that they were legacy dates, allowing for easy exclusion of them, for future reanalysis.

*Bison Timing*

To address the question of bison presence in the Lower Pecos, assays on bison remains—bone and hair—are preferred. However, an unfortunately tiny data set results from this criterion (n=5, assuming three Bonfire Shelter bone assays are on bison), limited further (n=2) by the exclusion of bone assays which do not meet modern standards. As a result, associated non-bison assays from secure contexts are also considered in the discussion. Due to the sample size—two assays directly on bison and seven assays purportedly associated with bison—statistical analyses on the bison data are not employed for this study.

*Fiber Artifacts*

To address the question of timing of fiber goods made with evergreen rosettes, sample selection was limited to those assays made directly on manufactured fiber artifacts (n=36). Many of these are from unprovenienced Lower Pecos collections. I debated whether to include assays on fiber goods that were not identified taxonomically (n=27), and ultimately chose to include them. Contributing to this decision is the overwhelming use of evergreen rosette succulents for manufacture of goods such as matting, basketry, cordage, and sandals, as reported in Andrews and Adovasio (1980) and as I have seen firsthand working with the Skiles family collection. If distinctive materials such as grasses, sedges, cane, reeds, or prickly pear were used in construction of a fiber object, I assume that the reporter will mention them.

### *Earth Oven Plant Baking*

Critical evaluation of assays to be included in my analyses of earth oven plant baking proved to be challenging. Assays on quids and coprolites are clear evidence of the eating of these plants. Assays on charred plants and charcoal from earth oven facilities have a high probability of being associated with plant baking. However, interpretation of the context of the assays often proved challenging, requiring educated guesses as to whether a given specimen was the product of plant baking, or some other activity. In some cases, the sample context was not clearly linked to plant baking, but the assay was on an evergreen rosette leaf, heart, or seed. Wanting to draft a high-confidence model of earth oven plant baking in the Lower Pecos, yet also wanting to include as many assays as possible, I ultimately decided to run my analyses twice, for comparison. In the more conservative, rigorously vetted model only assays on quids, coprolites containing evergreen rosette fossils, and charred botanicals from earth oven facilities were used (n=103). In the second analyses, assays on evergreen rosette plants not clearly associated with plant baking, as well as charcoal assays which are possibly related to earth oven cooking, were incorporated (n=204). The results of these analyses are presented in the next chapter.

# VI. ANALYSES AND DISCUSSION

This chapter begins with a discussion of biases in the radiocarbon data and other observations about the data. Subsequently, the analyses targeting the research questions presented in Chapters 3 and 5 are presented. Finally, the results of the analyses are synthesized with each other and with environmental proxy data and discussed.

Of the 1911 sites currently recorded within the boundaries of the Lower Pecos Canyonlands, assays from 50 sites have been radiocarbon dated (Figure 8). All the dated sites are in Val Verde County, Texas. The total number of radiocarbon assays compiled for this thesis is 463.

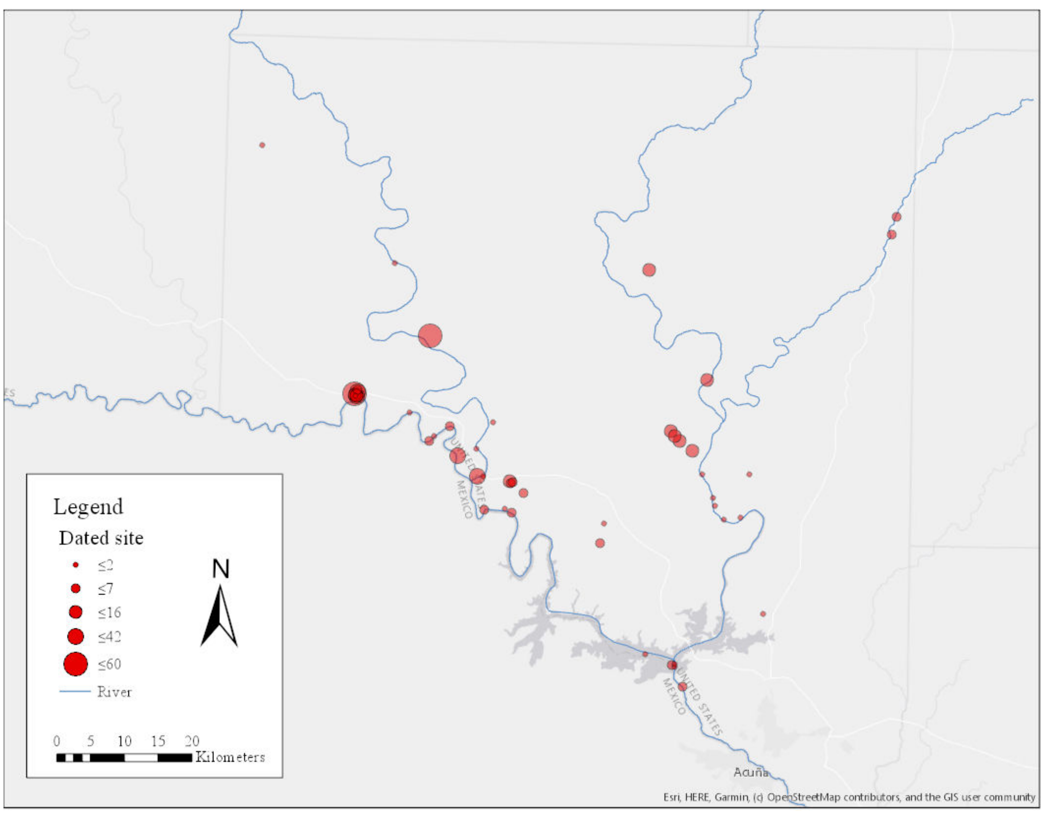


Figure 8. Lower Pecos sites with radiocarbon dates. Graduated circles correspond with quantity of radiocarbon assays from each site.

As shown in the preceding figure, most dated Lower Pecos sites are near river corridors. The stacked circles in the western portion of the map represent the extensive excavations in Eagle Nest Canyon. Sites away from river corridors have relatively few assays.

Approximately three-fourths of Lower Pecos assays are from rockshelters (n=345), with assays from terrace sites (n=80) and upland sites (n=42) comprising the remaining quarter (Figure 9). Unprovenienced samples account for approximately 1% of the Lower Pecos assays (n=7).

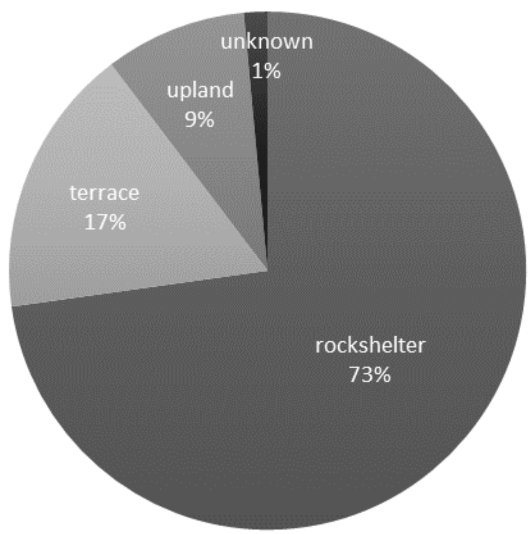


Figure 9. Percentage of assays from rockshelter, terrace, and upland sites, and from unprovenienced collections (unknown).

Over half of the Lower Pecos assays are from just six sites: Eagle Cave (n=60), Hinds Cave (n=55), Bonfire Shelter (n=39), Conejo Shelter (n=39), Arenosa Shelter (n=32), and Kelley Cave (n=29) (Figure 10). Most of these sites were excavated out of academic interest rather than archaeological salvage, and even those that were excavated for Amistad Reservoir salvage were also reported in dissertations.

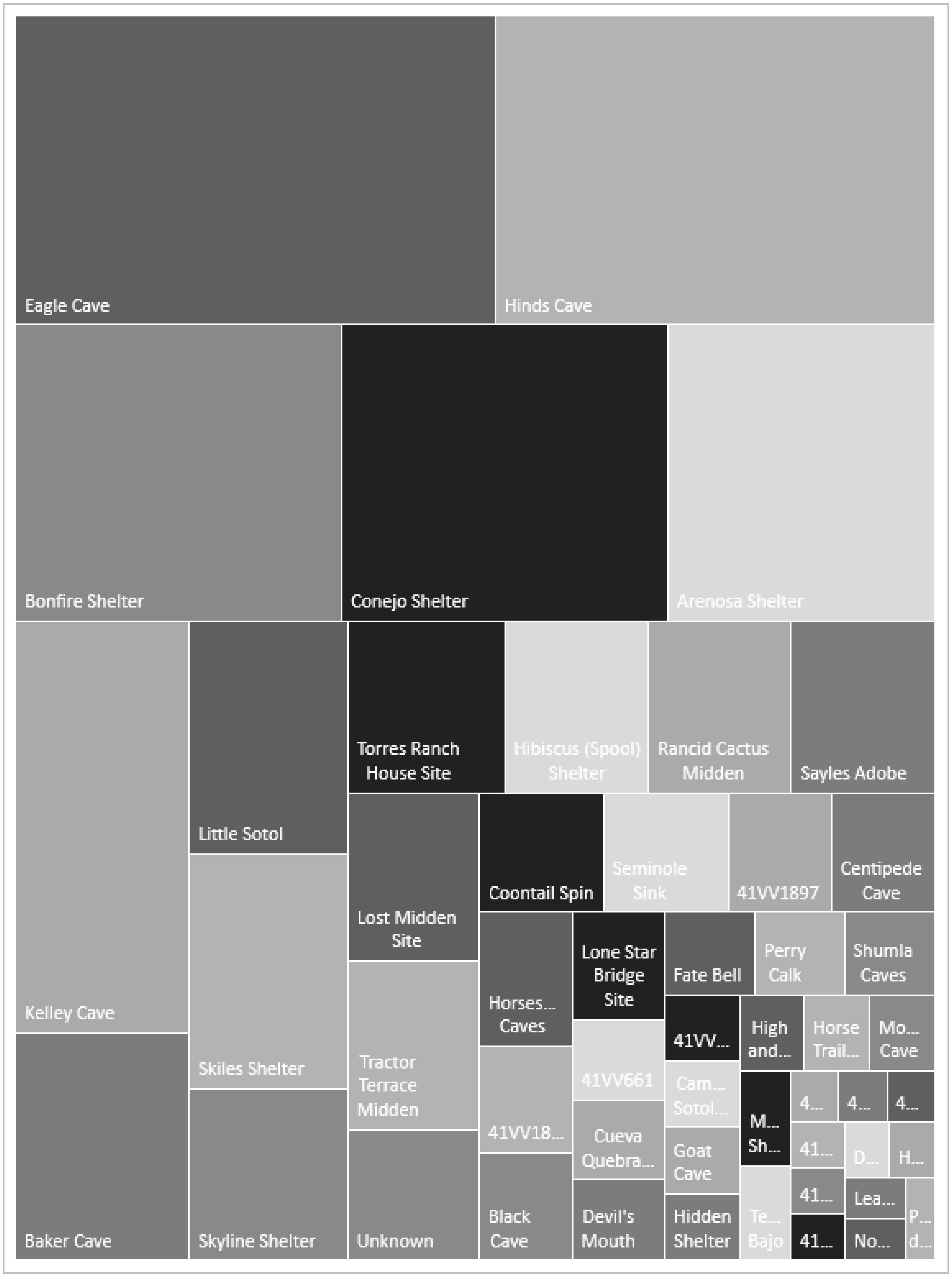


Figure 10. Relative quantity of assays by site; the majority of assays come from just six Lower Pecos sites.

Assays measured by AMS comprise approximately 60% of the data (n=290). Legacy assays comprise approximately 30% of the data (n=147). In spite of the relative abundance of modern assays, problems with reporting by the archaeologist remain common. Material types are insufficiently reported (i.e., charcoal) or are not reported at all (35% of the assays; n=166), and taxa was not identified for approximately 55% of the assays (n=256). Stratigraphic information was not reported for 41 assays. However, the majority of these are from human burials unsystematically exhumed by residents in the early part of the 20th century, though some were excavated by archaeologists. Admittedly, the original publications in which some assays were reported (as cited in Turpin 1991) proved rare and hard to locate, which may account for the lack of contextual or other information in the database, for those few assays. Despite these problems, only 68 assays are completely excluded from my analyses due to not meeting the basic criteria—14% of the data set. However, many assays used in my analyses suffer from one reporting issue or another.

***Analyses***

In this section the results of my analyses are presented. As previously discussed, analyses preformed include:

- Bayesian modeling of earth oven assays to investigate the timing of earth oven use for evergreen rosette plant baking (i.e., sotol, lechuguilla, yucca),
- Bayesian modeling of assays on fiber goods such as sandals, matting, and basketry made from evergreen rosette plants commonly baked in earth ovens, and

- a summed probability distribution (SPD) to investigate relative population fluctuations through time.

There are insufficient assays to model the timing of bison. However, bison presence in the region is discussed using the scant extant data.

After vetting the data, those selected for analyses were calibrated using OxCal v4.3 (Bronk Ramsey 2009) and the IntCal13 calibration curve (Reimer et al. 2013). Age ranges are given in calibrated years Before Present (cal BP) as 2σ (95% confidence) ranges, unless noted otherwise, and are presented in the database (Appendix A). In the proceeding sections, modeled dates are given in italics to differentiate them from unmodeled dates.

To investigate the impact of the newest calibration curve (IntCal13) on previously published split-sample dates, I used the R_Combine command in OxCal v4.3 to average assays that purportedly date the same event. Additionally, R_Combine was used to reevaluate assays that had been averaged previously, including duplicated University of Texas assays that had been published under one lab number (i.e., Tx-622, Tx-629, Tx-633, Tx-140) and more recent assays reported both individually and as a weighted average (i.e., Steelman et al. 2004 and Terry et al. 2006). The results of this exercise was by and large very minor variation (around a decade, give or take a few years) in the calibrated age ranges compared to the original reporting. However, an unanticipated effect of this exercise was finding that a handful of assays which purportedly date the same event have non-overlapping calibrated date ranges. These include previously averaged split-sample assay Tx-622, and Eagle Cave assays DAMS-010257/DAMS-011113 and DAMS-017956/DAMS-017957. Because the Eagle Cave DAMS assays are on individual seeds, as opposed to being from a single organism which was split in two parts, they will remain in the analyses. However, I chose to exclude Tx-622 from the analyses because I do not have enough information about the assay to evaluate why the results are non-overlapping.

A Bayesian approach to chronological modeling is presented in Chapter 4. As discussed, a visual evaluation of radiocarbon data often results in an overestimate of the duration of the archaeological event of interest, resulting in “a fuzzy prehistory which floats timelessly across centuries, an impression of change playing out over similarly extended timescales” (Whittle et al. 2011:19). That said, the Bayesian analysis method I am employing is intended to evaluate the start and end of earth oven plant baking and evergreen rosette fiber artifact manufacture, not to deduce fluctuating use of these technologies at a high resolution.

The Bayesian models and SPD were created with OxCal v4.3 (Bronk Ramsey 2009) and the IntCal13 calibration curve (Reimer et al. 2013). Bayesian OxCal models use a Markov chain Monte Carlo (MCMC) random sampling technique. As a result of this technique, model results will vary slightly each time the model is run. The OxCal Chronological Query Language (CQL) code is presented as digital supplementary material in Appendix C, so that the reader may re-run these analyses. As with all radiocarbon models, the results are interpretive estimates and will change with the addition of new information or when modeled with other methods. As noted, modeled dates are italicized in the proceeding sections to differentiate them from unmodeled dates.

Agreement indices and convergence integrals are calculated by OxCal each time the models are run. Agreement indices are “a measure of the agreement between the model (prior) and the observational data (likelihood)" (Bronk Ramsey 2019a). A minimum value of 60% is desired for agreement indices. The convergence integral is a measure of the effectiveness of the MCMC algorithm and is given for each date as well as the phase start and end. A value above 95% is desired for the convergence interval.

*Earth Oven Bayesian Phase Models*

As discussed in Chapter 5, earth oven plant baking is modeled twice—once using the radiocarbon data which are confidently correlated with earth oven use (n=103) and again incorporating additional lower-confidence assays (n=101) with the data confidently correlated with earth oven plant baking. The lower-confidence data are those assays which have insufficiently reported contextual information (yet are likely associated with earth ovens) or are assays directly on evergreen rosettes (i.e., sotol, lechuguilla, and yucca) but are not clearly linked to earth oven facilities (e.g., not found in earth oven or burned rock midden strata). Justifications for inclusion or exclusion of specific dates are given in the database (Appendix A).

The higher-confidence earth oven model (Figures 11 and 12) estimates a beginning of earth oven plant baking between *10732-10275 cal BP* (95% probability) and likely between *10562-10316 cal BP* (68% probability). The end of earth oven plant baking is estimated at *261 cal BP* through present (*-145 cal BP, or AD 2095*) (95%), and likely between *214 and 2 cal BP* (68%). The agreement index is $A_{model}$=86.1% and $A_{overall}$=88.8%. The convergence interval of the phase is 95.8% (start) 96.9% (end). A multiplot of the modeled data are broken across five pages (Figure 12).

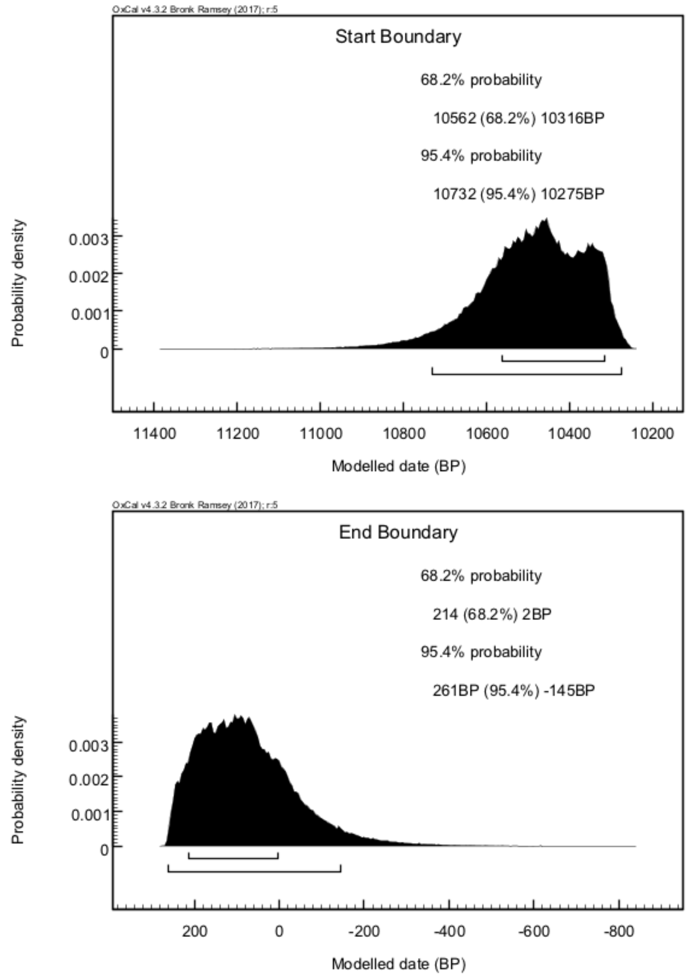


Figure 11. Estimated start and end ranges of LPC earth oven plant baking, modeled using the higher-confidence radiocarbon data.

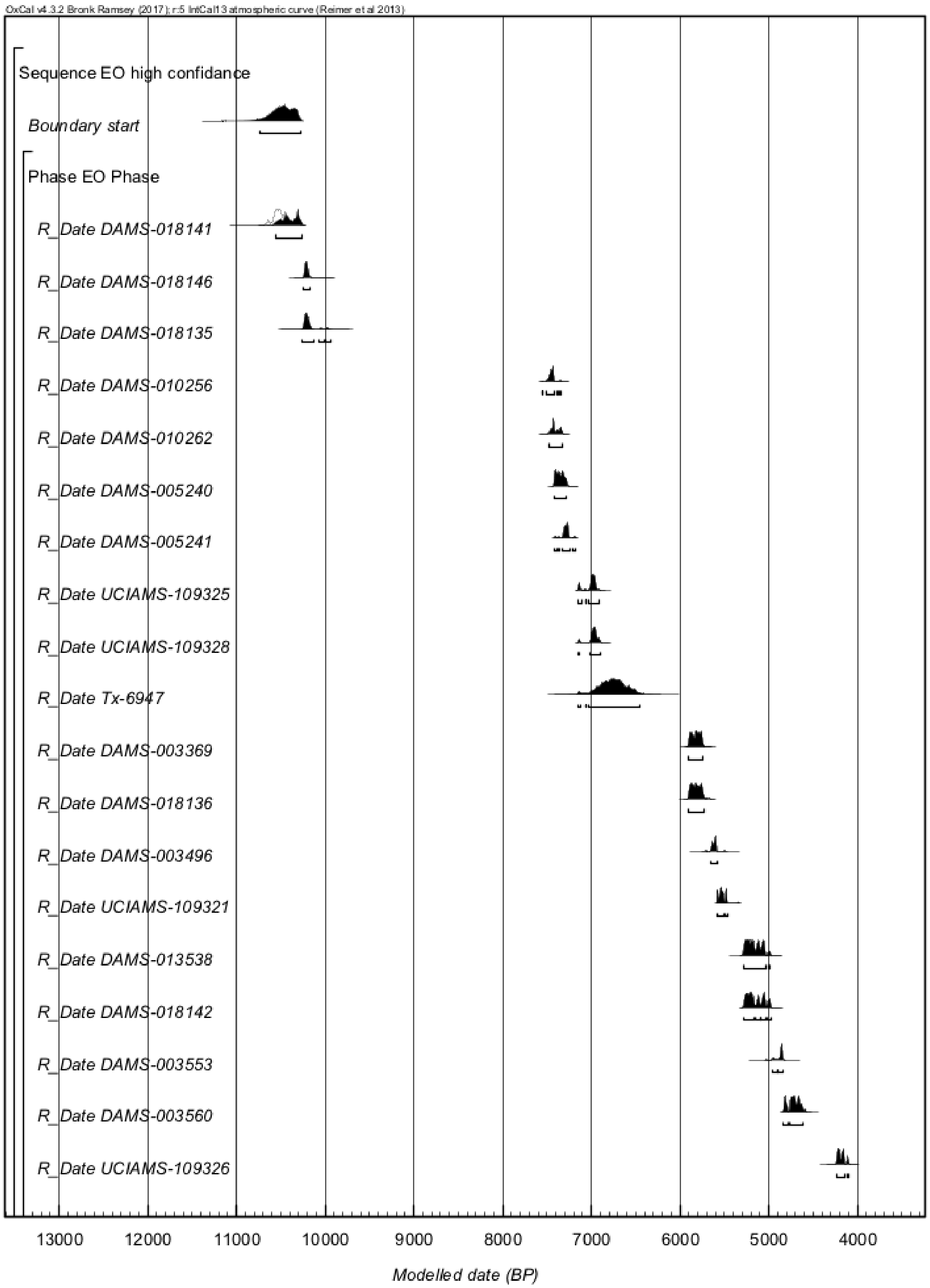


Figure 12. Modeled probability distributions for dates from high-confidence data from LPC earth oven contexts. Brackets illustrate the 95% (2σ) probability ranges for each date. Unmodeled likelihoods (unmodeled, calibrated distributions) are shown in outline, as seen most clearly in the assays which date closest to the start and end range.

