UNDERWATER GEOARCHAEOLOGY AT SPRING LAKE, SAN MARCOS, TEXAS

by

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CHAPTER 1

INTRODUCTION

The San Marcos Springs, now under the stewardship of Texas State University, present an exceptionally complete record of prehistoric human habitation spanning the Late Pleistocene and Holocene eras. Detailed geoarchaeological research established a preliminary depositional sequence of alluvial deposits spanning this same period (Nickels and Bousman 2010). However, the earliest artifacts recovered in controlled excavations date to only ~8380 cal BP (Oksanen 2008). Recent cultural resource management investigations associated with preparations for the removal of the former amusement park's submarine theater demonstrates that our knowledge of the fluvial geology is still incomplete (Leezer et al. 2011).

This thesis will present the methods, results, and interpretations of an investigation of Late Pleistocene and Holocene sediments in order to increase the resolution of our understanding of the geoarchaeological record of Spring Lake (Figure 1) with emphasis on inundated sediments. The objective of this research is to achieve a more thorough understanding of the stratigraphic contexts of alluvial deposits now flooded by a man-made lake in a chronologically controlled framework.

Research Problems

Because of the unique set of formation processes which have taken place around the San Marcos Springs, lake-bottom stratigraphy cannot be predicted at high resolution solely by existing terrestrial core samples and excavation profiles. Spring Lake has existed since the damming of the San Marcos River headwaters in 1849 (Bousman and

Nickels 2003), and since that time, the water level has been 10 to 15 feet higher than before the dam’s construction. As a result of this saturation, the deposition, erosion, and disturbance of sediments could have been drastically altered. This analysis of multiple core samples taken from within the lake will provide important stratigraphic contexts for future archaeological studies by lending a greater understanding to the lake bottom’s formation processes.

Figure 1. Satellite photo of project area. The horseshoe-shaped Spring Lake. Texas State University's Bobcat Stadium is prominently visible in the southeast quadrant.

CHAPTER 2

PROJECT SETTING AND BACKGROUND

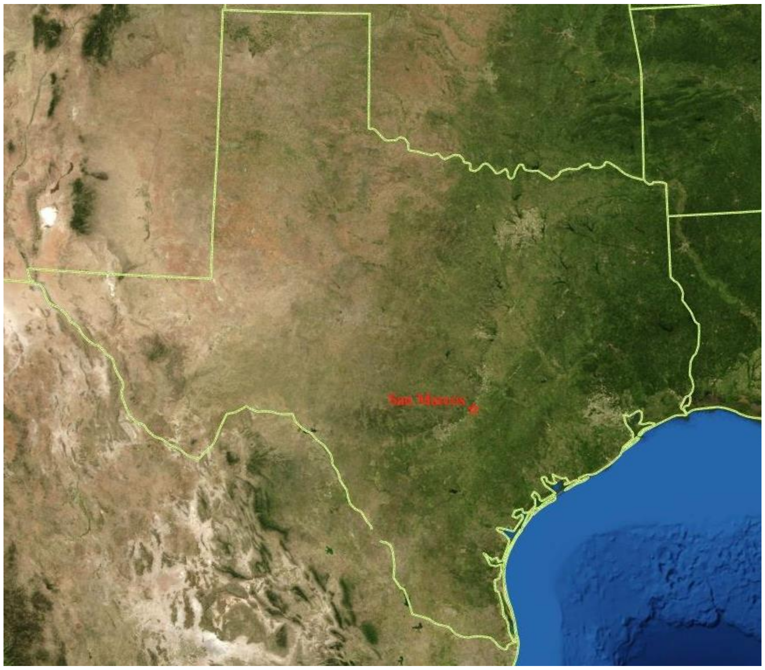

Figure 2. Project location in San Marcos, Texas.

The San Marcos Springs are at the base of the Balcones Escarpment in San Marcos, Texas (Figure 2) and form the uppermost perennially flowing headwaters of the San Marcos River. Sink Creek, an ephemeral stream, joins the spring channel just several hundred meters downstream from the majority of the springs. The springs are now inundated by Spring Lake with approximately 25 percent of the spring water issuing forth from several well-defined, rocky orifices while the remaining 75 percent emerges from sand boils (LBG-Guyton Associates 2004). Known as Canocanayestatetlo or “warm water” to the Cantona Indians, the springs have attracted a human presence for at least 13,000 years (Kimmel 2006; Nickels and Bousman 2010). Today, the San Marcos Springs are home to the Texas State University’s Meadows Center for Water and the Environment and serve as a vital resource to researchers and students, as well as the people of southeast-central Texas.

Bedrock Geology

The Balcones Escarpment, representing the surface expression of the Balcones Fault Zone, stretches in an arc from just east of Del Rio to San Antonio where it turns sharply north extending as far as Denton in north central Texas. The deformation within the Balcones Fault Zone is characterized by a series of *en echelon* normal faults with slightly southeast dipping to near-vertical displacement (Barnes 1992). The stratigraphic displacement for any single fault line scarp ranges from as little 60 m in the west to as much as 185 m just north of the northward bend in the fault zone (Klempt et al. 1975). Total stratigraphic displacement across the entire fault zone varies similarly, with a maximum displacement of 520 meters across a distance of 39 km also occurring just north of the bend in Comal County (George et al. 1952). Several faults run through the San Marcos