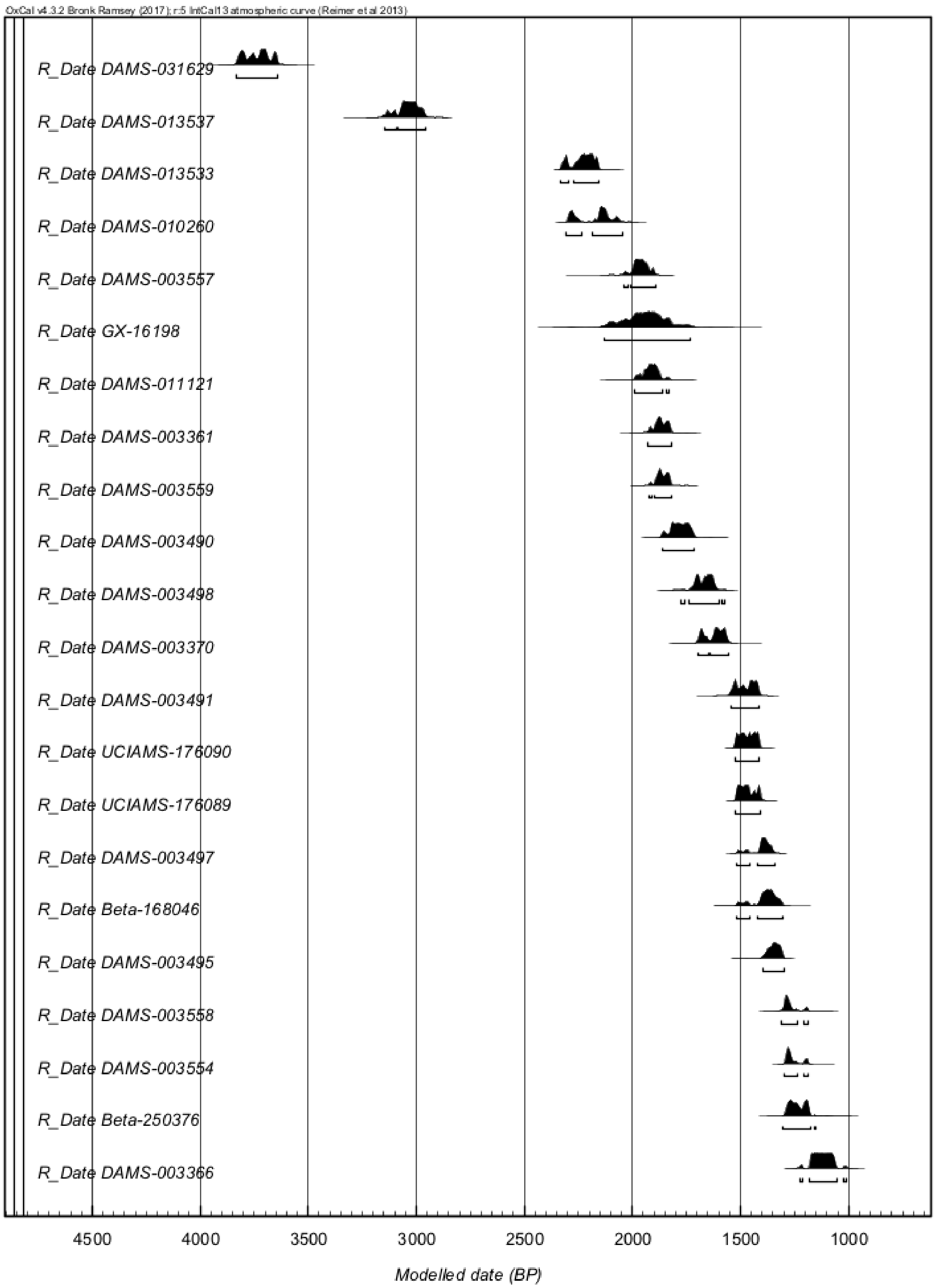


Figure 12. Continued

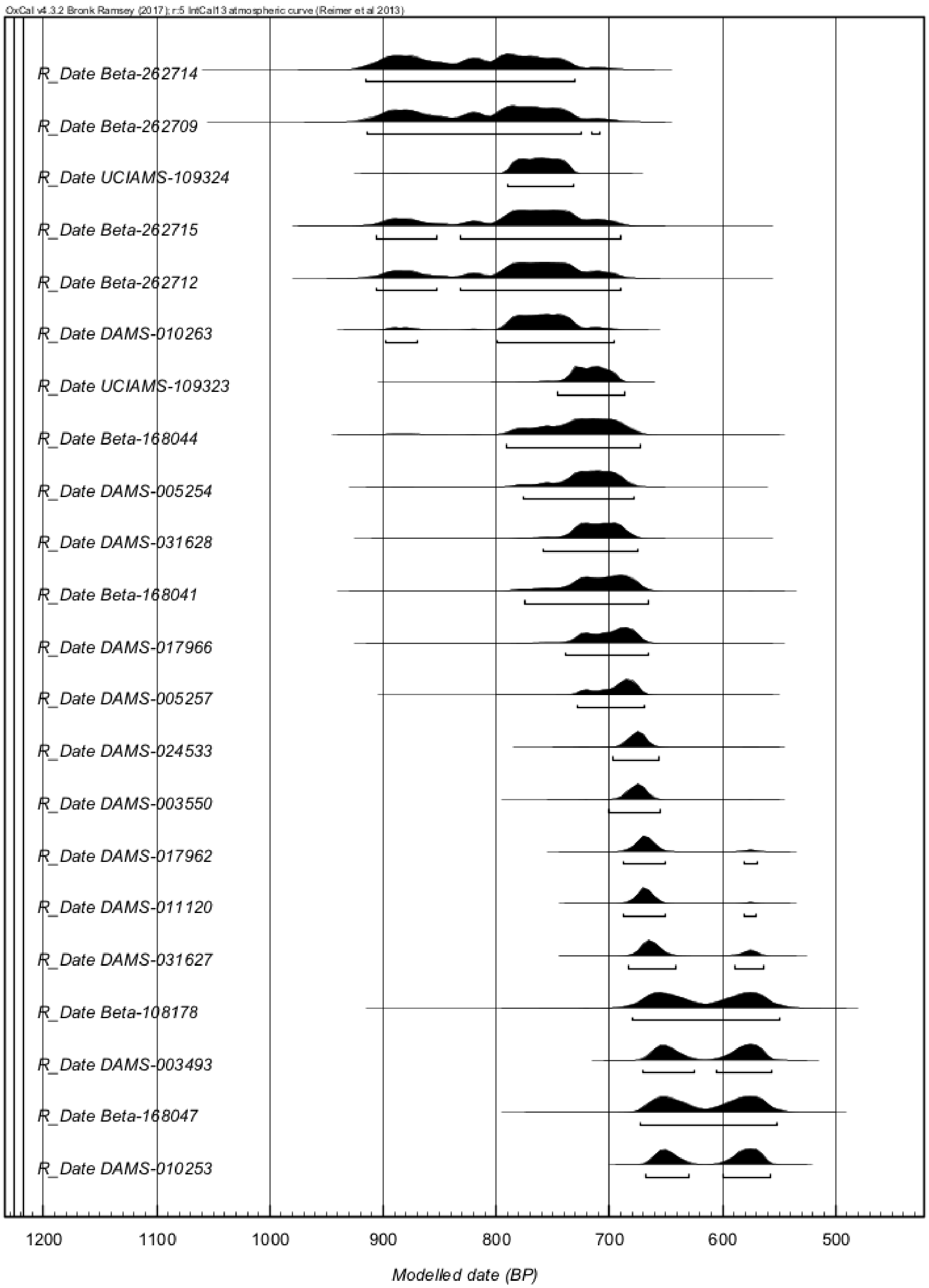


Figure 12. Continued

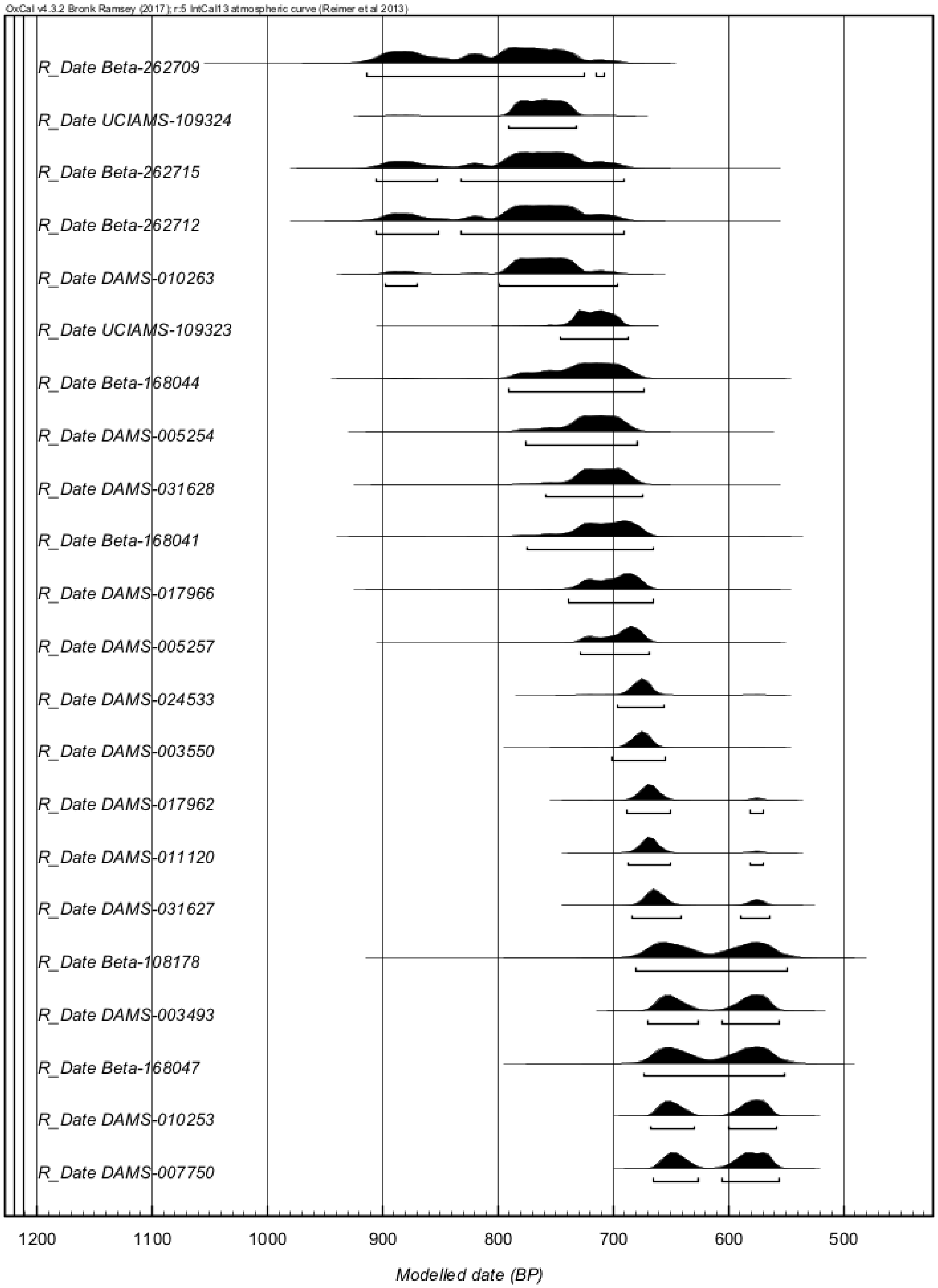


Figure 12. Continued

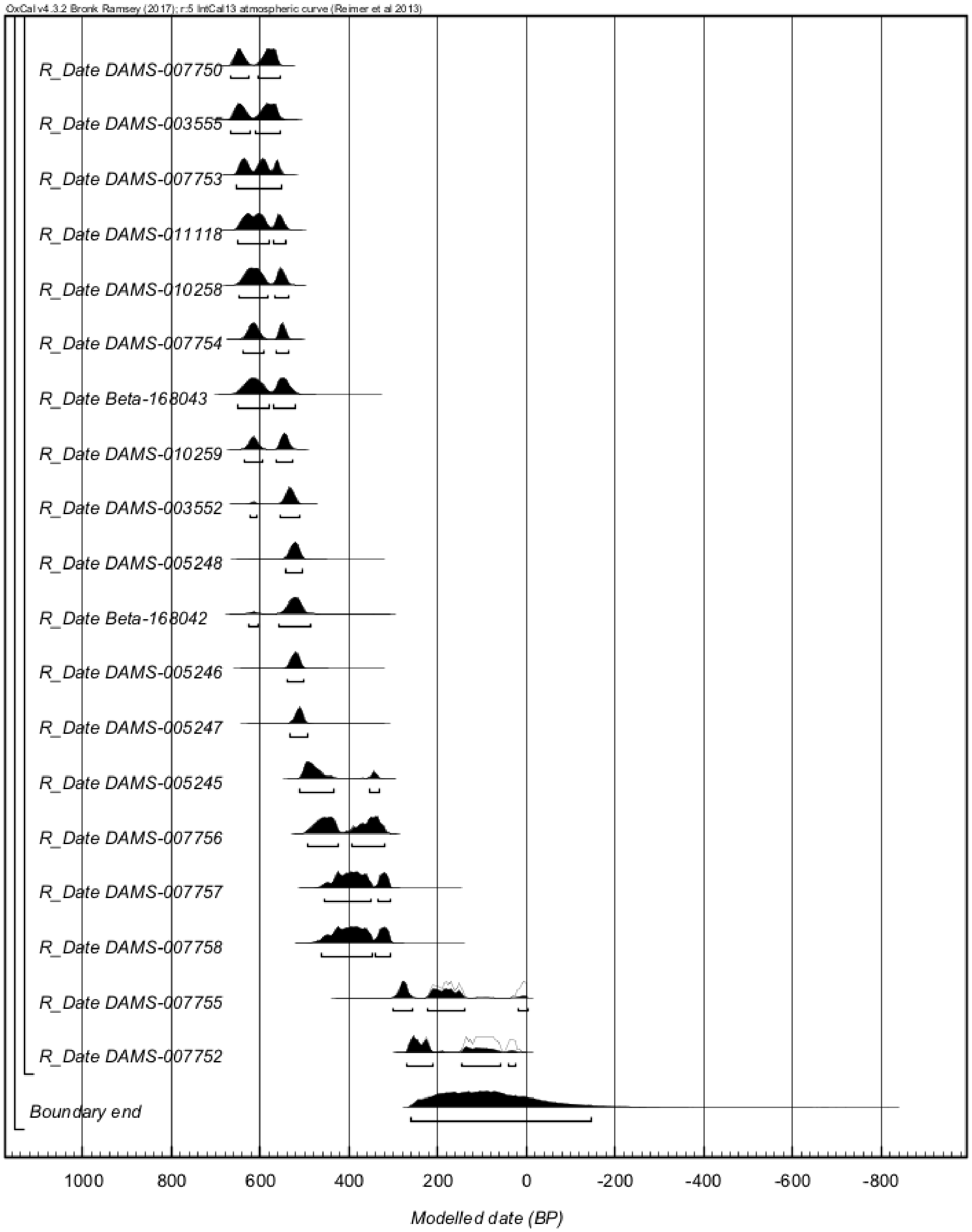


Figure 12. Continued

The earth oven model which incorporates lower-confidence data (Figure 13 and 14) estimates the beginning of earth oven plant baking between *10570-10264 cal BP* (95%*)*, and likely between *10446-10288 cal BP* (68%). The end of plant baking is estimated at between *258 cal BP-present (-24 cal BP, or AD 1974)* (95%*),* and likely between *212-69 cal BP* (68%). The model has an agreement index of $A_{model}$=71.2% and $A_{overall}$=86.8%. The convergence intervals are 96.6% (start of phase) and 97.5% (end). The earliest radiocarbon date in this model generated an error message, indicating poor agreement for that individual date (DAMS-018141; A=38.6%). This date was included in the higher-confidence model, where it was modeled with an acceptable agreement; the disagreement may be the result of chance (Bronk Ramsey 2019b), though it occurred in two iterations of the model. All of the modeled dates are presented in Figure 14, broken across 10 pages.

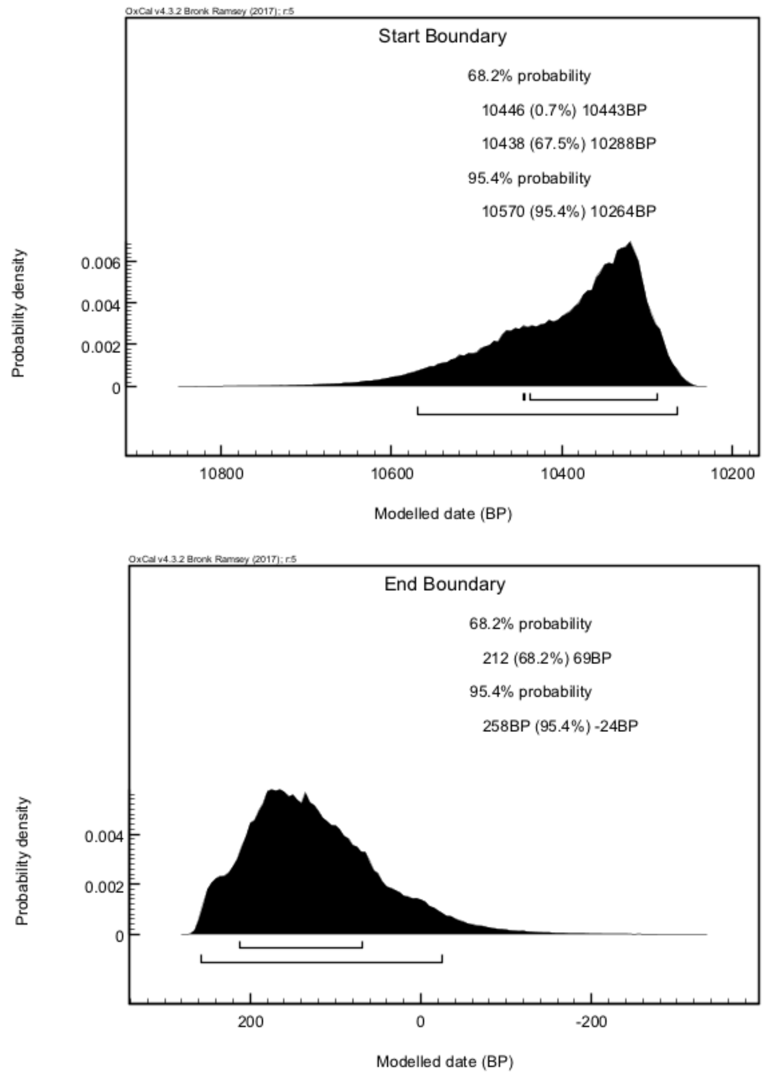


Figure 13. Estimated start and end ranges of LPC earth oven plant baking, modeled using the combined higher and lower-confidence radiocarbon data.

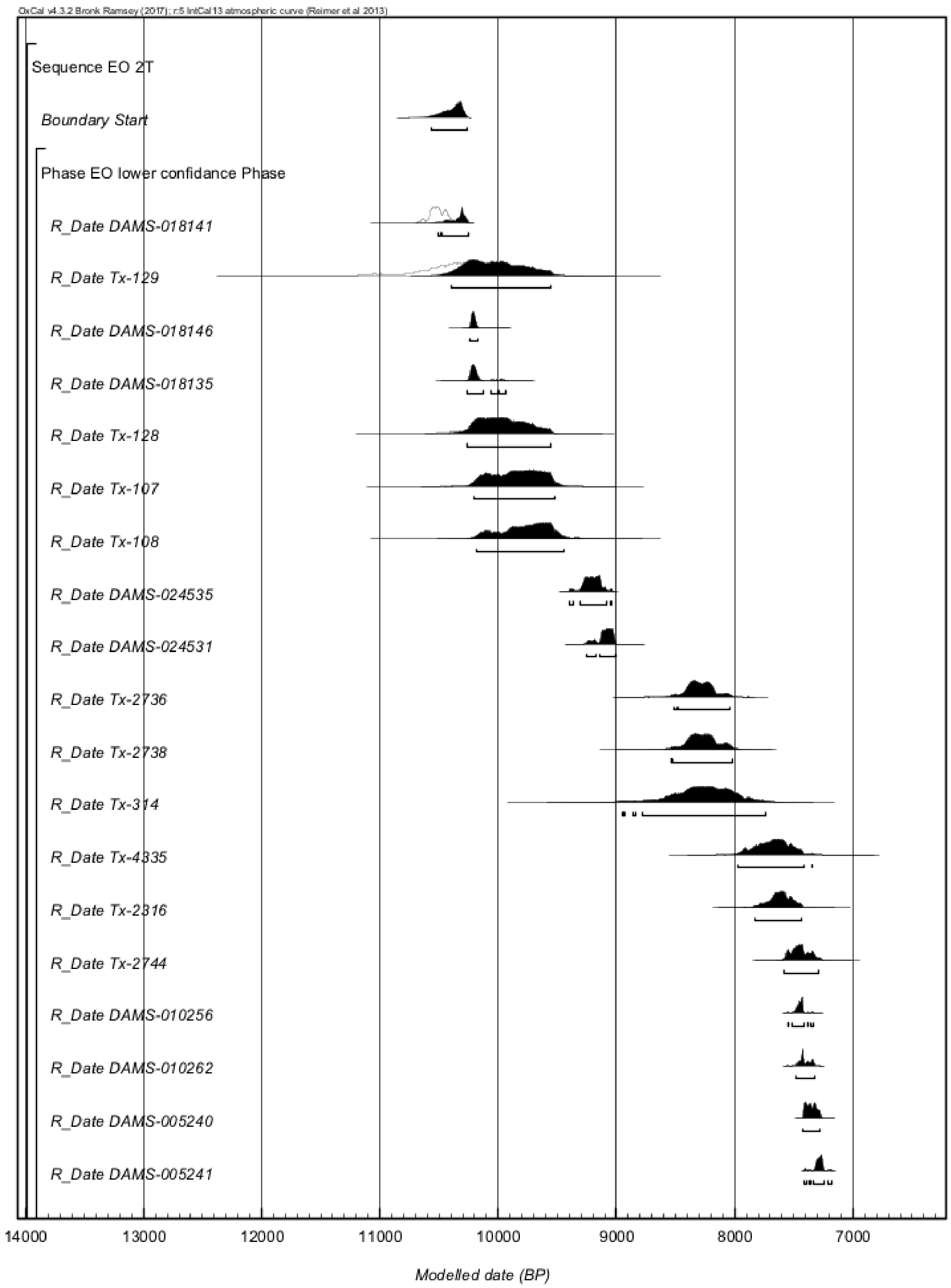


Figure 14. Modeled probability distributions for dates from high and low-confidence data from LPC earth oven contexts. Brackets illustrate the 95% (2σ) probability ranges for each date. Unmodeled likelihoods (unmodeled, calibrated distributions) are shown in outline, seen in this model in the assays which date closest to the start and end range.

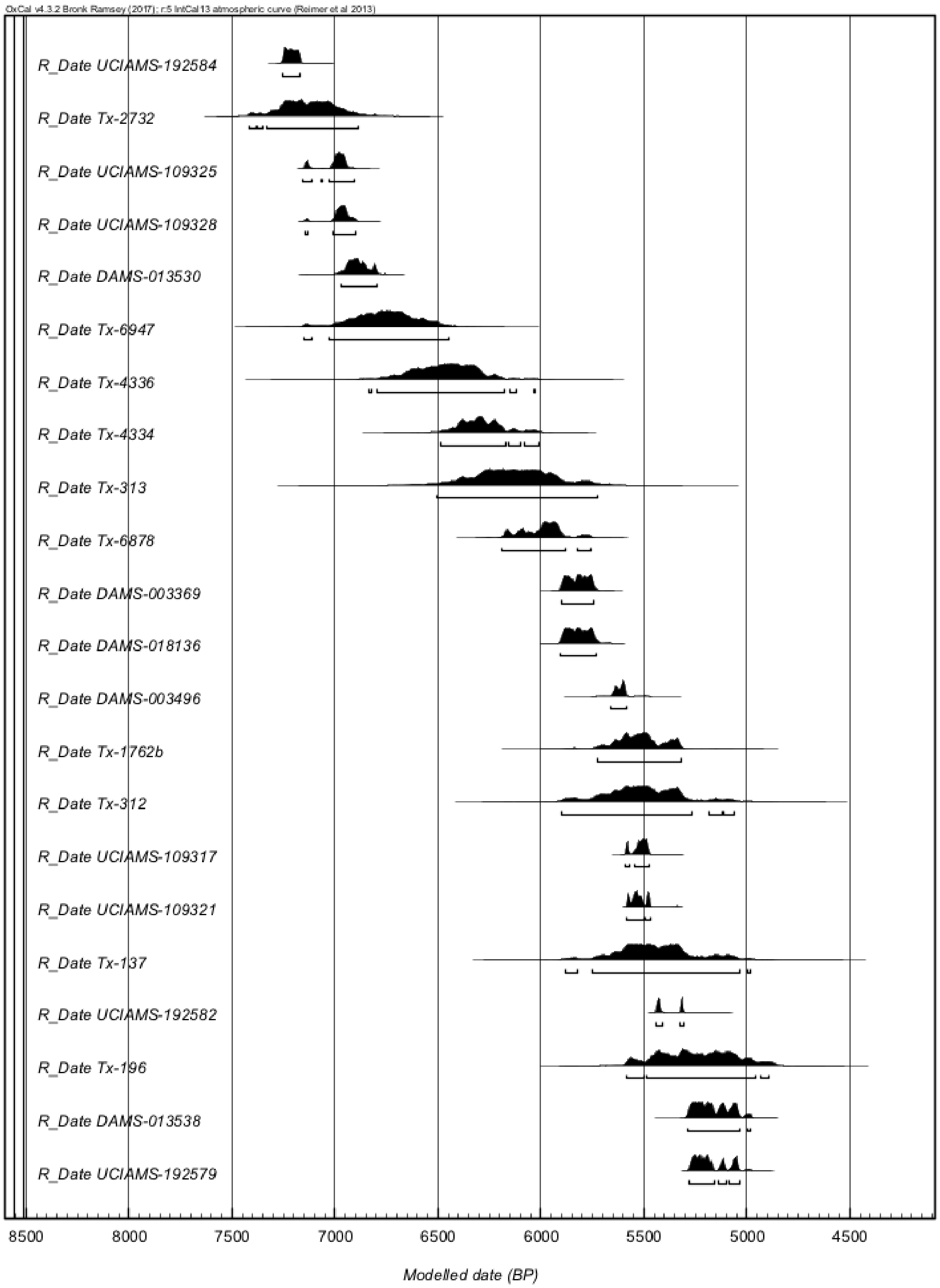


Figure 14. Continued

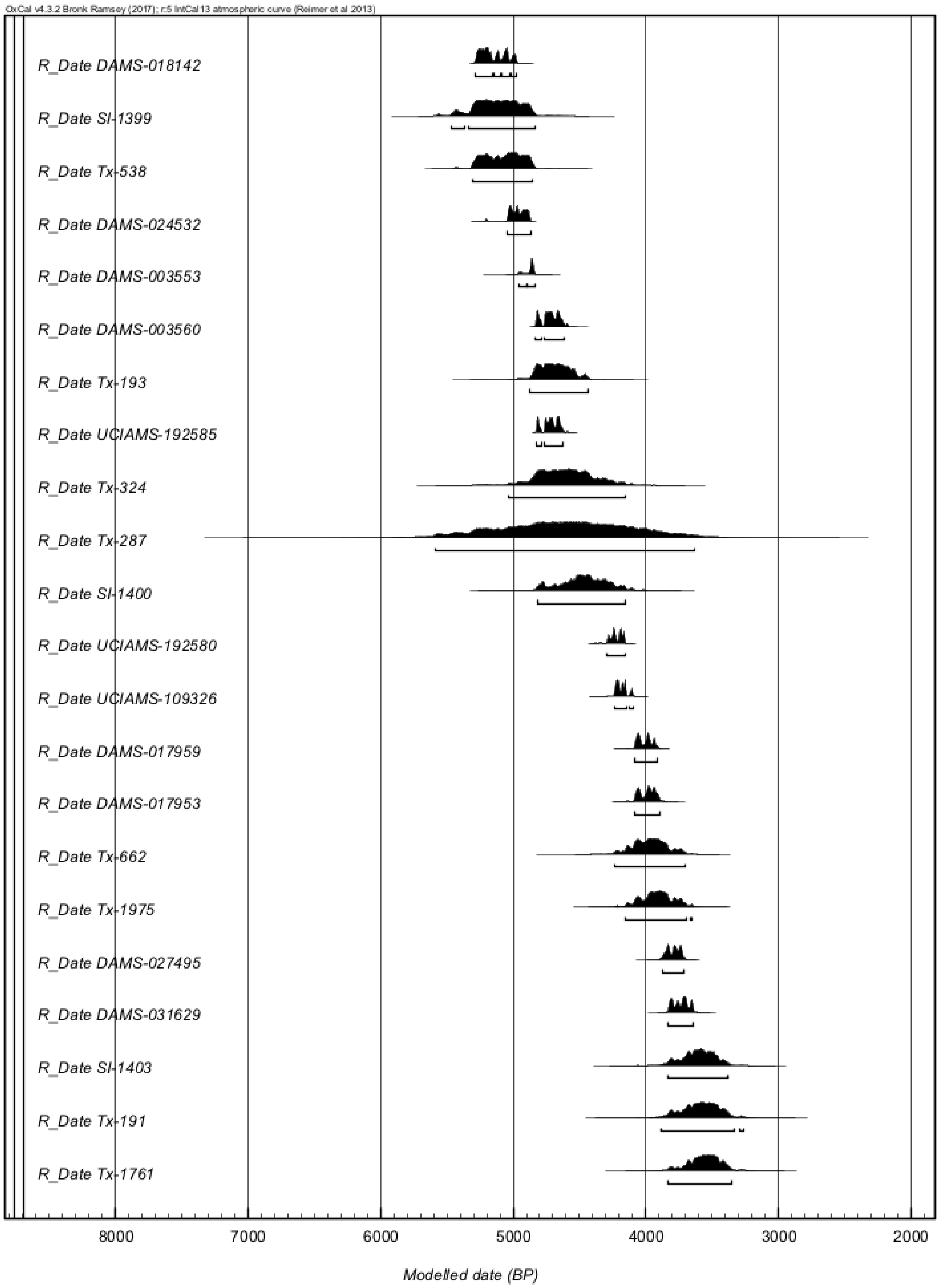


Figure 14. Continued

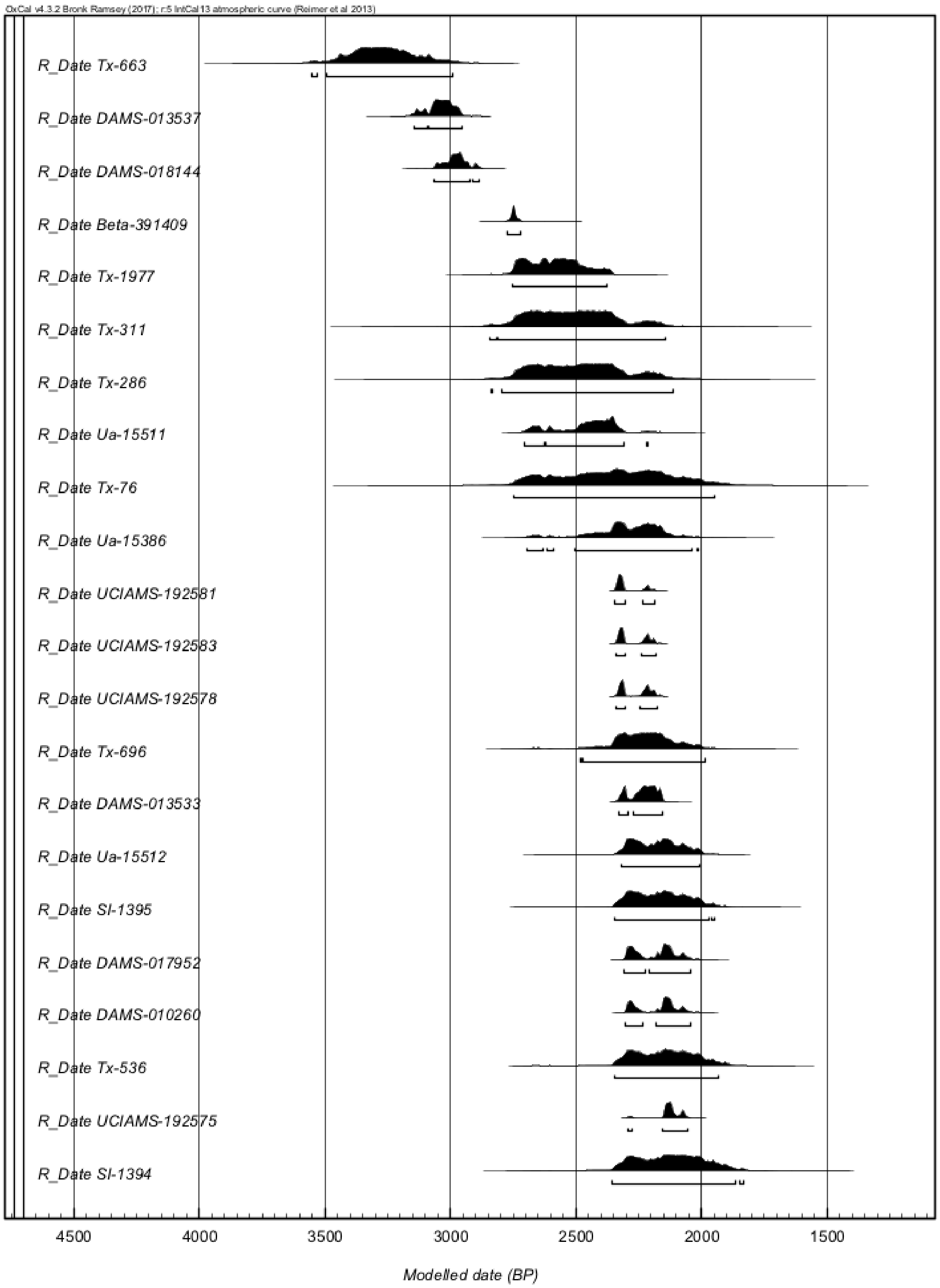


Figure 14. Continued

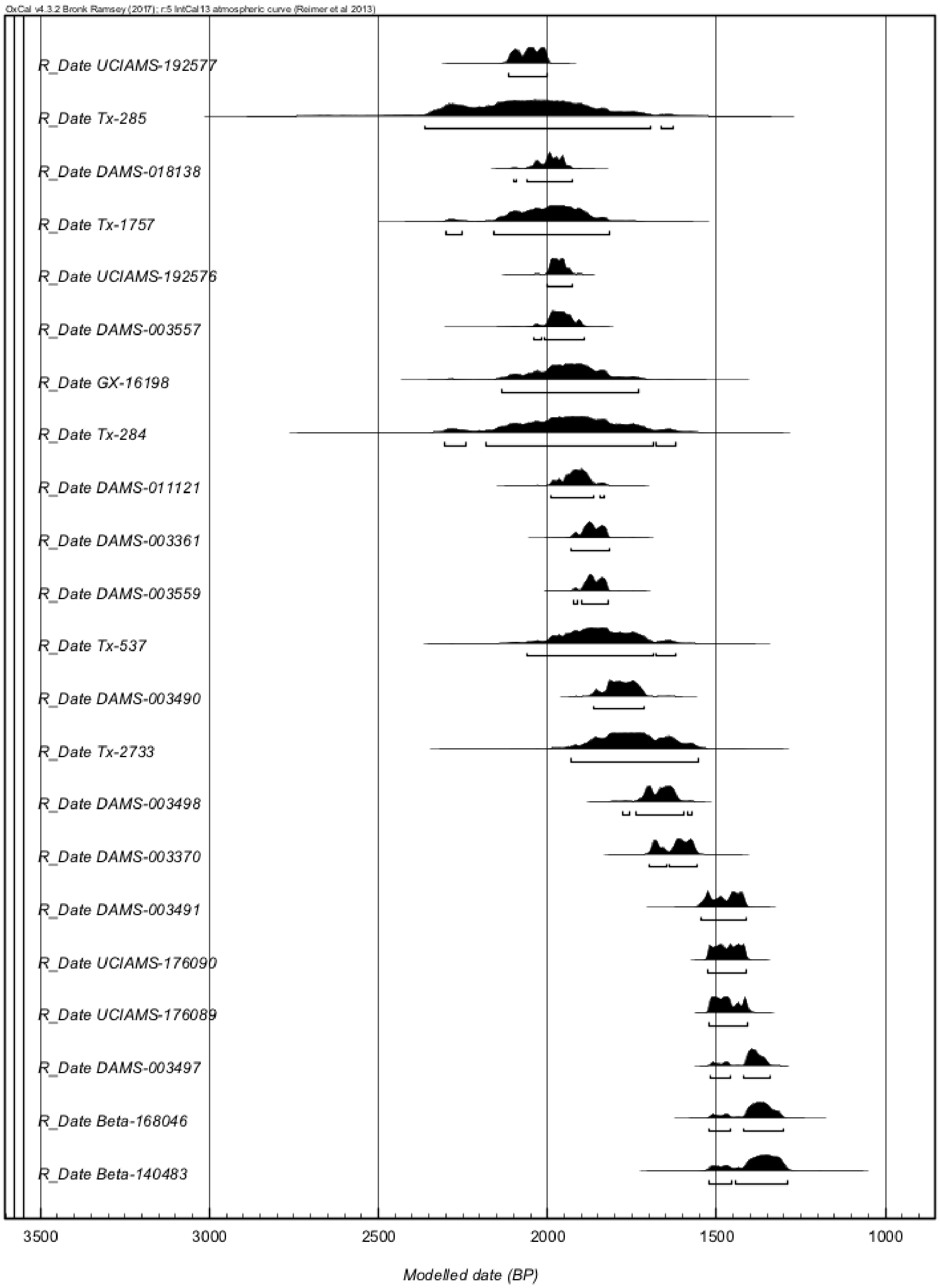


Figure 14. Continued

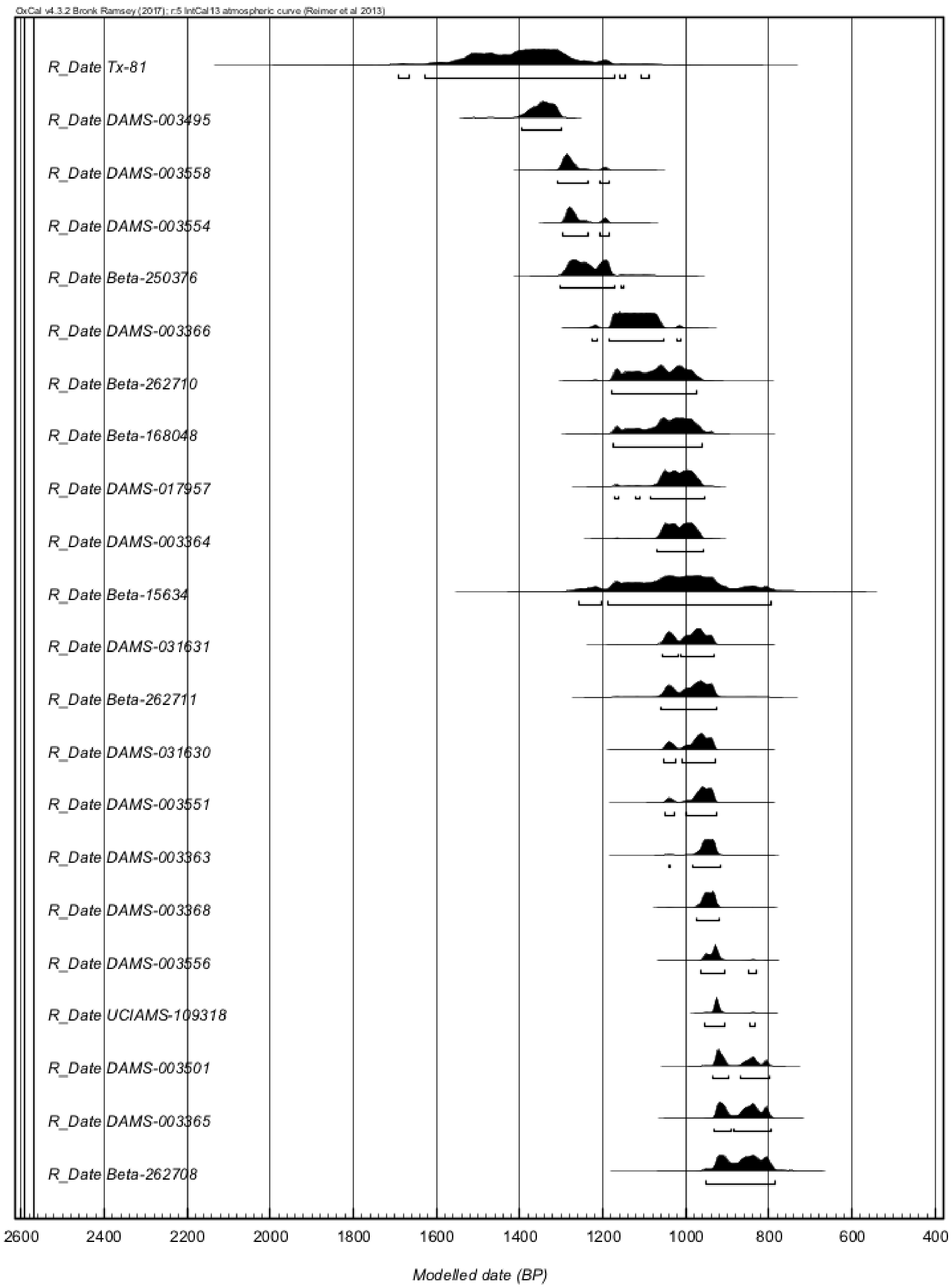


Figure 14. Continued

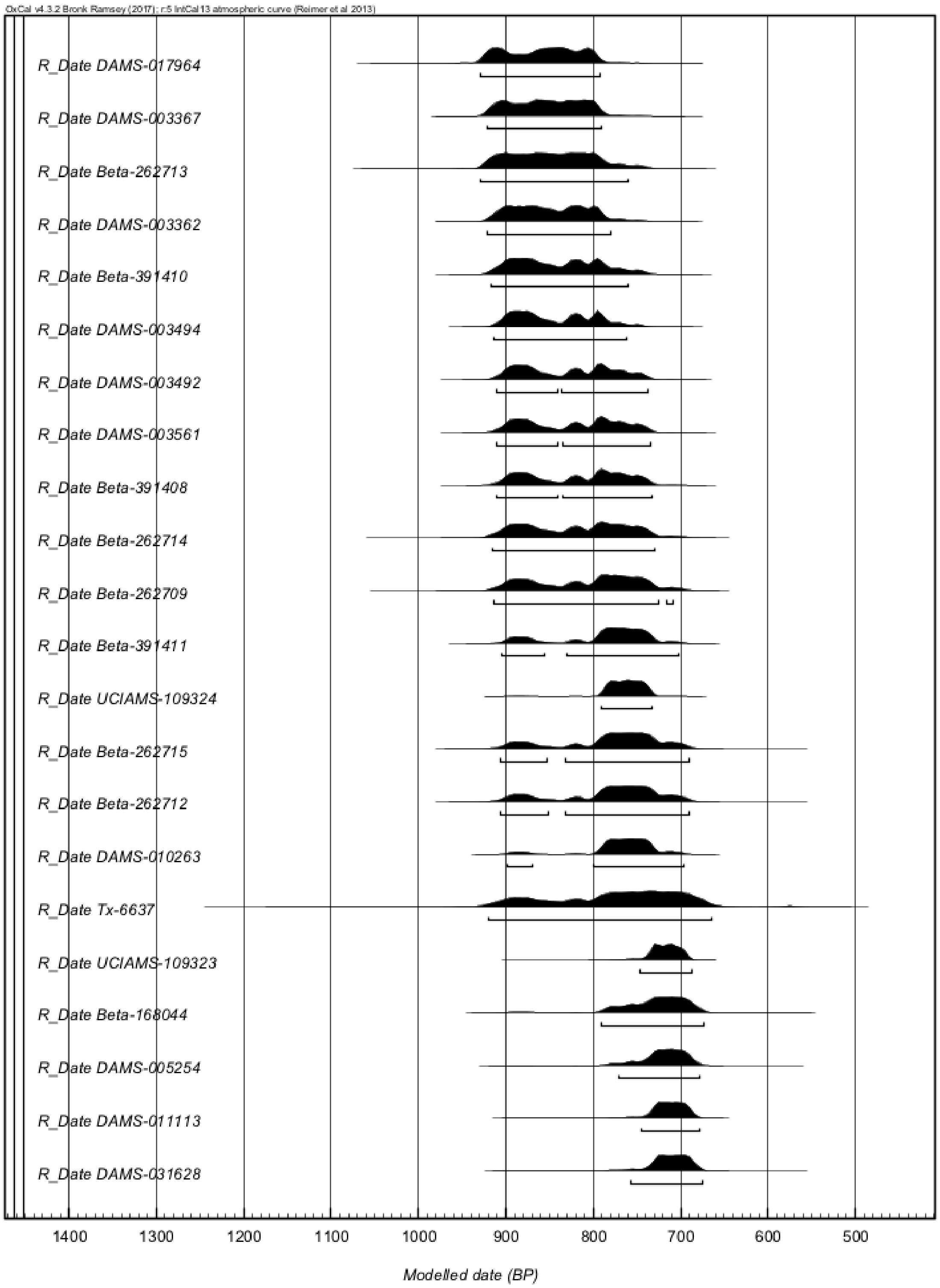


Figure 14. Continued

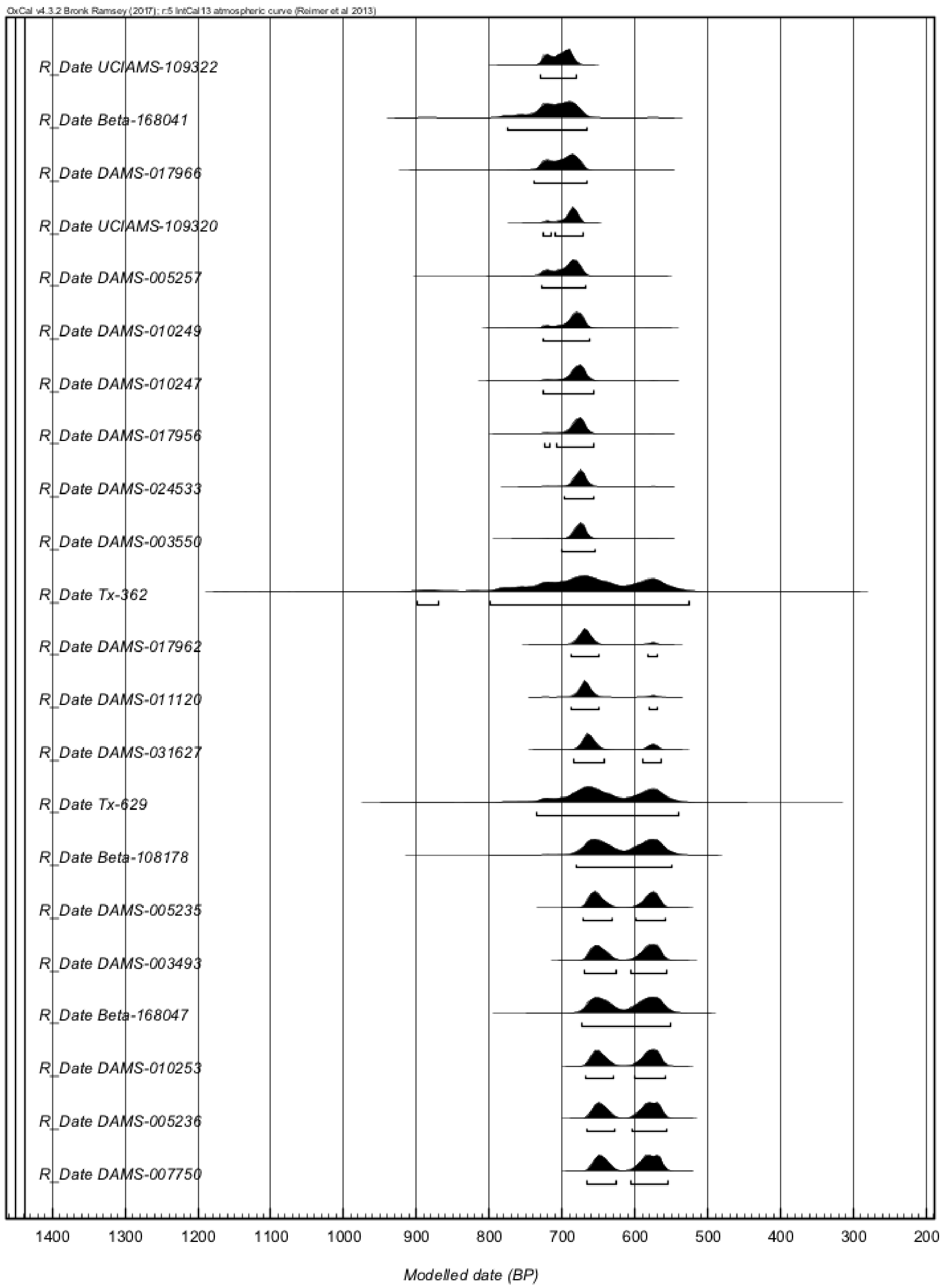


Figure 14. Continued

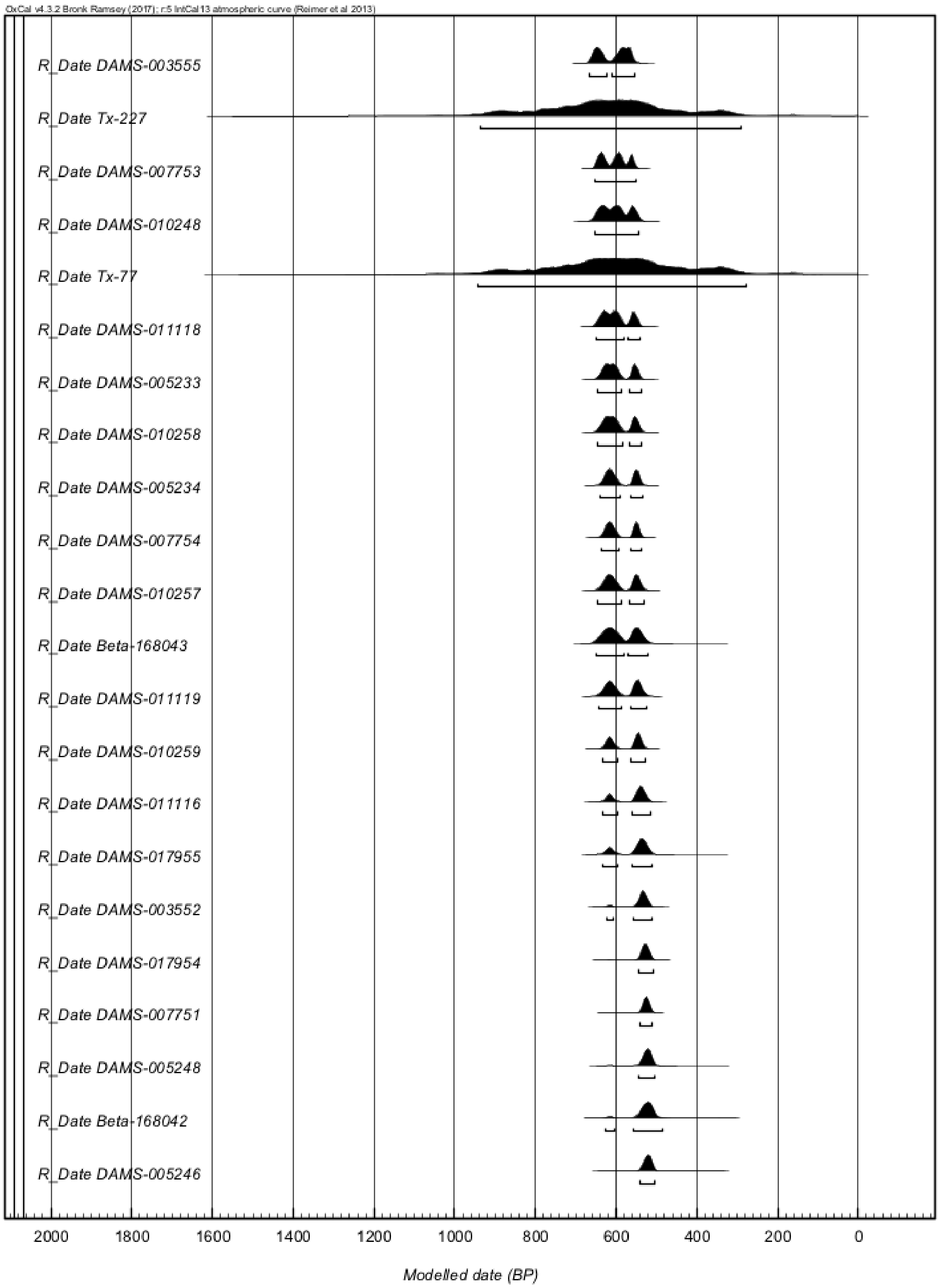


Figure 14. Continued

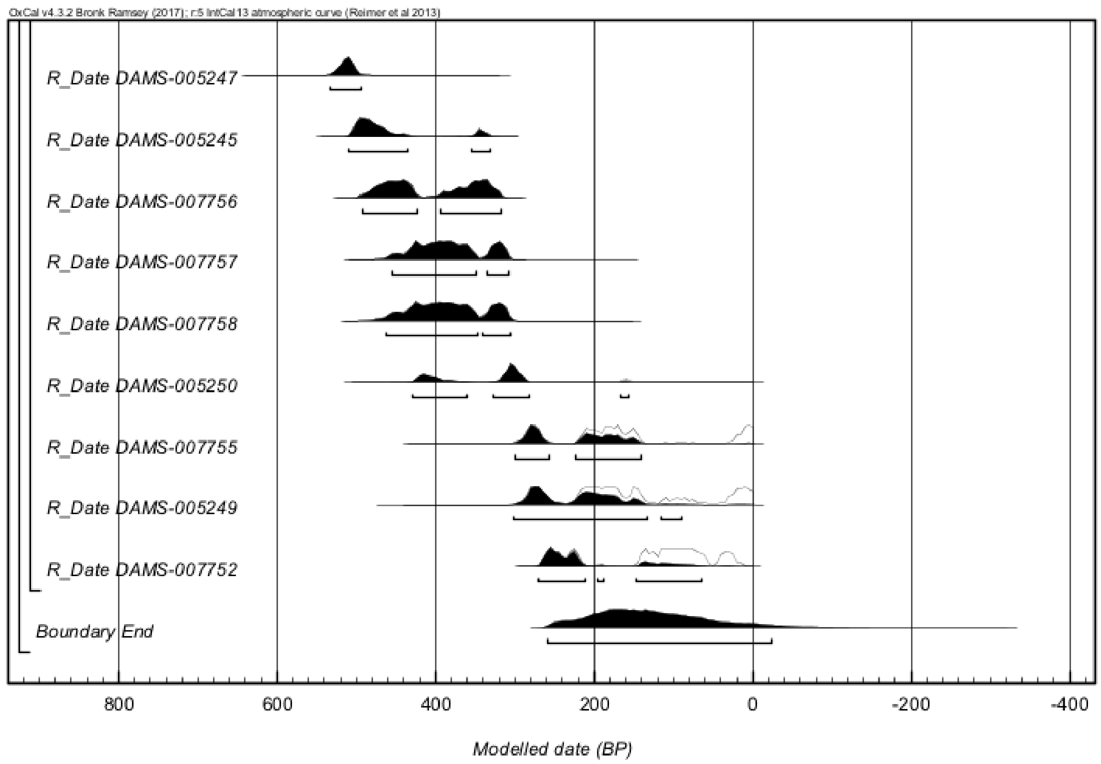


Figure 14. Continued.

*Fiber Artifact Phase Model*

Assays directly on fiber artifacts, such as basketry, matting, and sandals, were used for this Bayesian phase model. The start of the manufacture of fiber artifacts is dated to *5555-5070 cal BP* (95%), and likely dates to *5346-5127 cal BP* (68%). The end is dated to *610-148 cal BP* (95%), and likely dates to *534-393 cal BP* (68%). Agreement indices are $A_{model}$=97.4 and $A_{overall}$=97.5. The convergence interval of the phase start is 98.3%, and 99% for the phase end. The phase data are presented in Figure 15 and Figure 16, which is broken across two pages.

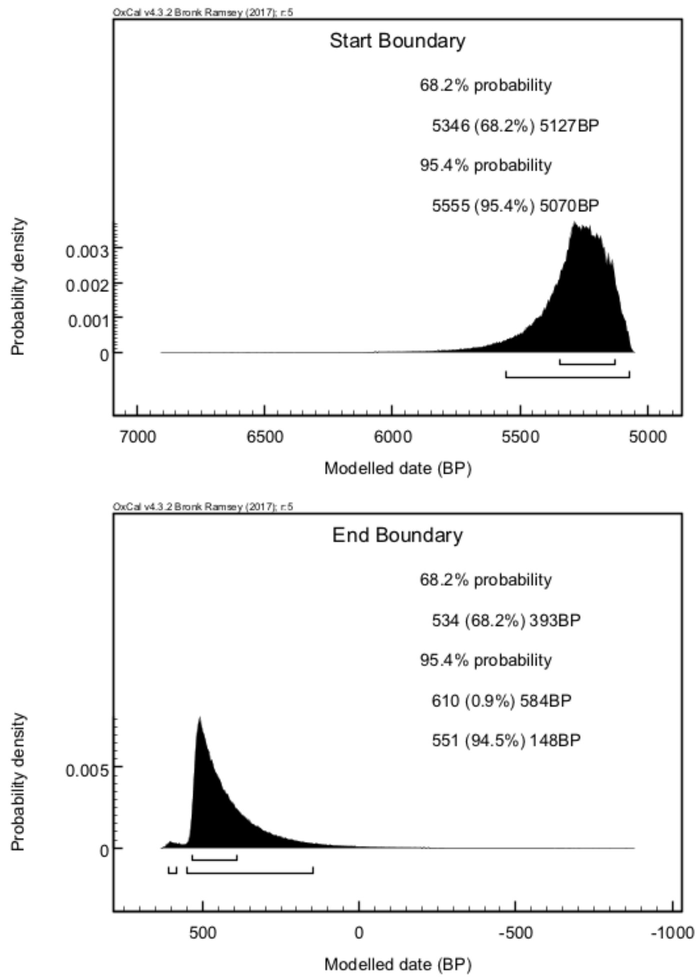


Figure 15. Estimated start and end ranges of a phase model of LPC fiber artifacts such as sandals, basketry, and matting.

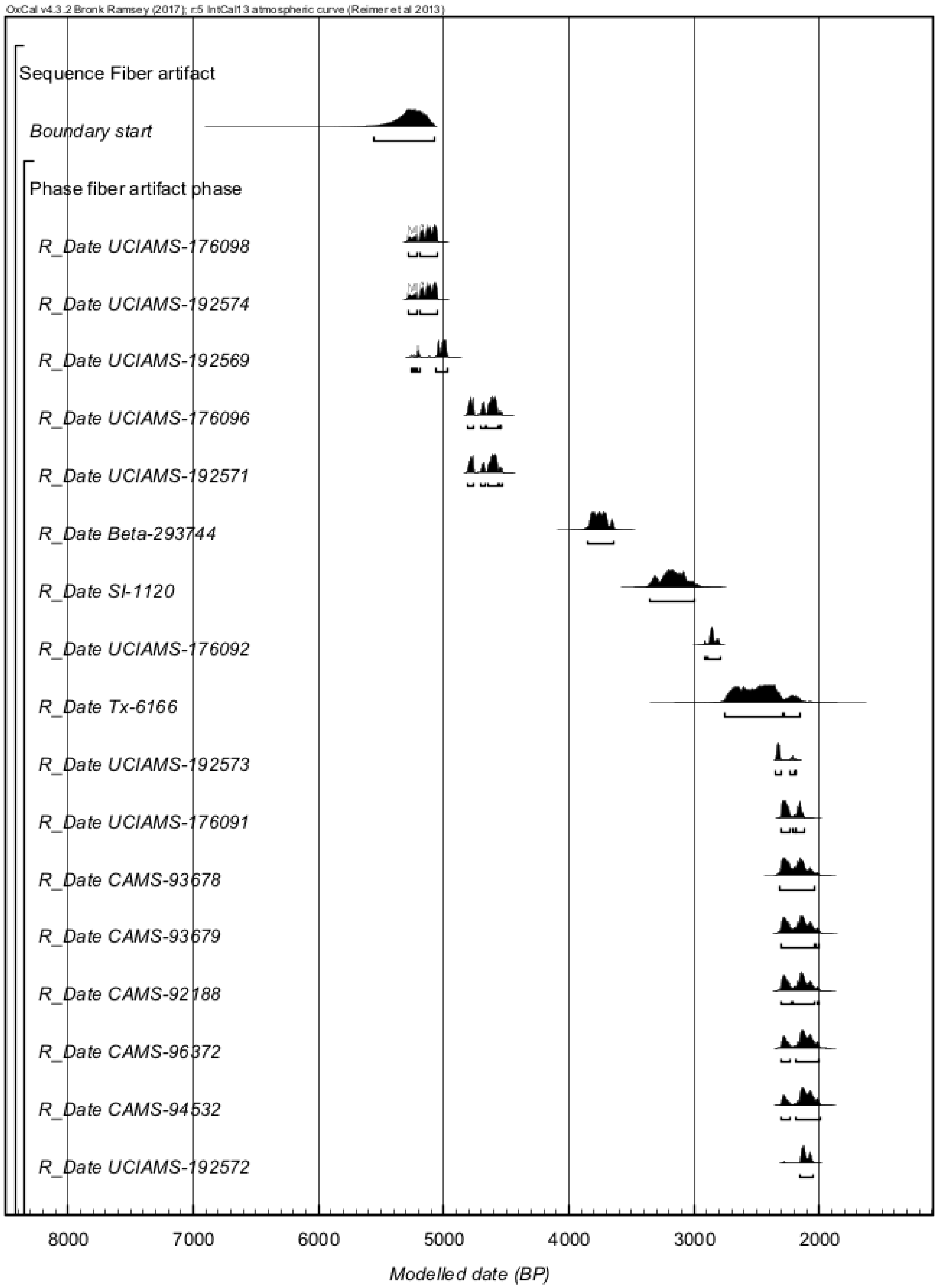


Figure 16. Modeled probability distributions for dates on fiber artifacts from the LPC. Brackets illustrate the 95% (2σ) probability ranges for each date. Unmodeled likelihoods (unmodeled, calibrated distributions) are shown in outline, as seen in the assays which date closest to the start range.

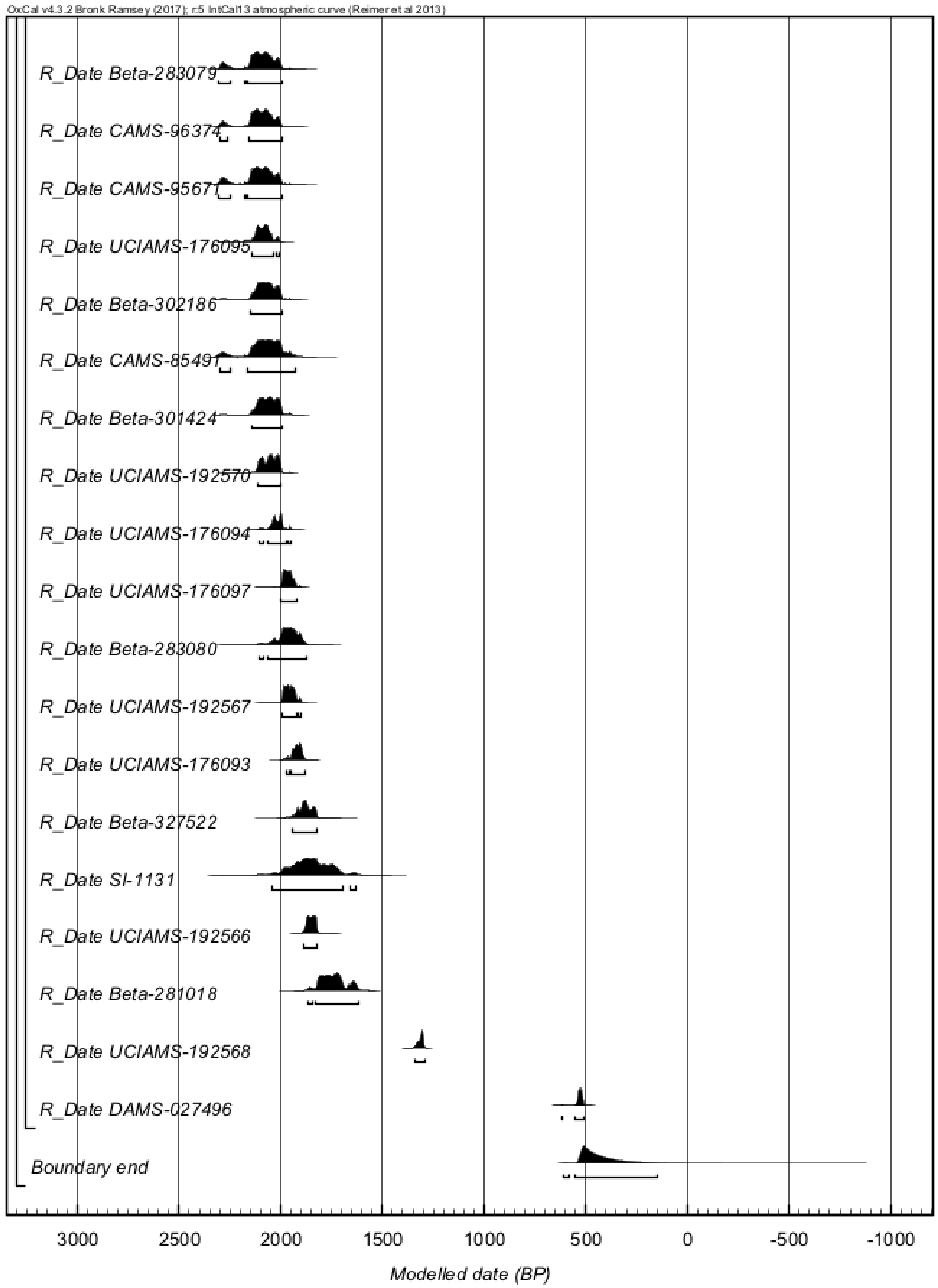


Figure 16. Continued

*Population Summed Probability Distribution*

As described in Chapter 5, relative human population fluctuations are estimated using a summed probability distribution. Only rockshelter data were used in this analysis (n=293), to mitigate the effects of taphonomic bias on the distribution. This is an unfortunately small sample size for SPD analysis. The *Sum* command in OxCal v4.3 was used to model the data at 2σ (Figure 17 and 18).

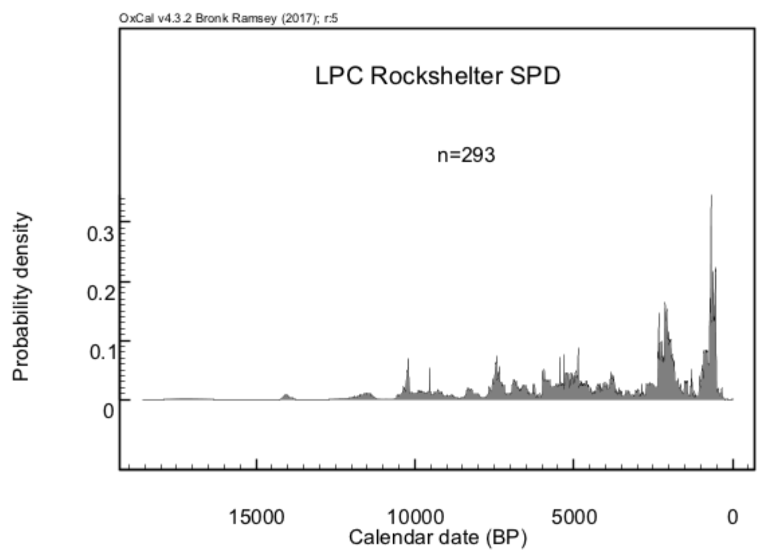


Figure 17. Summed probability distribution of Lower Pecos rockshelter dates.

A 500-year moving average trendline was applied to the SPD (Figures 18 and 19) using Microsoft Excel. The moving average reduces the effects of "artifacts" of the calibration curve caused by plateaus and troughs in the curve, a widely recognized problem encountered in radiocarbon SPDs (Ramsey 2017:1810-1811). I used a moving average of 500 years as recommended by Williams for data sets spanning the last 11 thousand years (2014:584). Though some Lower Pecos assays date to earlier than this, William's recommendation of an 800-year moving average for dates as early as 50 thousand years ago seems excessive given that the majority of the Lower Pecos assays date to the Holocene.

The earliest radiocarbon dates in this summed probability distribution are those from Cueva Quebrada: Tx-880 (17494-16259 cal BP) and Tx-881 (17979-16757 cal BP). These dates stand out as extremely early compared the remaining assays. The correlation of these assays with human activity is uncertain, casting doubt on whether they are truly archaeological. The next earliest dates are from Bonfire Shelter: DAMS-034547 (14145-13770 cal BP) and DAMS-034548 (14240-13925). These date ranges are from Bone Beds 1 and 2, respectively. Like Cueva Quebrada, Bone Bed 1 is not definitively archaeological. The scarcity of assays dating to before ca. 12,000 years ago is reflected in the low magnitude of the trendline during this period.

By ca. 12,000 years ago, the trendline increases gradually. There is a short dip in the trendline ca. 7500 cal BP, after which it continues to increase until ca. 5000 cal BP. Between ca. 5000 cal BP and 3500 cal BP, the trendline does not increase nor decrease substantially, but plateaus with slight undulations. Around 3500 cal BP the trendline decreases sharply until ca. 2300 cal BP. The trendline then sharply increases until around 1600 cal BP, declines gently until ca. 1000 cal BP, and then again increases until ca. 400 cal BP, after which the trendline begins its final decline.

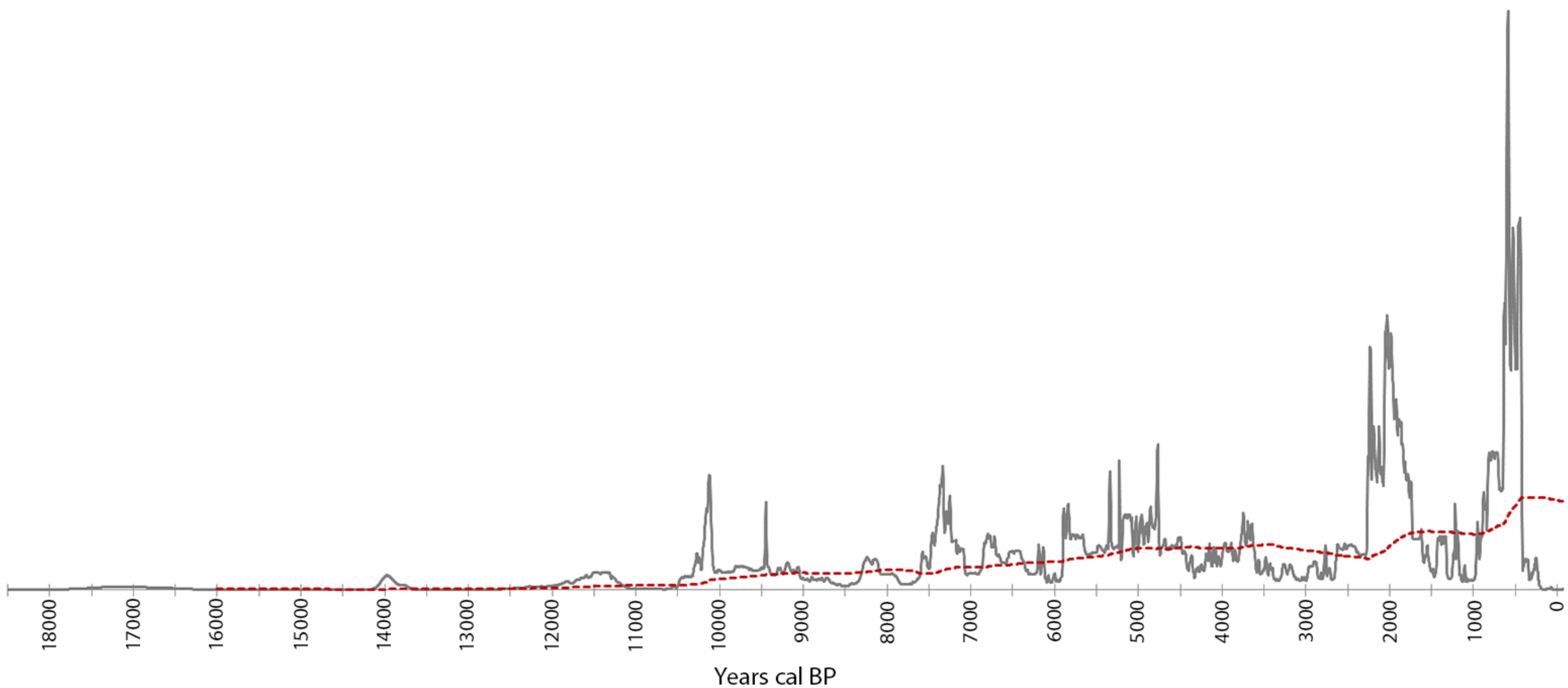


Figure 18. Summed probability distribution of vetted Lower Pecos rockshelter dates (solid line) and 500-year moving average trendline (dashed line).

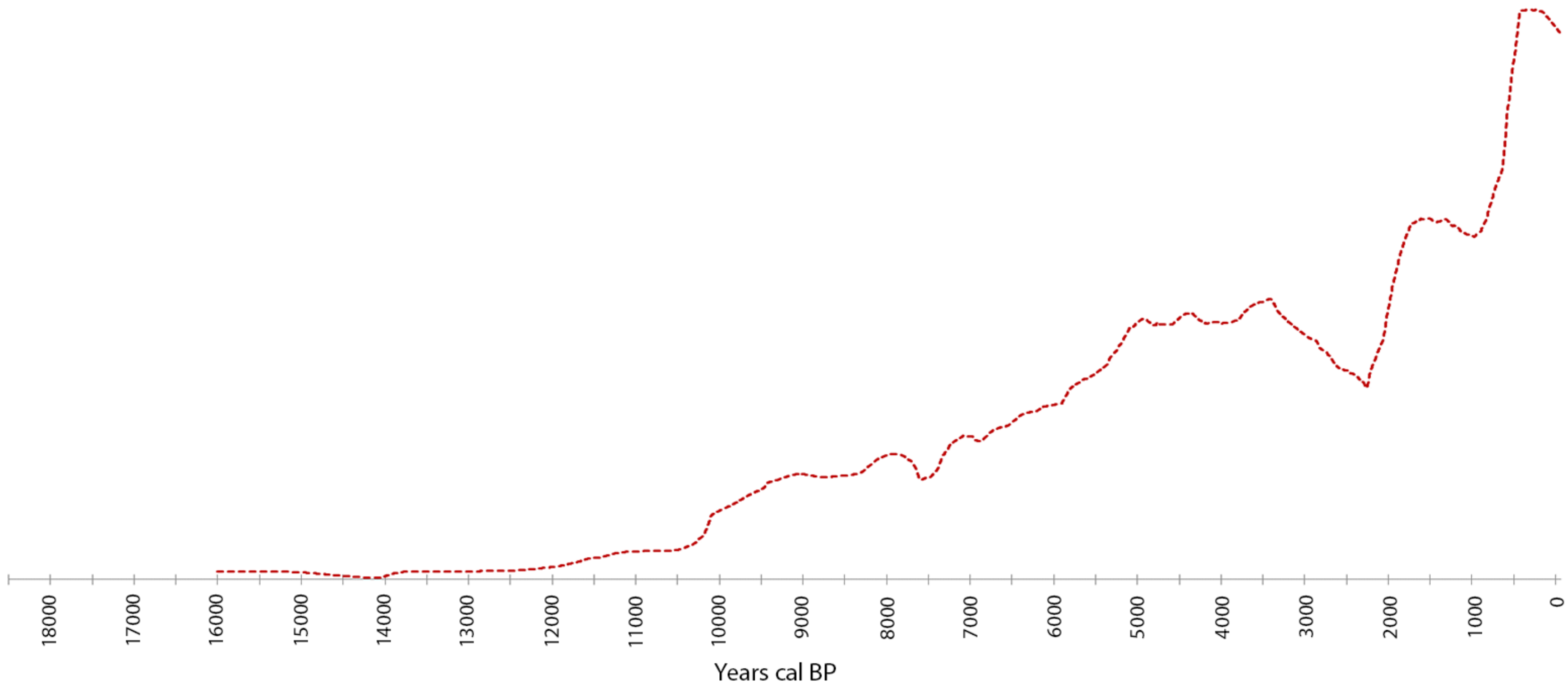


Figure 19. Lower Pecos 500-year moving average trendline, with scale of y-axis decreased compared to the previous figure; the trendlines are the same.

*Bison*

For addressing the timing of bison in the region, assays directly on bison remains are preferable to samples on taxa stratigraphically associated with bison. However, just two Lower Pecos assays on bison remains are reliably dated: the bison hair assay reported in this thesis (DAMS-027497) and a newly reported ASWT assay on charred *Bison bison* bone from Bonfire Shelter's Bone Bed 3 (DAMS-027372). Because of the scarcity of directly dated bison remains, assays associated with bison are discussed (Table 4). There are more Lower Pecos assays associated with bison than are discussed here, though I consider these to be problematic due to lack of contextual detail or due to material assayed (i.e., bone apatite, sediment).

Table 4. Lower Pecos assays associated with bison, listed from earliest calibrated date to latest.

| Sample Number | Material | $^{14}$C Age* (RCYBP) | cal BP (2σ) | Provenience | Site |
|---|---|---|---|---|---|
| Tx-881 | wood charcoal | 14300 ± 225 | 17979-16757 | Unit IC | Cueva Quebrada |
| Tx-880 | wood charcoal | 13920 ± 215 | 17494-16259 | Unit IC | Cueva Quebrada |
| DAMS-034548 | charcoal | 12189 ± 48 | 14240-13925 | Bone Bed 2 | Bonfire Shelter |
| DAMS-034555 | charcoal | 10115 ± 51 | 11999-11405 | Bone Bed 2 | Bonfire Shelter |
| Tx-6636 | charcoal | 3100 ± 70 | 3458-3080 | Unit 1 Level 13 | Skyline Shelter |
| Tx-131 | charcoal | 2510 ± 111 | 2841-2340 | Bone Bed 3 | Bonfire Shelter |
| Beta-207791 | unknown charred material | 2530 ± 40 | 2749-2489 | Bone Bed 3 | Bonfire Shelter |
| Beta-207789 | unknown charred material | 2500 ± 40 | 2742-2435 | Bone Bed 3 | Bonfire Shelter |
| DAMS-027372 | bison bone | 2516 ± 24 | 2740-2492 | Bone Bed 3 | Bonfire Shelter |
| Beta-207792 | unknown charred material | 2460 ± 40 | 2710-2364 | Bone Bed 3 | Bonfire Shelter |
| DAMS-027497 | bison hair | 361 ± 21 | 495-319 | N/A | Skiles Collection |

*Conventional ages; legacy UT data are corrected for estimated $\delta^{13}$C.

Assays associated with Pleistocene bison include those on single lumps of wood charcoal from Cueva Quebrada: Tx-880 (17494-16259 cal BP) and Tx-881 (17979-16757 cal BP). These assays are closely associated with extinct horse remains but are also associated with other Pleistocene fauna, including bison. As noted previously, it is not definite that humans were involved with the butchery of the fauna at Cueva Quebrada. Similar uncertainty surrounds Bonfire Shelter's Bone Bed 1 and Pleistocene bison remains found at Features 18 and 19 at Arenosa Shelter (undated). Assays dating Bonfire Shelter's Bone Bed 2 are charcoal (taxa not identified) samples: DAMS-034548 (14240-13925 cal BP) and DAMS-034555 (11999-11405 cal BP).

In the Holocene, bison presence is not indicated in the Lower Pecos radiocarbon record until ca. 3000 BP. A charcoal assay from Skyline Shelter (Tx-6636) is purportedly associated with bison and dates to 3458-3080 cal BP, though its context is inadequately reported. Bone Bed 3 at Bonfire shelter is the most-dated bison-bearing strata in the Lower Pecos. Three assays associated with Bonfire Shelter's Bone Bed 3 are on unknown charred material: Beta-207789 (2742-2435 cal BP), Beta-207791 (2749-2489 cal BP), Beta-207792 (2710-2364 cal BP). The ASWT bison bone assay from the lower portion of Bone Bed 3 (DAMS-027372; 2740-2492 cal BP) overlaps substantially with these three Beta Analytic assays. One legacy assay (Tx-131) from Bone Bed 3 dates to 2841-2340 cal BP. The latest date for Lower Pecos bison remains is the previously discussed bison hair assay measured for this thesis (DAMS-027497), which dates to 495-319 cal BP.

### *Discussion*

In this section the results of the analyses are discussed in concert with climate proxy data spanning the last 11,700 years (i.e., Wong et al. 2015). Limitations of the data are also discussed.

In Table 5, the start and end ranges of the Bayesian phase models are compared. The dates ranges for the two earth oven models are not extremely different, and indicate a start between ca. *10700-10300 cal BP*. Both models estimate an end to earth oven plant baking as recently as the 20th or even 21st century, which we know is untrue (other than experimental earth ovens built by archaeologists). Sites represented in the high confidence model include Conejo Shelter, Eagle Cave, Hibiscus Shelter, Kelley Cave, Little Sotol, Lone Star Bridge Site, Lost Midden Site, Rancid Cactus Midden, Sayles Adobe, Skiles Shelter, Skyline Shelter, Torres Ranch House, Tractor Terrace Midden, 41VV1895, 41VV1897, and 41VV661. The lower confidence model includes assays from Arenosa Shelter, Baker Cave, Black Cave, Cammack Sotol Pit, Coontail Spin, Devil's Rockshelter, Coontail Spin, Fate Bell, Hinds Cave, Hodge Site, Perry Calk, Piedra del Diablo, 41VV1207, 41VV2120, 41VV2139, and 41VV2205, as well as those from sites represented in the higher confidence model.

Table 5. Model estimates for start and end date ranges (cal BP) of Lower Pecos earth oven plant baking and fiber artifact manufacture.

| Model | Start (2σ) | Start (1σ) | End (2σ) | End (1σ) |
|---|---|---|---|---|
| Earth Oven (higher confidence) | *10732-10275* | *10562-10316* | *261-present* | *214-2* |
| Earth Oven (lower confidence) | *10570-10264* | *10446-10288* | *258-present* | *212-69* |
| Fiber Artifact | *5555-5070* | *5346-5127* | *610-148* | *534-393* |

The beginning of evergreen rosette fiber artifact manufacture is dated to ca. *5500-5000 cal BP*—much more recently than earth ovens. The end of fiber artifact manufacture dates to ca. *600-150 cal BP*, which imprecisely and unsatisfyingly includes both the Late Prehistoric and the ethnohistoric periods. Sites represented in the fiber artifacts data set are Conejo Shelter, Goat Cave, High and Dry Cave, Hinds Cave, Horseshoe Caves, Kelley Cave, Moorehead Cave, Mummy Shelter, and unprovenienced collections.

I suspect that this approximately 5000 year span of time to which Lower Pecos fiber artifacts date may be more indicative of the preservation of these fragile artifacts rather than the true duration of their manufacture; taphonomic processes continue in dry rockshelters, albeit at a much slower rate than at open (upland and terrace) sites. Additionally, carbonized botanicals (e.g., wood charcoal, such as found in burned rock middens) preserve better than uncharred botanicals used in construction of sandals and matting.

The end range of fiber artifact manufacture, though a long span of time, is interesting to consider in the context of historical data. As reviewed in Chapter 2, the ethnohistoric period in the Lower Pecos, beginning AD 1535, is believed to have been a time of instability in the region (Kenmotsu and Wade 2002). I speculate that this instability may have resulted in less intensive habitation of rockshelter sites, which in turn might diminish the accumulation of cultural material, such as fiber artifacts, at these sites. Additionally, material culture during the enthohistoric period incorporated new materials introduced by the continent's non-native inhabitants; these materials may have supplemented or replaced locally-derived resources such as evergreen rosettes in the manufacture of fiber goods. Finally, it is worth considering that upper deposits of Lower Pecos rockshelters are impacted by bioturbation from livestock and by 20$^{th}$ century looting, both of which contribute to the taphonomy of these deposits.

Despite uncertainties regarding the true period of use of evergreen rosettes for manufacture of fiber goods, it is known that these materials were being used between ca. *5500-150 cal BP*, and that the majority of assays on Lower Pecos evergreen rosette fiber artifacts are dated to between ca. 3000-1500 cal BP.

I consider the Bayesian phase models for both earth oven and fiber artifact manufacture to be rough estimates which will likely change with the addition of more assays and different model methods. In particular, the scant number of assays on fiber artifacts, and a poor understanding of the longevity of these materials in dry rockshelter contexts, seems problematic for addressing the timing of evergreen rosettes for manufacture of theses goods. However, I believe that extant data has the potential to create more precise models than those I presented here. Namely, I expect that re-analysis of these data with a *terminus ante quem* of AD 1880 (the end of the ethnohistoric period; Kenmotsu and Wade 2002:75) would achieve a more precise end range for earth oven plant baking and fiber artifact manufacture in the region. I also believe the extant earth oven data could be used for more complex Bayesian phase models, using apparent gaps in the data to investigate fluctuations in the use of earth oven plant baking through time. For example, there is a long gap in the so-called higher confidence earth oven model between ca. *10000-7500 cal BP.* In the lower confidence model this gap is not apparent, as legacy ages with long age ranges fill the gap. There are very few earth oven dates for the period ca. *4000-2400 cal BP* in the higher confidence model, though this is less apparent in the lower confidence model. The discrepancies between these models indicates that more information for the lower-confidence assays dating to these periods is in order—this may be achieved by consulting primary field records. Should these periods prove to reflect absence or significantly decreased use of earth ovens during these periods, the data may be modeled with multiple overlapping or non-overlapping phases, as appropriate.

The Lower Pecos rockshelter SPD, adjusted with the 500 year moving average trendline, has several limitations for evaluating population fluctuations: the relatively small sample size, the fact that taphonomic processes affect dry rockshelter deposits (albeit greatly reduced compared to open sites), and the reality that radiocarbon SPDs are inherently problematic due to effects of the calibration curve. Despite these limitations, potentially meaningful patterns emerge when the moving average trendline is compared to climate proxy data, earth oven data, and bison data.

A previous iteration of the Lower Pecos SPD was made in 2017 (i.e., Mauldin et al. 2017), to compare relative population fluctuations from Central Texas and the Lower

Pecos over the last 9000 years. Those Lower Pecos data were not adjusted for $\delta^{13}C$ nor critically vetted, resulting in a larger sample size but less accurate data. An interesting pattern in the 500-year moving average trendline was an increase of the Central Texas trendline and a decrease in the Lower Pecos trendline ca. 5100 cal BP. However, the corrected, vetted Lower Pecos data presented in this thesis do not show this decline ca. 5100 cal BP—rather, the trendline continues to increase here. However, without a larger sample size of vetted data, I am unconvinced that the SPD reflects more than very rough estimates of population change. Nonetheless, it is interesting to compare patterns seen in the moving average trendline with the Paleoenvironment proxy data discussed in Chapter 2 (i.e., Wong et al. 2015).

Wong et al. compared climate proxies from across Texas, spanning 11,700 years ago until AD 1950 (2015:163-65). Though these proxy data sets did not perfectly agree, several patterns emerged: a period of warming and drying from the Pleistocene into the middle Holocene was evident. Proxy records conflict about the timing of the maximum dry period, with some data indicating the thermal maximum occurred between 7000-5000 years ago (which corresponds with a steady increase in the Lower Pecos trendline) and others indicating it was ca. 5000-3000 years ago (which corresponds with a plateau in the trendline). The climate proxies indicate a short period of cooler, wetter conditions in the late Holocene, somewhere between 3000-1000 years ago. Interestingly, this period is characterized by a decline in the trendline to ca. 2300 cal BP, followed by an abrupt increase in the trendline. Proxy data indicate a dry period in the last two thousand years.

Though the population trendline dips at around 1000 cal BP, overall, it increases until the historic period.

Bison presence corresponds with the relatively cool, wet period at the end of the Pleistocene. As discussed, bison do not appear again in the radiocarbon record until ca. 3000-2000 cal BP (possibly as early as ca. 3500 cal BP, based on a single poorly reported assay from Skyline Shelter). Interestingly, bison presence corresponds with a decrease in the population trendline ca. 3000-2000 cal BP, and also correlates with a period of cooler, wetter weather indicated by some of the proxy records. Bison are represented again in the radiocarbon record ca. 500-300 cal BP.

For the most part, the climate proxies and bison data corroborate each other. Though the SPD moving average trendline is considered preliminary, some features of the trendline (i.e., peaks, troughs, and plateaus) correlate with changes in the environmental data and warrant further investigation with a more robust data set and additional lines of inquiry.

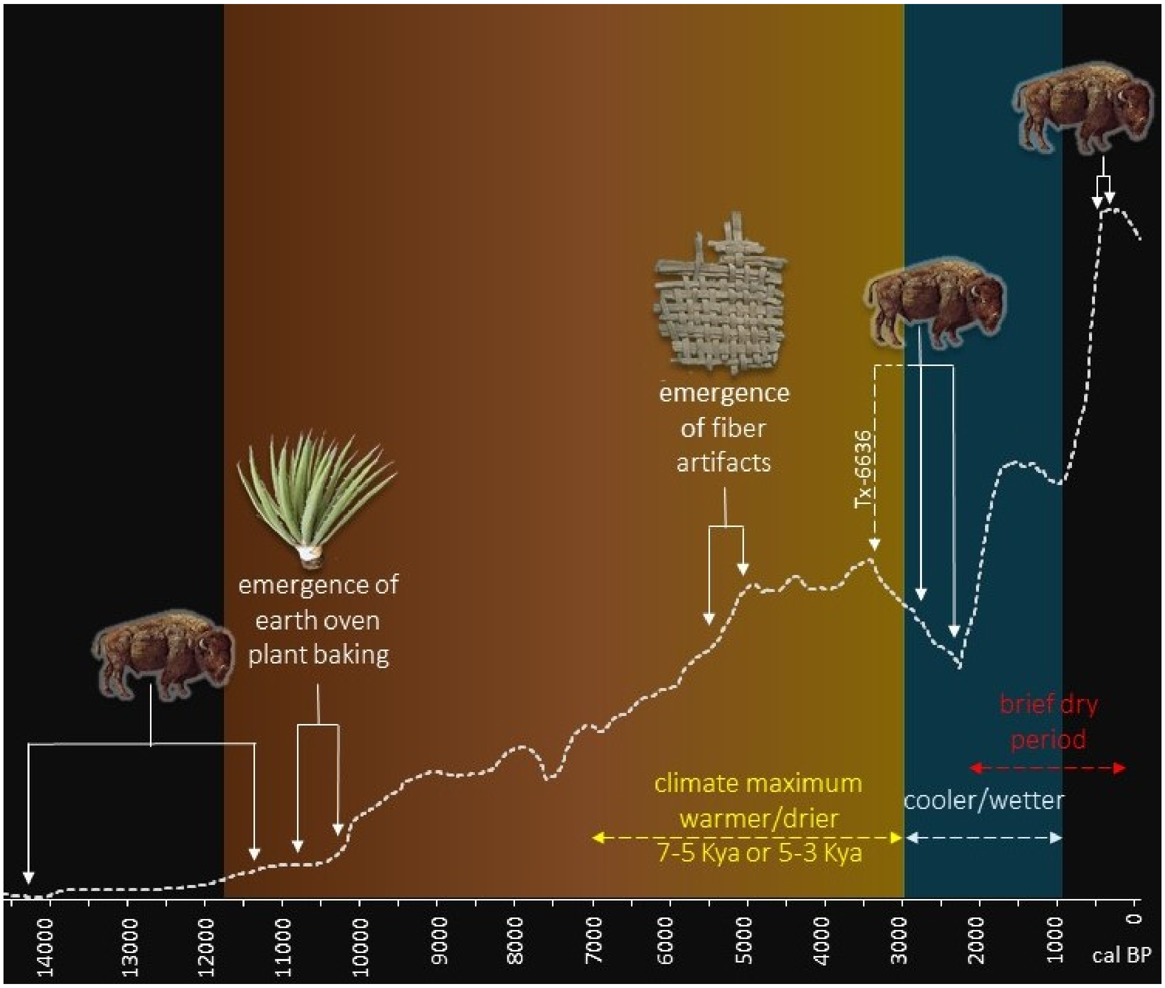


Figure 20. Moving average trendline (dashed white line) overlaying generalized paleoenvironmental data (Wong et al. 2015); yellow indicates warming/drying, blue (3000-1000 cal BP) indicates cooler, wetter climate, and the dashed red line indicates that a short dry period occurred sometime in range. Brackets with bison indicate bison presence occurring in given range, not spanning range; agave and fiber artifacts start/end given as modeled date ranges.

# VII. CONCLUDING THOUGHTS

This thesis project entailed compiling an exhaustive list of archaeological radiocarbon assays from the Lower Pecos Canyonlands region of southwest Texas and northern Coahuila. In total, 473 assays were compiled, all from north of the Rio Grande in Val Verde County, Texas. Included in this count are 100 newly reported assays from Ancient Southwest Texas Project excavations at Eagle Nest Canyon and Deadman's Creek. These 473 assays were critically vetted with the aim of using them to investigate the timing of earth oven plant baking of evergreen rosette desert succulents, such as sotol, lechuguilla, and yucca. Ancillary research questions were also addressed with these data: timing of bison in the region, use of evergreen rosette plants for manufacture of fiber artifacts, and relative human population fluctuations.

The radiocarbon database is available online (Appendix A). The database is at the heart of the thesis and readers are encouraged to review it. While the database is intended to be a resource for future research, the data were assembled to address my research questions; future researchers should revaluate these data and refer to primary sources listed in the database when constructing new radiocarbon models.

Bayesian phase models were used to estimate the start and end of earth oven use and fiber artifact manufacture in the Lower Pecos. A summed probability distribution with a 500-year moving average trendline was used to investigate relative human population fluctuations. A scarcity of bison data precluded modeling bison presence in the region, though the little extant data was discussed in Chapter 6. Results of these analyses were then compared with environmental proxy data (Wong et al. 2012) to evaluate patterns in prehistory.

Intriguing correlations were found when these data were overlain. Namely, the emergence of evergreen rosette plant baking ca. *10700-10200 cal BP* correlates with an increase in the population moving average trendline. The modeled emergence of fiber artifacts made with evergreen rosette plant fibers and leaves occurs ca. *5500-5000 cal BP*. Some climatic proxy records indicate that the thermal maximum occurred between ca. 5000-3000 cal BP (others indicate it was between 7000-5000 cal BP), which correlates with a plateau in the population trendline from ca. 5000-3400 cal BP. After this plateau, the population trendline declines at 3400 cal BP, reaching a low point ca. 2300 cal BP, after which the trendline steeply increases. This period corresponds to a relatively short cool, wet period that occurred sometime between 3000-1000 cal BP. Bison are represented in the Lower Pecos radiocarbon record at this time as well—dating to as early as ca. 3500 cal BP and as late as ca. 2300 cal BP. Climate proxy data indicate a period of drying in the last 2000 years, which corresponds to a generally increasing population trendline, with a short decrease ca. 1000 cal BP. Bison are again present in the region ca. 500-300 cal BP, indicated by a single assay on bison hair and corroborated by ethnographic accounts (Kenmotsu and Wade 2002:23). Around 400 cal BP the population trendline declines, which correlates with the intrusion of Spanish and other explorers and settlers of the so-called New World.

This project was undertaken in a climate of radiocarbon research touting that high-resolution chronologies are achievable by applying Bayesian methods to assays from precisely and thoughtfully documented contexts. In reality, the Lower Pecos radiocarbon data set is not robust enough to draft high-resolution chronologies. The results summarized in the preceding paragraph are preliminary and coarse-grained, and many more, better reported radiocarbon assays are needed before high resolution chronological models can be achieved for the Lower Pecos. In addition, there may be better choices in statistical methods to investigate the timing of earth oven plant baking and fiber artifact manufacture, such as kernel density estimates or more complex Bayesian models. Statistical methods such as these should be explored in future studies.

Targeting individual Lower Pecos sites is a step towards drafting high-resolution chronologies. To this end, I recommend intra-site Bayesian modeling of well-dated sites, in which stratigraphic priors are used to constrain the dates. Eagle Cave, recently excavated by ASWT, is an excellent candidate for such analyses. However, rockshelter stratigraphy is notoriously complex. Arguably, stratigraphically discreet terrace sites are better suited to drafting radiocarbon chronologies (Dering 2002:6.11). Though significant terrace site Arenosa Shelter is inundated by Amistad, the curated Arenosa collections contain many organic samples which may be dated. New dates from this site would not lend themselves well to intra-site Bayesian modeling, but also be an opportunity to assess the reliability of legacy dates. I strongly recommend re-dating Arenosa Shelter and investigating the potential of another significant Lower Pecos terrace site—Devil's Mouth—for re-dating as well.

A smaller step which must be taken to improve the radiocarbon record of the Lower Pecos is increased rigor in radiocarbon reporting. Despite being an essential tool in the field of archaeology, radiocarbon dating remains poorly understood by many archaeologists, as reflected in the cursory radiocarbon date reporting which afflicts the Lower Pecos archaeological record. Critical data which should be reported for all radiocarbon assays includes the conventional radiocarbon age given in RCYBP (1σ standard error), the laboratory number, the sample material (preferably identified to taxa), and the sample context. It is also important to report how the age was corrected for isotopic fractionation (measured by AMS or IRMS, or estimated), even if the $\delta^{13}C$ value was not reported by the lab. I strongly suggest that the reason for making a specific assay, as well as the relationship between the dated event, the event of interest, and the archaeological context, be discussed. With increased effort in assay reporting, these valuable data can maximize their potential for not only their reporter's immediate needs, but also for future analyses. To this end, I urge archaeologists to take responsibility for their own camel of Time.

The heretofore undiscussed theoretical framework for this thesis falls somewhere in the American and British processual and post-processual milieu. The roots of this thesis are processual—a major assumption is that the scientific method, applied using critical evaluations and statistical methods, can be used to deduce temporal patterns. However, the implications of conventional archaeological classifications of time (e.g., ages, periods, phases) on what research questions are asked, how dates are interpreted, and how narratives are constructed (see Griffiths 2017) were also considered.

In her paper exploring the theoretical framework of the Bayesian revolution, Griffiths (2017) argues that culture historical theory continues to inform how archaeologists conceptualize and describe archaeological time, despite the professed rejection of culture history amongst most 21st century archaeologists. To consider how archaeological theory intersects with scientific practice, Griffiths reviews the perspectives of processual archaeologists David Clarke and Colin Renfrew on radiocarbon analysis: Renfrew emphasized the importance of the sequence of radiocarbon analysis (i.e., chronological sequence, causality, narrative, and interpretation—in that order) and held that science could speak for itself, at least as far as radiocarbon dating is concerned (Griffiths 2017:1348-1349). In contrast, Clarke took a more “Romantic” perspective, arguing that the taxonomy of archaeological time—that is, the bounding and segmenting of time into descriptive chunks—frequently results in temporal boundaries drawn through the least understood events, thereby inadvertently deflecting the researcher’s attention away from them (Griffiths 2017:1349). One of Griffith’s most resonant arguments is that traditional chronological methods are often self-perpetuating: “The seemingly benign sequences, which we seek to populate with data, are charged with interpretative value, they structure our thinking” (Griffiths 2017:1349). Though Griffiths celebrates the romanticism of Clarke’s self-reflection, she does not reject the rigor of Renfrew’s, arguing that together these philosophies can inform better chronological models (Griffiths 2017:1356). I think that phases, periods, etc., are useful constructs for summarizing temporal patterns and describing unwieldy lengths of time. However, it is essential to recognize that temporal classification systems are a product of the archaeologist.

This thesis does not directly challenge the legacy or structure of chronology-production in the Lower Pecos Canyonlands. However, in it I have highlighted the potential of the Lower Pecos radiocarbon data set for drafting new kinds of models. In addition, radiocarbon dating methods have been described in an accessible manner, in the hopes that future Lower Pecos radiocarbon dating programs will be both thoughtfully executed and rigorously reported.

## APPENDIX SECTION

A. LOWER PECOS RADIOCARBON DATABASE

B. RADIOCARBON LABORATORY REPORTS

C. OXCAL CQL CODE FOR RADIOCARBON MODELS

D. LEROY JOHNSON'S COMMENTARY ON TURPIN 1991

# APPENDIX A: LOWER PECOS RADIOCARBON DATABASE

The Lower Pecos Canyonlands radiocarbon date database assembled for this thesis is available as digital supplementary material through Texas State University's website. It is archived as a comma-separated values (CSV) Excel spreadsheet but is also available in its original format, as a Microsoft Access database. The database is intended to be a tool for future research; however, users are encouraged to reference the original publications cited in the database.

The database contains three tables and one form. The "Master" table contains the data described in Chapter 5. The "Master" form displays these same data as a form. The "Calibrated dates (R_Date)" table contains the calibrated radiocarbon dates for assays used in my analyses, calibrated using OxCal v4.3 (Bronk Ramsey 2009) and the IntCal13 calibration curve (Reimer et al. 2013). Finally, the "R_Combine" table contains the results of combining split-sample assays using the R_Combine command in OxCal. Calibrated date ranges are given in RCYBP (2σ).

## APPENDIX B. RADIOCARBON LABORATORY REPORTS

Lab reports for newly reported radiocarbon assays consist of the DirectAMS lab report with $\delta^{13}C$ for the four assays made for this thesis, a list of all other ASWT radiocarbon assays made at DirectAMS (this is not the original lab report, but was compiled by DirectAMS for this thesis), and three original Beta Analytic lab reports for Eagle Cave assays.

Report: **1936-027494-027497** 28 August 2019

Customer: 1936
Emily McCuistion
Texas State University
701 Columbia Ave.
San Marcos, TX 78666
USA

Samples submitted for radiocarbon dating have been processed and measured by AMS. The following results were obtained:

| DirectAMS code | Submitter ID | Sample type | $\delta(^{13}C)$ | Fraction of modern | | Radiocarbon age | |
|---|---|---|---|---|---|---|---|
| | | | per mil | pMC | 1σ error | BP | 1σ error |
| D-AMS 027494 | CAR-613 | charcoal | -23.3 | 60.17 | 0.20 | 4081 | 27 |
| D-AMS 027495 | CAR-614 | charred plant fiber | -14.1 | 64.50 | 0.22 | 3523 | 27 |
| D-AMS 027496 | FN10509 | plant fiber | -9.8 | 93.90 | 0.27 | 506 | 23 |
| D-AMS 027497 | SCP-268 | bison hair | -7.5 | 95.61 | 0.25 | 361 | 21 |

Results are presented in units of percent modern carbon (pMC) and the uncalibrated radiocarbon age before present (BP). All results have been corrected for isotopic fractionation with an $\delta^{13}C$ value measured on the prepared carbon by the accelerator. These $\delta^{13}C$ values provide the most accurate radiocarbon ages, but cannot be used to investigate environmental conditions, nor for trophic and nutritional interpretations. The pMC reported requires no further correction for fractionation.

Report: **1936-ASWT Compilation** 12 September 2019

Customer: 1936
Emily McCuistion
Texas State University
701 Columbia Ave.
San Marcos, TX 78666
USA

Samples submitted for radiocarbon dating have been processed and measured by AMS. The following results were obtained:

| DirectAMS code | Site ID | Site Name | Report Date | δ($^{13}C$) | Fraction of modern | | Radiocarbon age | |
|---|---|---|---|---|---|---|---|---|
| | | | | per mil | pMC | 1σ error | BP | 1σ error |
| DAMS-010247 | 41VV0167 | Eagle Cave | 31-May-15 | -31.2 | 91.24 | 0.32 | 737 | 29 |
| DAMS-010248 | 41VV0167 | Eagle Cave | 31-May-15 | -23.0 | 92.76 | 0.37 | 604 | 32 |
| DAMS-010257 | 41VV0167 | Eagle Cave | 31-May-15 | -23.2 | 93.12 | 0.32 | 572 | 27 |
| DAMS-010258 | 41VV0167 | Eagle Cave | 31-May-15 | -22.9 | 92.98 | 0.29 | 584 | 25 |
| DAMS-010259 | 41VV0167 | Eagle Cave | 31-May-15 | -30.1 | 93.29 | 0.25 | 558 | 21 |
| DAMS-010260 | 41VV0167 | Eagle Cave | 31-May-15 | -24.5 | 76.50 | 0.26 | 2152 | 27 |
| DAMS-010261 | 41VV0167 | Eagle Cave | 31-May-15 | -23.1 | 55.54 | 0.28 | 4724 | 40 |
| DAMS-011113 | 41VV0167 | Eagle Cave | 9-Jul-15 | -11.3 | 90.50 | 0.25 | 802 | 22 |
| DAMS-011121 | 41VV0167 | Eagle Cave | 9-Jul-15 | -8.1 | 78.32 | 0.30 | 1963 | 31 |
| DAMS-011122 | 41VV0167 | Eagle Cave | 9-Jul-15 | -25.7 | 53.35 | 0.19 | 5047 | 29 |
| DAMS-013530 | 41VV0167 | Eagle Cave | 4-Dec-15 | -11.3 | 47.13 | 0.18 | 6043 | 31 |
| DAMS-013532 | 41VV0167 | Eagle Cave | 4-Dec-15 | -19.3 | 48.81 | 0.18 | 5762 | 30 |
| DAMS-013533 | 41VV0167 | Eagle Cave | 4-Dec-15 | -26.2 | 75.76 | 0.23 | 2230 | 24 |
| DAMS-013534 | 41VV0167 | Eagle Cave | 4-Dec-15 | -19.5 | 75.80 | 0.23 | 2226 | 24 |
| DAMS-013536 | 41VV0167 | Eagle Cave | 4-Dec-15 | -9.5 | 75.36 | 0.22 | 2272 | 23 |
| DAMS-013537 | 41VV0167 | Eagle Cave | 4-Dec-15 | -20.1 | 69.68 | 0.23 | 2902 | 27 |
| DAMS-013538 | 41VV0167 | Eagle Cave | 4-Dec-15 | -29.0 | 57.24 | 0.19 | 4482 | 27 |
| DAMS-013539 | 41VV0167 | Eagle Cave | 4-Dec-15 | -22.5 | 44.72 | 0.17 | 6465 | 31 |
| DAMS-013541 | 41VV0167 | Eagle Cave | 4-Dec-15 | -12.4 | 74.70 | 0.23 | 2343 | 25 |
| DAMS-017952 | 41VV0167 | Eagle Cave | 9-Sep-16 | -19.4 | 76.45 | 0.31 | 2157 | 33 |
| DAMS-017953 | 41VV0167 | Eagle Cave | 9-Sep-16 | -38.8 | 63.43 | 0.25 | 3657 | 32 |
| DAMS-017954 | 41VV0167 | Eagle Cave | 9-Sep-16 | -21.7 | 93.87 | 0.26 | 508 | 22 |
| DAMS-017955 | 41VV0167 | Eagle Cave | 9-Sep-16 | -14.1 | 93.59 | 0.37 | 532 | 32 |
| DAMS-017956 | 41VV0167 | Eagle Cave | 9-Sep-16 | -20.8 | 91.24 | 0.30 | 736 | 26 |

Report: **1936-ASWT Compilation** 12 September 2019

| DirectAMS code | Site ID | Site Name | Report Date | δ($^{13}$C) | Fraction of modern | | Radiocarbon age | |
|---|---|---|---|---|---|---|---|---|
| | | | | per mil | pMC | 1σ error | BP | 1σ error |
| DAMS-017957 | 41VV0167 | Eagle Cave | 9-Sep-16 | -21.6 | 86.99 | 0.30 | 1120 | 28 |
| DAMS-017958 | 41VV0167 | Eagle Cave | 9-Sep-16 | -32.6 | 64.08 | 0.30 | 3575 | 38 |
| DAMS-017959 | 41VV0167 | Eagle Cave | 9-Sep-16 | -19.5 | 63.35 | 0.19 | 3667 | 24 |
| DAMS-018135 | 41VV0167 | Eagle Cave | 20-Sep-16 | -32.4 | 32.52 | 0.21 | 9024 | 52 |
| DAMS-018136 | 41VV0167 | Eagle Cave | 20-Sep-16 | -7.6 | 53.28 | 0.22 | 5058 | 33 |
| DAMS-018137 | 41VV0167 | Eagle Cave | 20-Sep-16 | -3.1 | 62.87 | 0.22 | 3728 | 28 |
| DAMS-018138 | 41VV0167 | Eagle Cave | 20-Sep-16 | -15.1 | 77.59 | 0.21 | 2038 | 22 |
| DAMS-018139 | 41VV0167 | Eagle Cave | 20-Sep-16 | -43.6 | 57.47 | 0.29 | 4450 | 41 |
| DAMS-018140 | 41VV0167 | Eagle Cave | 20-Sep-16 | -50.7 | 48.53 | 0.25 | 5808 | 41 |
| DAMS-018141 | 41VV0167 | Eagle Cave | 20-Sep-16 | -26.1 | 31.40 | 0.19 | 9305 | 49 |
| DAMS-018142 | 41VV0167 | Eagle Cave | 20-Sep-16 | -16.6 | 57.34 | 0.19 | 4468 | 27 |
| DAMS-018143 | 41VV0167 | Eagle Cave | 20-Sep-16 | -26.6 | 32.13 | 0.13 | 9121 | 33 |
| DAMS-018144 | 41VV0167 | Eagle Cave | 20-Sep-16 | -10.8 | 70.04 | 0.21 | 2861 | 24 |
| DAMS-018145 | 41VV0167 | Eagle Cave | 20-Sep-16 | -18.8 | 31.94 | 0.12 | 9168 | 30 |
| DAMS-018146 | 41VV0167 | Eagle Cave | 20-Sep-16 | -20.6 | 32.51 | 0.13 | 9026 | 32 |
| DAMS-018387 | 41VV0166 | Horse Trail Shelter | 30-Sep-16 | -15.2 | 79.95 | 0.23 | 1798 | 23 |
| DAMS-005233 | 41VV0164 | Kelley Cave | 21-Mar-14 | -26.1 | 92.96 | 0.26 | 586 | 22 |
| DAMS-005234 | 41VV0164 | Kelley Cave | 21-Mar-14 | -30.5 | 93.12 | 0.23 | 573 | 20 |
| DAMS-005235 | 41VV0164 | Kelley Cave | 21-Mar-14 | -14.9 | 92.12 | 0.29 | 659 | 25 |
| DAMS-005236 | 41VV0164 | Kelley Cave | 21-Mar-14 | -22.7 | 92.31 | 0.25 | 643 | 22 |
| DAMS-005237 | 41VV0164 | Kelley Cave | 21-Mar-14 | -26.7 | 50.75 | 0.17 | 5448 | 27 |
| DAMS-005238 | 41VV0164 | Kelley Cave | 21-Mar-14 | -25.1 | 66.11 | 0.21 | 3324 | 26 |
| DAMS-005239 | 41VV0164 | Kelley Cave | 21-Mar-14 | -25.9 | 56.34 | 0.19 | 4609 | 27 |
| DAMS-005240 | 41VV0164 | Kelley Cave | 21-Mar-14 | -31.4 | 45.01 | 0.16 | 6413 | 29 |
| DAMS-005241 | 41VV0164 | Kelley Cave | 21-Mar-14 | -32.4 | 45.35 | 0.16 | 6352 | 28 |
| DAMS-005242 | 41VV0164 | Kelley Cave | 21-Mar-14 | -34.1 | 44.15 | 0.15 | 6568 | 27 |
| DAMS-005243 | 41VV0164 | Kelley Cave | 21-Mar-14 | -18.6 | 43.70 | 0.15 | 6650 | 28 |
| DAMS-007759 | 41VV0164 | Kelley Cave | 15-Oct-14 | -21.1 | 44.70 | 0.15 | 6468 | 27 |
| DAMS-007761 | 41VV0164 | Kelley Cave | 15-Oct-14 | -28.6 | 73.68 | 0.19 | 2454 | 21 |
| DAMS-007762 | 41VV0164 | Kelley Cave | 15-Oct-14 | -19.0 | 44.05 | 0.15 | 6586 | 27 |
| DAMS-007763 | 41VV0164 | Kelley Cave | 15-Oct-14 | -26.0 | 64.36 | 0.19 | 3540 | 24 |
| DAMS-010249 | 41VV0164 | Kelley Cave | 31-May-15 | -24.9 | 91.13 | 0.32 | 746 | 29 |
| DAMS-010250 | 41VV0164 | Kelley Cave | 31-May-15 | -20.8 | 88.99 | 0.35 | 937 | 31 |

Report: **1936-ASWT Compilation** 12 September 2019

| DirectAMS code | Site ID | Site Name | Report Date | δ($^{13}$C) | Fraction of modern | | Radiocarbon age | |
|---|---|---|---|---|---|---|---|---|
| | | | | per mil | pMC | 1σ error | BP | 1σ error |
| DAMS-010251 | 41VV0164 | Kelley Cave | 31-May-15 | -29.7 | 91.05 | 0.31 | 753 | 27 |
| DAMS-010252 | 41VV0164 | Kelley Cave | 31-May-15 | -28.5 | 93.00 | 0.22 | 583 | 19 |
| DAMS-010253 | 41VV0164 | Kelley Cave | 31-May-15 | -19.2 | 92.24 | 0.25 | 649 | 22 |
| DAMS-010254 | 41VV0164 | Kelley Cave | 31-May-15 | -21.5 | 88.67 | 0.35 | 966 | 32 |
| DAMS-010255 | 41VV0164 | Kelley Cave | 31-May-15 | -26.3 | 28.80 | 0.16 | 10000 | 45 |
| DAMS-010256 | 41VV0164 | Kelley Cave | 31-May-15 | -27.4 | 44.36 | 0.18 | 6530 | 33 |
| DAMS-011114 | 41VV0164 | Kelley Cave | 9-Jul-15 | -28.1 | 28.71 | 0.12 | 10025 | 34 |
| DAMS-011115 | 41VV0164 | Kelley Cave | 9-Jul-15 | -22.5 | 88.09 | 0.30 | 1019 | 27 |
| DAMS-011116 | 41VV0164 | Kelley Cave | 9-Jul-15 | -23.1 | 93.50 | 0.30 | 540 | 26 |
| DAMS-011118 | 41VV0164 | Kelley Cave | 9-Jul-15 | -23.1 | 92.85 | 0.29 | 596 | 25 |
| DAMS-011119 | 41VV0164 | Kelley Cave | 9-Jul-15 | -24.1 | 93.22 | 0.34 | 564 | 29 |
| DAMS-003370 | 41VV2037 | Little Sotol | 30-Jul-13 | -16.6 | 80.81 | 0.24 | 1712 | 24 |
| DAMS-003501 | 41VV2037 | Little Sotol | 3-Sep-13 | -15.9 | 88.55 | 0.24 | 977 | 22 |
| DAMS-003561 | 41VV2037 | Little Sotol | 30-Sep-13 | -19.1 | 89.48 | 0.32 | 893 | 29 |
| DAMS-007755 | 41VV2167 | Lone Star Bridge Site | 15-Oct-14 | -25.3 | 97.71 | 0.33 | 186 | 27 |
| DAMS-007756 | 41VV2167 | Lone Star Bridge Site | 15-Oct-14 | -20.0 | 95.66 | 0.24 | 356 | 20 |
| DAMS-007757 | 41VV2167 | Lone Star Bridge Site | 15-Oct-14 | -23.4 | 96.10 | 0.22 | 320 | 18 |
| DAMS-007758 | 41VV2167 | Lone Star Bridge Site | 15-Oct-14 | -23.6 | 96.10 | 0.28 | 320 | 23 |
| DAMS-003362 | 41VV2053 | Rancid Cactus Midden | 30-Jul-13 | -3.9 | 89.17 | 0.30 | 921 | 27 |
| DAMS-003363 | 41VV2053 | Rancid Cactus Midden | 30-Jul-13 | -24.3 | 87.91 | 0.29 | 1035 | 26 |
| DAMS-003364 | 41VV2053 | Rancid Cactus Midden | 30-Jul-13 | -20.4 | 87.04 | 0.28 | 1115 | 26 |
| DAMS-003365 | 41VV2053 | Rancid Cactus Midden | 30-Jul-13 | -25.3 | 88.68 | 0.30 | 965 | 27 |
| DAMS-003366 | 41VV2053 | Rancid Cactus Midden | 30-Jul-13 | -27.5 | 86.20 | 0.29 | 1193 | 27 |
| DAMS-003367 | 41VV2053 | Rancid Cactus Midden | 30-Jul-13 | -24.6 | 89.04 | 0.30 | 933 | 27 |

Report: **1936-ASWT Compilation** 12 September 2019

| DirectAMS code | Site ID | Site Name | Report Date | δ($^{13}$C) | Fraction of modern | | Radiocarbon age | |
|---|---|---|---|---|---|---|---|---|
| | | | | per mil | pMC | 1σ error | BP | 1σ error |
| DAMS-003368 | 41VV2053 | Rancid Cactus Midden | 30-Jul-13 | -25.0 | 87.96 | 0.26 | 1031 | 24 |
| DAMS-003494 | 41VV2053 | Rancid Cactus Midden | 3-Sep-13 | -13.5 | 89.32 | 0.26 | 907 | 23 |
| DAMS-003555 | 41VV2053 | Rancid Cactus Midden | 3-Sep-13 | -21.7 | 92.36 | 0.33 | 638 | 28 |
| DAMS-003556 | 41VV2053 | Rancid Cactus Midden | 3-Sep-13 | -20.4 | 88.21 | 0.24 | 1007 | 22 |
| DAMS-017962 | 41VV2239 | Sayles Adobe | 9-Sep-16 | -35.3 | 91.57 | 0.28 | 707 | 25 |
| DAMS-017963 | 41VV2239 | Sayles Adobe | 9-Sep-16 | -24.6 | 70.79 | 0.33 | 2775 | 37 |
| DAMS-017964 | 41VV2239 | Sayles Adobe | 9-Sep-16 | -13.8 | 88.85 | 0.37 | 950 | 33 |
| DAMS-017965 | 41VV2239 | Sayles Adobe | 9-Sep-16 | -29.5 | 69.26 | 0.22 | 2951 | 26 |
| DAMS-017966 | 41VV2239 | Sayles Adobe | 9-Sep-16 | -31.4 | 90.86 | 0.36 | 770 | 32 |
| DAMS-024531 | 41VV2239 | Sayles Adobe | 6-Oct-17 | -23.6 | 36.24 | 0.16 | 8154 | 35 |
| DAMS-024532 | 41VV2239 | Sayles Adobe | 6-Oct-17 | -22.5 | 57.80 | 0.19 | 4404 | 26 |
| DAMS-024533 | 41VV2239 | Sayles Adobe | 6-Oct-17 | -28.7 | 91.31 | 0.26 | 730 | 23 |
| DAMS-024534 | 41VV2239 | Sayles Adobe | 6-Oct-17 | -18.2 | 91.35 | 0.24 | 727 | 21 |
| DAMS-024535 | 41VV2239 | Sayles Adobe | 6-Oct-17 | -18.7 | 35.87 | 0.15 | 8236 | 34 |
| DAMS-005252 | 41VV0165 | Skiles Shelter | 21-Mar-14 | -21.8 | 92.91 | 0.32 | 591 | 28 |
| DAMS-005253 | 41VV0165 | Skiles Shelter | 21-Mar-14 | -22.6 | 93.99 | 0.28 | 498 | 24 |
| DAMS-005254 | 41VV0165 | Skiles Shelter | 21-Mar-14 | -4.6 | 90.44 | 0.31 | 807 | 28 |
| DAMS-005255 | 41VV0165 | Skiles Shelter | 21-Mar-14 | -28.7 | 93.07 | 0.31 | 577 | 27 |
| DAMS-005257 | 41VV0165 | Skiles Shelter | 21-Mar-14 | -7.6 | 90.95 | 0.30 | 762 | 26 |
| DAMS-010262 | 41VV0165 | Skiles Shelter | 31-May-15 | -12.1 | 44.52 | 0.20 | 6500 | 36 |
| DAMS-010263 | 41VV0165 | Skiles Shelter | 31-May-15 | -21.5 | 89.87 | 0.29 | 858 | 26 |
| DAMS-010264 | 41VV0165 | Skiles Shelter | 31-May-15 | -29.6 | 91.49 | 0.30 | 715 | 26 |
| DAMS-011120 | 41VV0165 | Skiles Shelter | 9-Jul-15 | -24.3 | 91.57 | 0.26 | 707 | 23 |
| DAMS-031626 | 41VV0165 | Skiles Shelter | 31-Jan-19 | -9.7 | 92.58 | 0.27 | 619 | 23 |
| DAMS-031627 | 41VV0165 | Skiles Shelter | 31-Jan-19 | -17.3 | 91.76 | 0.30 | 691 | 26 |
| DAMS-031628 | 41VV0165 | Skiles Shelter | 31-Jan-19 | 0.7 | 90.57 | 0.31 | 796 | 27 |
| DAMS-031629 | 41VV0165 | Skiles Shelter | 31-Jan-19 | -9.6 | 65.00 | 0.25 | 3460 | 31 |
| DAMS-031630 | 41VV0165 | Skiles Shelter | 31-Jan-19 | -1.2 | 87.56 | 0.31 | 1067 | 28 |
| DAMS-031631 | 41VV0165 | Skiles Shelter | 31-Jan-19 | -17.2 | 87.43 | 0.34 | 1079 | 31 |
| DAMS-003361 | 41VV1340 | Spool shelter | 30-Jul-13 | -5.9 | 78.73 | 0.26 | 1921 | 27 |

DirectAMS
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Report: **1936-ASWT Compilation** 12 September 2019

| DirectAMS code | Site ID | Site Name | Report Date | δ($^{13}$C) | Fraction of modern | | Radiocarbon age | |
|---|---|---|---|---|---|---|---|---|
| | | | | per mil | pMC | 1σ error | BP | 1σ error |
| DAMS-003490 | 41VV1340 | Spool shelter | 3-Sep-13 | -8.2 | 79.46 | 0.27 | 1847 | 27 |
| DAMS-003491 | 41VV1340 | Spool shelter | 3-Sep-13 | -5.9 | 81.97 | 0.26 | 1597 | 25 |
| DAMS-003492 | 41VV1340 | Spool shelter | 3-Sep-13 | -17.1 | 89.43 | 0.31 | 897 | 28 |
| DAMS-003493 | 41VV1340 | Spool shelter | 3-Sep-13 | -14.4 | 92.22 | 0.30 | 651 | 26 |
| DAMS-003550 | 41VV1340 | Spool shelter | 30-Sep-13 | -21.0 | 91.31 | 0.27 | 730 | 24 |
| DAMS-003551 | 41VV1340 | Spool shelter | 3-Sep-13 | -18.9 | 87.66 | 0.27 | 1058 | 25 |
| DAMS-003552 | 41VV1340 | Spool shelter | 3-Sep-13 | -19.5 | 93.69 | 0.28 | 524 | 24 |
| DAMS-003553 | 41VV1340 | Spool shelter | 3-Sep-13 | -16.2 | 58.48 | 0.19 | 4310 | 26 |
| DAMS-003554 | 41VV1340 | Spool shelter | 3-Sep-13 | -28.1 | 84.80 | 0.24 | 1324 | 22 |
| DAMS-005245 | 41VV0890 | Torres Ranch House Site | 21-Mar-14 | -19.5 | 95.16 | 0.27 | 399 | 23 |
| DAMS-005246 | 41VV0890 | Torres Ranch House Site | 21-Mar-14 | -21.1 | 94.11 | 0.29 | 488 | 25 |
| DAMS-005247 | 41VV0890 | Torres Ranch House Site | 21-Mar-14 | -27.4 | 94.43 | 0.28 | 460 | 24 |
| DAMS-005248 | 41VV0890 | Torres Ranch House Site | 21-Mar-14 | -21.1 | 94.06 | 0.31 | 492 | 26 |
| DAMS-005249 | 41VV0890 | Torres Ranch House Site | 21-Mar-14 | -21.7 | 97.89 | 0.41 | 171 | 34 |
| DAMS-005250 | 41VV0890 | Torres Ranch House Site | 21-Mar-14 | -25.1 | 96.69 | 0.30 | 270 | 25 |
| DAMS-007750 | 41VV0890 | Torres Ranch House Site | 15-Oct-14 | -24.4 | 92.34 | 0.24 | 640 | 21 |
| DAMS-007751 | 41VV0890 | Torres Ranch House Site | 15-Oct-14 | -24.8 | 93.94 | 0.20 | 502 | 17 |
| DAMS-007752 | 41VV0890 | Torres Ranch House Site | 15-Oct-14 | -9.3 | 98.55 | 0.22 | 117 | 18 |
| DAMS-007753 | 41VV0890 | Torres Ranch House Site | 15-Oct-14 | -21.8 | 92.64 | 0.21 | 614 | 18 |
| DAMS-007754 | 41VV0890 | Torres Ranch House Site | 15-Oct-14 | -23.6 | 93.11 | 0.21 | 573 | 18 |
| DAMS-003369 | 41VV2055 | Tractor Terrace Midden | 30-Jul-13 | -10.0 | 53.23 | 0.19 | 5065 | 28 |
| DAMS-003495 | 41VV2055 | Tractor Terrace Midden | 3-Sep-13 | -4.9 | 83.42 | 0.30 | 1456 | 29 |

Report: **1936-ASWT Compilation** 12 September 2019

| DirectAMS code | Site ID | Site Name | Report Date | $\delta(^{13}C)$ | Fraction of modern | | Radiocarbon age | |
|---|---|---|---|---|---|---|---|---|
| | | | | per mil | pMC | 1σ error | BP | 1σ error |
| DAMS-003496 | 41VV2055 | Tractor Terrace Midden | 3-Sep-13 | -4.4 | 54.51 | 0.21 | 4874 | 31 |
| DAMS-003497 | 41VV2055 | Tractor Terrace Midden | 3-Sep-13 | -6.7 | 82.83 | 0.24 | 1513 | 23 |
| DAMS-003498 | 41VV2055 | Tractor Terrace Midden | 3-Sep-13 | -20.2 | 80.29 | 0.26 | 1763 | 26 |
| DAMS-003557 | 41VV2055 | Tractor Terrace Midden | 3-Sep-13 | -29.6 | 77.82 | 0.27 | 2014 | 28 |
| DAMS-003558 | 41VV2055 | Tractor Terrace Midden | 3-Sep-13 | -24.0 | 84.58 | 0.33 | 1345 | 31 |
| DAMS-003559 | 41VV2055 | Tractor Terrace Midden | 3-Sep-13 | -11.7 | 78.78 | 0.22 | 1916 | 22 |
| DAMS-003560 | 41VV2055 | Tractor Terrace Midden | 3-Sep-13 | -11.7 | 59.49 | 0.20 | 4172 | 27 |

Results are presented in units of percent modern carbon (pMC) and the uncalibrated radiocarbon age before present (BP). All results have been corrected for isotopic fractionation with an $\delta^{13}C$ value measured on the prepared carbon by the accelerator. These $\delta^{13}C$ values provide the most accurate radiocarbon ages, but cannot be used to investigate environmental conditions, nor for trophic and nutritional interpretations. The pMC reported requires no further correction for fractionation.

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**Darden Hood**
President

**Ronald Hatfield**
**Christopher Patrick**
Deputy Directors

September 29, 2016

Dr. Stephen L. Black
Texas State University
Anthropology
601 University Drive
San Marcos, TX 78666
USA

RE: Radiocarbon Dating Results.

Dear Dr. Black:

Enclosed are the radiocarbon dating results for two samples recently sent to us. As usual, the method of analysis is listed on the report with the results and calibration data is provided where applicable. The Conventional Radiocarbon Ages have all been corrected for total fractionation effects and where applicable, calibration was performed using 2013 calibration databases (cited on the graph pages).

The web directory containing the table of results and PDF download also contains pictures, a cvs spreadsheet download option and a quality assurance report containing expected vs. measured values for 3-5 working standards analyzed simultaneously with your samples.

Reported results are accredited to ISO/IEC 17025:2005 Testing Accreditation PJLA #59423 standards and all chemistry was performed here in our laboratory and counted in our own accelerators here. Since Beta is not a teaching laboratory, only graduates trained to strict protocols of the ISO/IEC 17025:2005 Testing Accreditation PJLA #59423 program participated in the analyses.

As always Conventional Radiocarbon Ages and sigmas are rounded to the nearest 10 years per the conventions of the 1977 International Radiocarbon Conference. When counting statistics produce sigmas lower than +/- 30 years, a conservative +/- 30 BP is cited for the result. The reported d13C values were measured separately in an IRMS (isotope ratio mass spectrometer). They are NOT the AMS d13C which would include fractionation effects from natural, chemistry and AMS induced sources.

When interpreting the results, please consider any communications you may have had with us regarding the samples. As always, your inquiries are most welcome. If you have any questions or would like further details of the analyses, please do not hesitate to contact us.

Our invoice will be emailed separately. Please, forward it to the appropriate officer or send a credit card authorization. Thank you. As always, if you have any questions or would like to discuss the results, don't hesitate to contact me.

Sincerely,

Darden Hood
Digital signature on file

Beta Analytic Inc.
DR. M.A. TAMERS and MR. D.G. HOOD
4985 S.W. 74 COURT
MIAMI, FLORIDA, USA 33155
**PH:** 305-667-5167 **FAX:** 305-663-0964
beta@radiocarbon.com

# REPORT OF RADIOCARBON DATING ANALYSES

Dr. Stephen L. Black — Report Date: 9/29/2016

Texas State University — Material Received: 9/20/2016

| Sample Data | Measured Radiocarbon Age | Isotopes Results o/oo | Conventional Radiocarbon Age(*) |
|---|---|---|---|
| Beta - 445875 | 8290 +/- 30 BP | d13C= -26.4 | 8270 +/- 30 BP |

SAMPLE: 41VV167-FN34781
ANALYSIS: AMS-Standard delivery
MATERIAL/PRETREATMENT: (charred material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal BC 7450 to 7395 (Cal BP 9400 to 9345) and Cal BC 7375 to 7185 (Cal BP 9325 to 9135)
Cal BC 7375 to 7185 (Cal BP 9325 to 9135)

| Sample Data | Measured Radiocarbon Age | Isotopes Results o/oo | Conventional Radiocarbon Age(*) |
|---|---|---|---|
| Beta - 445876 | 11180 +/- 40 BP | d13C= -23.7 | 11200 +/- 40 BP |

SAMPLE: 41VV167-FN35575
ANALYSIS: AMS-Standard delivery
MATERIAL/PRETREATMENT: (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 11165 to 11080 (Cal BP 13115 to 13030) and

Results are ISO-17025 accredited. AMS measurements were made on one of 4 in-house NEC SSAMS accelerator mass spectrometers.The reported age is the "Conventional Radiocarbon Age", corrected for isotopic fraction using the d13C. Age is reported as RCYBP (radiocarbon years before present, abbreviated as BP, "present" = AD 1950). By international convention, the modern reference standard was 95% the 14C signature of NBS SRM-4990C (oxalic acid) and calculated using the Libby 14C half life (5568 years). Quoted error on the BP date is 1 sigma (1 relative standard deviation with 68% probability) of counting error (only) on the combined measurements of sample, background and modern reference standards. Total error at Beta (counting + laboratory) is known to be well within +/- 2 sigma. d13C values are reported in parts per thousand (per mil) relative to PDB-1 measured on a Thermo Delta Plus IRMS. Typical d13C error is +/- 0.3 o/oo. Percent modern carbon (pMC) and Delta 14C (D14C) are not absolute. They equate to the Conventional Radiocarbon Age. Calendar calibrated results were calculated the material appropriate 2013 database (INTCAL13, MARINE13 or SHCAL13). See graph report for references.

# CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12 = -26.4 o/oo : lab. mult = 1)

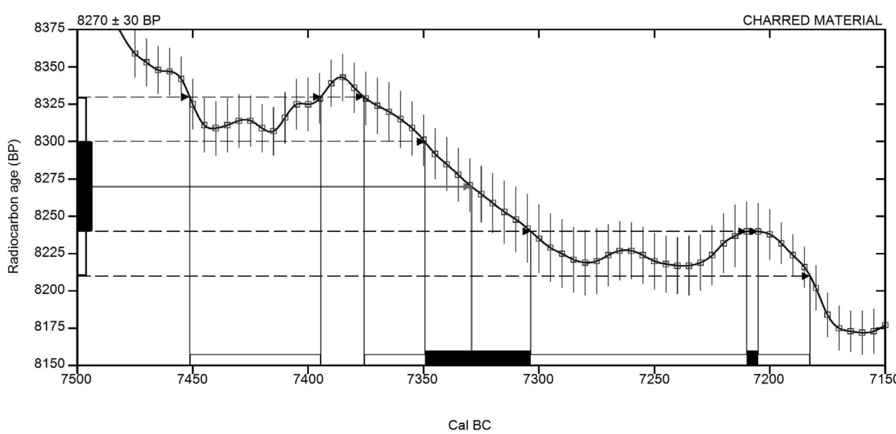
**Laboratory number** **Beta-445875 : 41VV167-FN34781**

**Conventional radiocarbon age** **8270 ± 30 BP**

**Calibrated Result (95% Probability)** **Cal BC 7450 to 7395 (Cal BP 9400 to 9345)**
**Cal BC 7375 to 7185 (Cal BP 9325 to 9135)**

Intercept of radiocarbon age with calibration curve Cal BC 7330 (Cal BP 9280)

Calibrated Result (68% Probability) Cal BC 7350 to 7305 (Cal BP 9300 to 9255)
Cal BC 7210 to 7205 (Cal BP 9160 to 9155)




**Database used**
**INTCAL13**

**References**
**Mathematics used for calibration scenario**

A Simplified Approach to Calibrating C14 Dates, Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2):317-322

**References to INTCAL13 database**

Reimer PJ et al. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. Radiocarbon 55(4):1869–1887., 2013.



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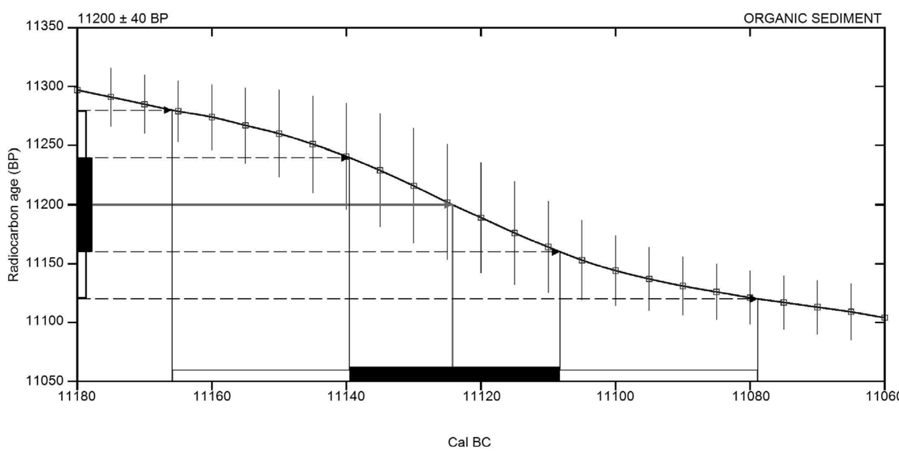
# CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12 = -23.7 o/oo : lab. mult = 1)

| | |
|---|---|
| **Laboratory number** | **Beta-445876 : 41VV167-FN35575** |
| **Conventional radiocarbon age** | **11200 ± 40 BP** |
| **Calibrated Result (95% Probability)** | **Cal BC 11165 to 11080 (Cal BP 13115 to 13030)** |
| Intercept of radiocarbon age with calibration curve | Cal BC 11125 (Cal BP 13075) |
| Calibrated Result (68% Probability) | Cal BC 11140 to 11110 (Cal BP 13090 to 13060) |




**Database used**
**INTCAL13**

**References**
**Mathematics used for calibration scenario**

A Simplified Approach to Calibrating C14 Dates, Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2):317-322

**References to INTCAL13 database**

Reimer PJ et al. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. Radiocarbon 55(4):1869–1887., 2013.



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**Darden Hood**
President

**Ronald Hatfield**
**Christopher Patrick**
Deputy Directors

October 28, 2016

Dr. Raymond Mauldin
University of Texas
Center for Archaeological Research
One UTSA Circle
San Antonio, TX 78249
USA

RE: Radiocarbon Dating Results.

Dear Dr. Mauldin:

Enclosed is the radiocarbon dating result for one sample recently sent to us. As usual, specifics of the analysis are listed on the report with the result and calibration data is provided where applicable. The Conventional Radiocarbon Age has been corrected for total fractionation effects and where applicable, calibration was performed using 2013 calibration databases (cited on the graph pages).

The web directory containing the table of results and PDF download also contains pictures, a cvs spreadsheet download option and a quality assurance report containing expected vs. measured values for 3-5 working standards analyzed simultaneously with your samples.

The reported result is accredited to ISO/IEC 17025:2005 Testing Accreditation PJLA #59423 standards and all pretreatments and chemistry were performed here in our laboratories and counted in our own accelerators here in Miami. Since Beta is not a teaching laboratory, only graduates trained to strict protocols of the ISO/IEC 17025:2005 Testing Accreditation PJLA #59423 program participated in the analysis.

As always Conventional Radiocarbon Ages and sigmas are rounded to the nearest 10 years per the conventions of the 1977 International Radiocarbon Conference. When counting statistics produce sigmas lower than +/- 30 years, a conservative +/- 30 BP is cited for the result. The reported d13C was measured separately in an IRMS (isotope ratio mass spectrometer). It is NOT the AMS d13C which would include fractionation effects from natural, chemistry and AMS induced sources.

When interpreting the result, please consider any communications you may have had with us regarding the sample. As always, your inquiries are most welcome. If you have any questions or would like further details of the analysis, please do not hesitate to contact us.

Thank you for prepaying the analyses. As always, if you have any questions or would like to discuss the results, don't hesitate to contact me.

Sincerely ,

Darden Hood
Digital signature on file

Beta Analytic Inc.
DR. M.A. TAMERS and MR. D.G. HOOD

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MIAMI, FLORIDA, USA 33155
**PH:** 305-667-5167 **FAX:** 305-663-0964
beta@radiocarbon.com

# REPORT OF RADIOCARBON DATING ANALYSES

Dr. Raymond Mauldin — Report Date: 10/28/2016

University of Texas — Material Received: 10/19/2016

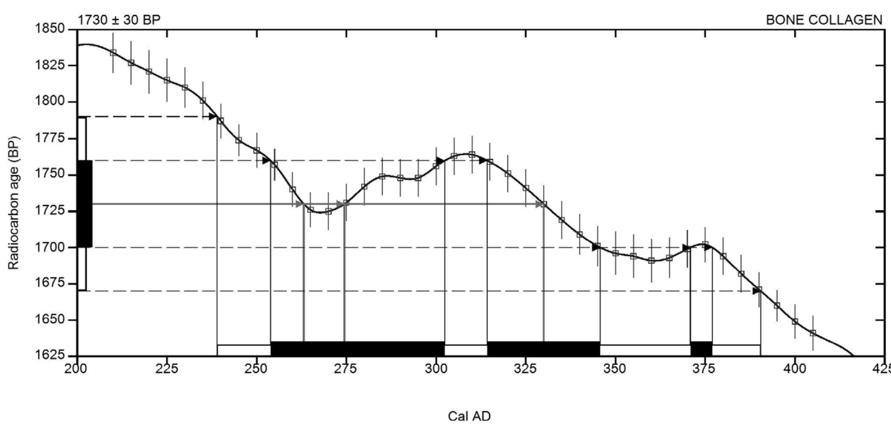
| Sample Data | Measured Radiocarbon Age | Isotopes Results o/oo | Conventional Radiocarbon Age(*) |
|---|---|---|---|
| Beta - 448091<br>SAMPLE: 41VV166H205B<br>ANALYSIS: AMS-Standard delivery<br>MATERIAL/PRETREATMENT: (bone collagen): collagen extraction: with alkali<br>2 SIGMA CALIBRATION : Cal AD 240 to 390 (Cal BP 1710 to 1560) | 1490 +/- 30 BP | d13C= -10.4<br>d15N= 10.8 | 1730 +/- 30 BP |

Results are ISO/IEC-17025:2005 accredited. AMS measurements were made on one of 4 in-house NEC SSAMS accelerator mass spectrometers.The reported age is the "Conventional Radiocarbon Age", corrected for isotopic fraction using the d13C. Age is reported as RCYBP (radiocarbon years before present, abbreviated as BP, "present" = AD 1950). By international convention, the modern reference standard was 95% the 14C signature of NBS SRM-4990C (oxalic acid) and calculated using the Libby 14C half life (5568 years). Quoted error on the BP date is 1 sigma (1 relative standard deviation with 68% probability) of counting error (only) on the combined measurements of sample, background and modern reference standards. Total error at Beta (counting + laboratory) is known to be well within +/- 2 sigma. d13C values are reported in parts per thousand (per mil) relative to PDB-1 measured on a Thermo Delta Plus IRMS. Typical d13C error is +/- 0.3 o/oo. Percent modern carbon (pMC) and Delta 14C (D14C) are not absolute. They equate to the Conventional Radiocarbon Age. Calendar calibrated results were calculated the material appropriate 2013 database (INTCAL13, MARINE13 or SHCAL13). See graph report for references.

## CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12 = -10.4 o/oo : lab. mult = 1)

| | |
|---|---|
| **Laboratory number** | **Beta-448091 : 41VV166H205B** |
| **Conventional radiocarbon age** | **1730 ± 30 BP** |
| **Calibrated Result (95% Probability)** | **Cal AD 240 to 390 (Cal BP 1710 to 1560)** |
| Intercept of radiocarbon age with calibration curve | Cal AD 265 (Cal BP 1685)<br>Cal AD 275 (Cal BP 1675)<br>Cal AD 330 (Cal BP 1620) |
| Calibrated Result (68% Probability) | Cal AD 255 to 300 (Cal BP 1695 to 1650)<br>Cal AD 315 to 345 (Cal BP 1635 to 1605)<br>Cal AD 370 to 375 (Cal BP 1580 to 1575) |




**Database used**
**INTCAL13**

**References**


**Mathematics used for calibration scenario**
A Simplified Approach to Calibrating C14 Dates, Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2):317-322
**References to INTCAL13 database**
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ISO/IEC 17025:2005-Accredited Testing Laboratory

January 28, 2019

Dr. Jim I. Mead
The Mammoth Site
PO Box 692
Hot Springs, SD 57747
USA

RE: Radiocarbon Dating Results

Dear Dr. Mead,

Enclosed is the radiocarbon dating result for one sample recently sent to us. As usual, specifics of the analysis are listed on the report with the result and calibration data is provided where applicable. The Conventional Radiocarbon Age has been corrected for total fractionation effects and where applicable, calibration was performed using 2013 calibration databases (cited on the graph pages).

The web directory containing the table of results and PDF download also contains pictures, a cvs spreadsheet download option and a quality assurance report containing expected vs. measured values for 3-5 working standards analyzed simultaneously with your samples.

The reported result is accredited to ISO/IEC 17025:2005 Testing Accreditation PJLA #59423 standards and all pretreatments and chemistry were performed here in our laboratories and counted in our own accelerators here in Miami. Since Beta is not a teaching laboratory, only graduates trained to strict protocols of the ISO/IEC 17025:2005 Testing Accreditation PJLA #59423 program participated in the analysis.

As always Conventional Radiocarbon Ages and sigmas are rounded to the nearest 10 years per the conventions of the 1977 International Radiocarbon Conference. When counting statistics produce sigmas lower than +/- 30 years, a conservative +/- 30 BP is cited for the result. The reported d13C was measured separately in an IRMS (isotope ratio mass spectrometer). It is NOT the AMS d13C which would include fractionation effects from natural, chemistry and AMS induced sources.

When interpreting the result, please consider any communications you may have had with us regarding the sample. As always, your inquiries are most welcome. If you have any questions or would like further details of the analysis, please do not hesitate to contact us.

Thank you for prepaying the analyses. As always, if you have any questions or would like to discuss the results, don't hesitate to contact us.

Sincerely,

Digital signature on file

Ronald E. Hatfield Director

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Miami, Florida 33155
Tel: 305-667-5167
Fax: 305-663-0964
info@betalabservices.com

BETA Beta Analytic TESTING LABORATORY

ISO/IEC 17025:2005-Accredited Testing Laboratory

## REPORT OF RADIOCARBON DATING ANALYSES

Jim I. Mead — Report Date: January 28, 2019

The Mammoth Site — Material Received: January 17, 2019

| Laboratory Number | Sample Code Number | Conventional Radiocarbon Age (BP) or Percent Modern Carbon (pMC) & Stable Isotopes<br>Calendar Calibrated Results: 95.4 % Probability High Probability Density Range Method (HPD) | |
|---|---|---|---|
| **Beta - 516053** | **EC-1dung** | **10500 +/- 40 BP** | IRMS δ13C: -18.5 o/oo |

| | | |
|---|---|---|
| **(91.4%)** | **10641 - 10429 cal BC** | **(12590 - 12378 cal BP)** |
| **( 2.9%)** | **10331 - 10287 cal BC** | **(12280 - 12236 cal BP)** |
| **( 1.0%)** | **10383 - 10354 cal BC** | **(12332 - 12303 cal BP)** |

Submitter Material: Dung
Pretreatment: (dung) acid/alkali/acid
Analyzed Material: Dung
Analysis Service: AMS-Standard delivery
Percent Modern Carbon: 27.06 +/- 0.13 pMC
Fraction Modern Carbon: 0.2706 +/- 0.0013
D14C: -729.40 +/- 1.35 o/oo
Δ14C: -731.65 +/- 1.35 o/oo(1950:2,019.00)
Measured Radiocarbon Age: (without d13C correction): 10390 +/- 40 BP
Calibration: BetaCal3.21: HPD method: INTCAL13

Results are ISO/IEC-17025:2005 accredited. No sub-contracting or student labor was used in the analyses. All work was done at Beta in 4 in-house NEC accelerator mass spectrometers and 4 Thermo IRMSs. The "Conventional Radiocarbon Age" was calculated using the Libby half-life (5568 years), is corrected for total isotopic fraction and was used for calendar calibration where applicable. The Age is rounded to the nearest 10 years and is reported as radiocarbon years before present (BP), "present" = AD 1950. Results greater than the modern reference are reported as percent modern carbon (pMC). The modern reference standard was 95% the 14C signature of NIST SRM-4990C (oxalic acid). Quoted errors are 1 sigma counting statistics. Calculated sigmas less than 30 BP on the Conventional Radiocarbon Age are conservatively rounded up to 30. d13C values are on the material itself (not the AMS d13C). d13C and d15N values are relative to VPDB-1. References for calendar calibrations are cited at the bottom of calibration graph pages.

BetaCal 3.21

# Calibration of Radiocarbon Age to Calendar Years

(High Probability Density Range Method (HPD): INTCAL13)

(Variables: d13C = -18.5 o/oo)

**Laboratory number** **Beta-516053**

**Conventional radiocarbon age** **10500 ± 40 BP**

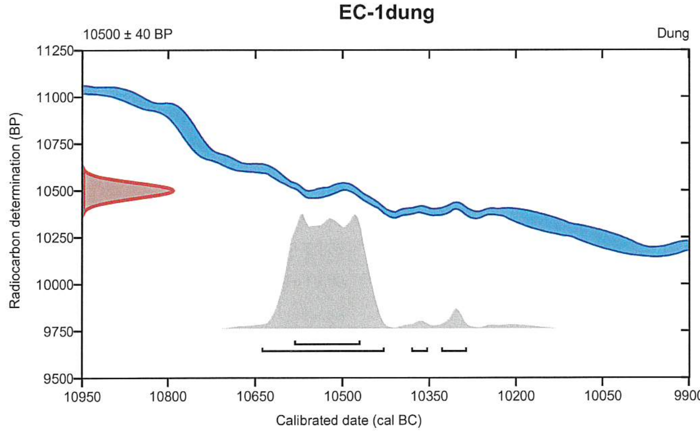
95.4% probability

| | | |
|---|---|---|
| (91.4%) | 10641 - 10429 cal BC | (12590 - 12378 cal BP) |
| (2.9%) | 10331 - 10287 cal BC | (12280 - 12236 cal BP) |
| (1%) | 10383 - 10354 cal BC | (12332 - 12303 cal BP) |

68.2% probability

| | | |
|---|---|---|
| (68.2%) | 10585 - 10471 cal BC | (12534 - 12420 cal BP) |

**EC-1dung**




**Database used**
**INTCAL13**

**References**

**References to Probability Method**
Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1), 337-360.
**References to Database INTCAL13**
Reimer, et.al., 2013, Radiocarbon55(4).

**Beta Analytic Radiocarbon Dating Laboratory**
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**Beta Analytic Inc**
4985 SW 74 Court
Miami, Florida 33155
Tel: 305-667-5167
Fax: 305-663-0964
info@betalabservices.com

BETA Beta Analytic TESTING LABORATORY

ISO/IEC 17025:2005-Accredited Testing Laboratory

## Quality Assurance Report

This report provides the results of reference materials used to validate radiocarbon analyses prior to reporting. Known-value reference materials were analyzed quasi-simultaneously with the unknowns. Results are reported as expected values vs measured values. Reported values are calculated relative to NIST SRM-4990B and corrected for isotopic fractionation. Results are reported using the direct analytical measure percent modern carbon (pMC) with one relative standard deviation. Agreement between expected and measured values is taken as being within 2 sigma agreement (error x 2) to account for total laboratory error.

**Report Date:** January 28, 2019
**Submitter:** Dr. Jim I. Mead

### QA MEASUREMENTS

Reference 1

| | |
|---|---|
| Expected Value: | 129.41 +/- 0.06 pMC |
| Measured Value: | 129.36 +/- 0.43 pMC |
| Agreement: | Accepted |

Reference 2

| | |
|---|---|
| Expected Value: | 0.51 +/-0.04 |
| Measured Value: | 0.51 +/- 0.04 pMC |
| Agreement: | Accepted |

Reference 3

| | |
|---|---|
| Expected Value: | 96.69 +/- 0.50 pMC |
| Measured Value: | 96.91 +/- 0.35 pMC |
| Agreement: | Accepted |

COMMENT: All measurements passed acceptance tests.

Validation: R.E. Hatfield
Digital signature on file

Date: January 28, 2019

# APPENDIX C. OXCAL CQL CODE FOR RADIOCARBON MODELS

This section contains CQL code for replicating analyses presented in this thesis, including both higher and lower confidence earth oven models, the fiber artifact model, and the summed probability distribution.

High Confidence Earth Oven model:

```
Plot()
 {
  Sequence("EO high confidence")
  {
   Boundary("start");
   Phase("EO Phase")
   {
    R_Date("DAMS-018141", 9305, 49);
    R_Date("DAMS-018146", 9026, 32);
    R_Date("DAMS-018135", 9024, 52);
    R_Date("DAMS-010256", 6530, 33);
    R_Date("DAMS-010262", 6500, 36);
    R_Date("DAMS-005240", 6413, 29);
    R_Date("DAMS-005241", 6352, 28);
    R_Date("UCIAMS-109325", 6115, 20);
    R_Date("UCIAMS-109328", 6100, 20);
    R_Date("Tx-6947", 5920, 120);
    R_Date("DAMS-003369", 5065, 28);
    R_Date("DAMS-018136", 5058, 33);
    R_Date("DAMS-003496", 4874, 31);
    R_Date("UCIAMS-109321", 4755, 15);
    R_Date("DAMS-013538", 4482, 27);
    R_Date("DAMS-018142", 4468, 27);
    R_Date("DAMS-003553", 4310, 26);
    R_Date("DAMS-003560", 4172, 27);
    R_Date("UCIAMS-109326", 3795, 15);
    R_Date("DAMS-031629", 3460, 31);
    R_Date("DAMS-013537", 2902, 27);
    R_Date("DAMS-013533", 2230, 24);
    R_Date("DAMS-010260", 2152, 27);
    R_Date("DAMS-003557", 2014, 28);
    R_Date("GX-16198", 1980, 80);
    R_Date("DAMS-011121", 1963, 31);
    R_Date("DAMS-003361", 1921, 27);
    R_Date("DAMS-003559", 1916, 22);
    R_Date("DAMS-003490", 1847, 27);
```

```
R_Date("DAMS-003498", 1763, 26);
R_Date("DAMS-003370", 1712, 24);
R_Date("DAMS-003491", 1597, 25);
R_Date("UCIAMS-176090", 1575, 15);
R_Date("UCIAMS-176089", 1560, 15);
R_Date("DAMS-003497", 1513, 23);
R_Date("Beta-168046", 1490, 40);
R_Date("DAMS-003495", 1456, 29);
R_Date("DAMS-003558", 1345, 31);
R_Date("DAMS-003554", 1324, 22);
R_Date("Beta-250376", 1300, 40);
R_Date("DAMS-003366", 1193, 27);
R_Date("Beta-262710", 1150, 40);
R_Date("Beta-168048", 1130, 40);
R_Date("DAMS-003364", 1115, 26);
R_Date("DAMS-031631", 1079, 31);
R_Date("Beta-262711", 1070, 40);
R_Date("DAMS-031630", 1067, 28);
R_Date("DAMS-003551", 1058, 25);
R_Date("DAMS-003363", 1035, 26);
R_Date("DAMS-003368", 1031, 24);
R_Date("DAMS-003556", 1007, 22);
R_Date("UCIAMS-109318", 995, 15);
R_Date("DAMS-003501", 977, 22);
R_Date("DAMS-003365", 965, 27);
R_Date("Beta-262708", 960, 40);
R_Date("DAMS-017964", 950, 33);
R_Date("DAMS-003367", 933, 27);
R_Date("Beta-262713", 930, 40);
R_Date("DAMS-003362", 921, 27);
R_Date("DAMS-003494", 907, 23);
R_Date("DAMS-003492", 897, 28);
R_Date("DAMS-003561", 893, 29);
R_Date("Beta-262714", 890, 40);
R_Date("Beta-262709", 880, 40);
R_Date("UCIAMS-109324", 860, 15);
R_Date("Beta-262715", 860, 40);
R_Date("Beta-262712", 860, 40);
R_Date("DAMS-010263", 858, 26);
R_Date("UCIAMS-109323", 815, 15);
R_Date("Beta-168044", 810, 40);
R_Date("DAMS-005254", 807, 28);
R_Date("DAMS-031628", 796, 27);
R_Date("Beta-168041", 780, 40);
R_Date("DAMS-017966", 770, 32);
R_Date("DAMS-005257", 762, 26);
R_Date("DAMS-024533", 730, 23);
R_Date("DAMS-003550", 730, 24);
R_Date("DAMS-017962", 707, 25);
R_Date("DAMS-011120", 707, 23);
R_Date("DAMS-031627", 691, 26);
R_Date("Beta-108178", 660, 50);
R_Date("DAMS-003493", 651, 26);
```

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    R_Date("Beta-168047", 650, 40);
    R_Date("DAMS-010253", 649, 22);
    R_Date("DAMS-007750", 640, 21);
    R_Date("DAMS-003555", 638, 28);
    R_Date("DAMS-007753", 614, 18);
    R_Date("DAMS-011118", 596, 25);
    R_Date("DAMS-010258", 584, 25);
    R_Date("DAMS-007754", 573, 18);
    R_Date("Beta-168043", 570, 40);
    R_Date("DAMS-010259", 558, 21);
    R_Date("DAMS-003552", 524, 24);
    R_Date("DAMS-005248", 492, 26);
    R_Date("Beta-168042", 490, 40);
    R_Date("DAMS-005246", 488, 25);
    R_Date("DAMS-005247", 460, 24);
    R_Date("DAMS-005245", 399, 23);
    R_Date("DAMS-007756", 356, 20);
    R_Date("DAMS-007757", 320, 18);
    R_Date("DAMS-007758", 320, 23);
    R_Date("DAMS-007755", 186, 27);
    R_Date("DAMS-007752", 117, 18);
   };
   Boundary("end");
  };
 };
```

Lower Confidence Earth Oven model:

```
Plot()
 {
  Sequence("EO 2T")
  {
   Boundary("Start");
   Phase("EO lower confidence Phase")
   {
    R_Date("DAMS-018141", 9305, 49);
    R_Date("Tx-129", 9030, 235);
    R_Date("DAMS-018146", 9026, 32);
    R_Date("DAMS-018135", 9024, 52);
    R_Date("Tx-128", 8910, 148);
    R_Date("Tx-107", 8760, 158);
    R_Date("Tx-108", 8680, 158);
    R_Date("DAMS-024535", 8236, 34);
    R_Date("DAMS-024531", 8154, 35);
    R_Date("Tx-2736", 7490, 111);
    R_Date("Tx-2738", 7470, 129);
    R_Date("Tx-314", 7430, 245);
    R_Date("Tx-4335", 6800, 167);
    R_Date("Tx-2316", 6750, 111);
    R_Date("Tx-2744", 6540, 85);
```

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R_Date("DAMS-005241", 6352, 28);
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R_Date("Tx-2732", 6230, 102);
R_Date("UCIAMS-109325", 6115, 20);
R_Date("UCIAMS-109328", 6100, 20);
R_Date("DAMS-013530", 6043, 31);
R_Date("Tx-6947", 5920, 120);
R_Date("Tx-4336", 5650, 148);
R_Date("Tx-4334", 5500, 93);
R_Date("Tx-313", 5360, 177);
R_Date("Tx-6878", 5210, 70);
R_Date("DAMS-003369", 5065, 28);
R_Date("DAMS-018136", 5058, 33);
R_Date("DAMS-003496", 4874, 31);
R_Date("Tx-1762b", 4803, 96);
R_Date("Tx-312", 4790, 148);
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R_Date("UCIAMS-109321", 4755, 15);
R_Date("Tx-137", 4740, 148);
R_Date("UCIAMS-192582", 4615, 15);
R_Date("Tx-196", 4580, 120);
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R_Date("UCIAMS-192579", 4475, 15);
R_Date("DAMS-018142", 4468, 27);
R_Date("SI-1399", 4465, 120);
R_Date("Tx-538", 4430, 93);
R_Date("DAMS-024532", 4404, 26);
R_Date("DAMS-003553", 4310, 26);
R_Date("DAMS-003560", 4172, 27);
R_Date("Tx-193", 4170, 93);
R_Date("UCIAMS-192585", 4165, 15);
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R_Date("Tx-287", 4080, 383);
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R_Date("UCIAMS-192580", 3835, 15);
R_Date("UCIAMS-109326", 3795, 15);
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R_Date("Tx-1975", 3600, 85);
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R_Date("Tx-1761", 3310, 102);
R_Date("Tx-663", 3080, 102);
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R_Date("DAMS-018144", 2861, 24);
R_Date("Beta-391409", 2610, 30);
R_Date("Tx-1977", 2520, 69);
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R_Date("Tx-286", 2410, 148);
R_Date("Ua-15511", 2370, 60);
R_Date("Tx-76", 2300, 167);
R_Date("Ua-15386", 2280, 90);
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R_Date("UCIAMS-192583", 2260, 15);
R_Date("UCIAMS-192578", 2255, 15);
R_Date("Tx-696", 2230, 93);
R_Date("DAMS-013533", 2230, 24);
R_Date("Ua-15512", 2165, 60);
R_Date("SI-1395", 2165, 85);
R_Date("DAMS-017952", 2157, 33);
R_Date("DAMS-010260", 2152, 27);
R_Date("Tx-536", 2150, 93);
R_Date("UCIAMS-192575", 2135, 15);
R_Date("SI-1394", 2130, 116);
R_Date("UCIAMS-192577", 2085, 15);
R_Date("Tx-285", 2070, 148);
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R_Date("Tx-1757", 2023, 77);
R_Date("UCIAMS-192576", 2020, 15);
R_Date("DAMS-003557", 2014, 28);
R_Date("GX-16198", 1980, 80);
R_Date("Tx-284", 1970, 120);
R_Date("DAMS-011121", 1963, 31);
R_Date("DAMS-003361", 1921, 27);
R_Date("DAMS-003559", 1916, 22);
R_Date("Tx-537", 1910, 85);
R_Date("DAMS-003490", 1847, 27);
R_Date("Tx-2733", 1820, 85);
R_Date("DAMS-003498", 1763, 26);
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R_Date("UCIAMS-176090", 1575, 15);
R_Date("UCIAMS-176089", 1560, 15);
R_Date("DAMS-003497", 1513, 23);
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R_Date("Beta-140483", 1470, 60);
R_Date("Tx-81", 1467, 120);
R_Date("DAMS-003495", 1456, 29);
R_Date("DAMS-003558", 1345, 31);
R_Date("DAMS-003554", 1324, 22);
R_Date("Beta-250376", 1300, 40);
R_Date("DAMS-003366", 1193, 27);
R_Date("Beta-262710", 1150, 40);
R_Date("Beta-168048", 1130, 40);
R_Date("DAMS-017957", 1120, 28);
R_Date("DAMS-003364", 1115, 26);
R_Date("Beta-15634", 1090, 100);
R_Date("DAMS-031631", 1079, 31);
R_Date("Beta-262711", 1070, 40);
R_Date("DAMS-031630", 1067, 28);
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R_Date("DAMS-003363", 1035, 26);
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R_Date("DAMS-003556", 1007, 22);
R_Date("UCIAMS-109318", 995, 15);
R_Date("DAMS-003501", 977, 22);
R_Date("DAMS-003365", 965, 27);
R_Date("Beta-262708", 960, 40);
R_Date("DAMS-017964", 950, 33);
R_Date("DAMS-003367", 933, 27);
R_Date("Beta-262713", 930, 40);
R_Date("DAMS-003362", 921, 27);
R_Date("Beta-391410", 910, 30);
R_Date("DAMS-003494", 907, 23);
R_Date("DAMS-003492", 897, 28);
R_Date("DAMS-003561", 893, 29);
R_Date("Beta-391408", 890, 30);
R_Date("Beta-262714", 890, 40);
R_Date("Beta-262709", 880, 40);
R_Date("Beta-391411", 870, 30);
R_Date("UCIAMS-109324", 860, 15);
R_Date("Beta-262715", 860, 40);
R_Date("Beta-262712", 860, 40);
R_Date("DAMS-010263", 858, 26);
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R_Date("UCIAMS-109323", 815, 15);
R_Date("Beta-168044", 810, 40);
R_Date("DAMS-005254", 807, 28);
R_Date("DAMS-011113", 802, 22);
R_Date("DAMS-031628", 796, 27);
R_Date("UCIAMS-109322", 785, 15);
R_Date("Beta-168041", 780, 40);
R_Date("DAMS-017966", 770, 32);
R_Date("UCIAMS-109320", 765, 15);
R_Date("DAMS-005257", 762, 26);
R_Date("DAMS-010249", 746, 29);
R_Date("DAMS-010247", 737, 29);
R_Date("DAMS-017956", 736, 26);
R_Date("DAMS-024533", 730, 23);
R_Date("DAMS-003550", 730, 24);
R_Date("Tx-362", 710, 93);
R_Date("DAMS-017962", 707, 25);
R_Date("DAMS-011120", 707, 23);
R_Date("DAMS-031627", 691, 26);
R_Date("Tx-629", 690, 69);
R_Date("Beta-108178", 660, 50);
R_Date("DAMS-005235", 659, 25);
R_Date("DAMS-003493", 651, 26);
R_Date("Beta-168047", 650, 40);
R_Date("DAMS-010253", 649, 22);
R_Date("DAMS-005236", 643, 22);
R_Date("DAMS-007750", 640, 21);
R_Date("DAMS-003555", 638, 28);
```

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   R_Date("Tx-227", 625, 191);
   R_Date("DAMS-007753", 614, 18);
   R_Date("DAMS-010248", 604, 32);
   R_Date("Tx-77", 600, 196);
   R_Date("DAMS-011118", 596, 25);
   R_Date("DAMS-005233", 586, 22);
   R_Date("DAMS-010258", 584, 25);
   R_Date("DAMS-005234", 573, 20);
   R_Date("DAMS-007754", 573, 18);
   R_Date("DAMS-010257", 572, 27);
   R_Date("Beta-168043", 570, 40);
   R_Date("DAMS-011119", 564, 29);
   R_Date("DAMS-010259", 558, 21);
   R_Date("DAMS-011116", 540, 26);
   R_Date("DAMS-017955", 532, 32);
   R_Date("DAMS-003552", 524, 24);
   R_Date("DAMS-017954", 508, 22);
   R_Date("DAMS-007751", 502, 17);
   R_Date("DAMS-005248", 492, 26);
   R_Date("Beta-168042", 490, 40);
   R_Date("DAMS-005246", 488, 25);
   R_Date("DAMS-005247", 460, 24);
   R_Date("DAMS-005245", 399, 23);
   R_Date("DAMS-007756", 356, 20);
   R_Date("DAMS-007757", 320, 18);
   R_Date("DAMS-007758", 320, 23);
   R_Date("DAMS-005250", 270, 25);
   R_Date("DAMS-007755", 186, 27);
   R_Date("DAMS-005249", 171, 34);
   R_Date("DAMS-007752", 117, 18);
  };
  Boundary("End");
 };
};
```

Fiber artifact model:

```
Plot()
 {
  Sequence("Fiber artifact")
  {
   Boundary("start");
   Phase("fiber artifact phase")
   {
    R_Date("UCIAMS-176098", 4500, 15);
    R_Date("UCIAMS-192574", 4500, 15);
    R_Date("UCIAMS-192569", 4440, 15);
    R_Date("UCIAMS-176096", 4120, 15);
    R_Date("UCIAMS-192571", 4115, 15);
```

```
  R_Date("Beta-293744", 3480, 40);
  R_Date("SI-1120", 2993, 64);
  R_Date("UCIAMS-176092", 2765, 15);
  R_Date("Tx-6166", 2399, 125);
  R_Date("UCIAMS-192573", 2275, 15);
  R_Date("UCIAMS-176091", 2180, 20);
  R_Date("CAMS-93678", 2170, 45);
  R_Date("CAMS-93679", 2155, 45);
  R_Date("CAMS-92188", 2155, 40);
  R_Date("CAMS-96372", 2140, 40);
  R_Date("CAMS-94532", 2135, 40);
  R_Date("UCIAMS-192572", 2130, 15);
  R_Date("Beta-283079", 2120, 40);
  R_Date("CAMS-96374", 2120, 35);
  R_Date("CAMS-95671", 2120, 40);
  R_Date("UCIAMS-176095", 2110, 15);
  R_Date("Beta-302186", 2100, 30);
  R_Date("CAMS-85491", 2095, 50);
  R_Date("Beta-301424", 2090, 30);
  R_Date("UCIAMS-192570", 2085, 15);
  R_Date("UCIAMS-176094", 2055, 15);
  R_Date("UCIAMS-176097", 2015, 15);
  R_Date("Beta-283080", 2010, 40);
  R_Date("UCIAMS-192567", 2005, 15);
  R_Date("UCIAMS-176093", 1975, 15);
  R_Date("Beta-327522", 1930, 30);
  R_Date("SI-1131", 1913, 77);
  R_Date("UCIAMS-192566", 1900, 15);
  R_Date("Beta-281018", 1810, 40);
  R_Date("UCIAMS-192568", 1410, 15);
  R_Date("DAMS-027496", 506, 23);
 };
 Boundary("end");
};
};
```

Rockshelter summed probability distribution:

```
Plot()
 {
  Sum("Lower Pecos")
  {
   R_Date("DAMS-031628", 796, 27);
   R_Date("DAMS-031630", 1067, 28);
   R_Date("Beta-207789", 2500, 40);
   R_Date("Beta-448091", 1730, 30);
   R_Date("Beta-207791", 2530, 40);
   R_Date("DAMS-018144", 2861, 24);
   R_Date("GX-16198", 1980, 80);
   R_Date("DAMS-011113", 802, 22);
```

```
R_Date("DAMS-013530", 6043, 31);
R_Date("DAMS-010262", 6500, 36);
R_Date("DAMS-013541", 2343, 25);
R_Date("Beta-179749", 5940, 80);
R_Date("SI-1120", 2993, 64);
R_Date("SI-1131", 1913, 77);
R_Date("Tx-1757", 2023, 77);
R_Date("Tx-1762b", 4803, 96);
R_Date("Beta-179750", 6270, 90);
R_Date("Tx-81", 1467, 120);
R_Date("DAMS-017955", 532, 32);
R_Date("DAMS-027495", 3523, 27);
R_Date("DAMS-003493", 651, 26);
R_Date("CAMS-86525", 2210, 45);
R_Date("CAMS-88194", 2125, 40);
R_Date("CAMS-91410", 2095, 40);
R_Date("CAMS-96371", 2115, 35);
R_Date("CAMS-86846", 5160, 45);
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# APPENDIX D. LEROY JOHNSON'S COMMENTARY ON TURPIN 1991

'Lower Pecos Radiocarbon dates' LeRoy Johnson



filename dates, June 20, 1991:

In this document I have gone through Turpin's new (1991) article on radiocarbon assays for the Lower Pecos region, especially her core dates for the named periods. Unfortunately, Turpin included assays from mixed contexts in her lists of core dates, and they are consequently unreliable. What I have done, is to look at the dart and points associated stratigraphically with the dates she reports, and select out those with MAINLY the proper period-marker styles. When that is accomplished, the named periods have the following time ranges (expressed in dates corrected by tree-ring data).

VIEJO PERIOD, Table 1.6, p. 26, Early Archaic points

| | |
|---|---|
| 6,200-3,700 B.C. | using Tx-314, -525, -1758, -6878, and -6947. |

EAGLE NEST PERIOD, Table 1.7, p. 29, Pandale points

| | |
|---|---|
| 3550-2100 B.C. | (Tx-117), -137, -196, -203, -660, -773, -1762b, -1979, -6635, SI1401. In caclulating this range, assay Tx-117 is discounted and considered aberrant. |

SAN FELIPE PERIOD, Table 1.8, p. 30, Val Verde and Langtry points

| | |
|---|---|
| 1700-1600 B.C. | Tx-136, -191, -1761. |

CIBOLA PERIOD, divided into subperiods A and B

| | |
|---|---|
| A: ca. 1350 B.C. | Tx-663, -6636 Marshall points |
| B: 1000-600 B.C. | Tx-47, -106, -131, -1977 Castroville and |

Montell points

FLANDERS PERIOD, Table 1.10, p. 33, "Shumla" points

ca. 300 B.C. Tx-145

BLUE HILLS PERIOD, Table 1.11, p. 34, Ensor and Frio points

250 B.C.-A.D. 100 Tx-284, -536, -537, SI1394, SI1395

FLECHA PERIOD, Table 1.12, p. 36, most arrowhead styles

A.D. 900-1550 Tx-204, -227, -361, -649, -650, -706, -707

Viejo period, Table 1.6, p. 26 (Early Archaic pd.)
6,200 – 3,700 B.C. Tx-314, 1758, 6947, 6878, 525.

Eagle Nest period, Table 1.7, p. 29 (Pandale)
(Tx-117), -137, -773, -1762b, -196, -203,
3550-2100 B.C. -1979, -660, SI 1401, Tx-6635
(eliminates Tx-117)

San Felipe period, Table 1.8, p. 30 (Val Verde, Langtry)
1700-1600 B.C. Tx-136, -191, -1761.

Cibola period, divided, Table 1.9, p. 31
A: ca. 1350 B.C. Tx-6636, -663 (Marshall)
B: 1000-600 B.C. Tx-47, -106, -1977, -131.
(Castroville, Montell)

Flanders period, Table 1.10, p. 33
ca. 300 B.C. Tx-145 ("Shumla")

Blue Hills period, Table 1.11, p. 34
250 B.C.–A.D 100 Tx-536, -284, -537, SI 1395, SI 1394
(Ensor, Frio)

Flecha period, Table 1.12, p. 36
A.D. 900-1550 Tx-706, -204, -227, -361, -707, -649, -650.
(most arrowhead styles)
pottery

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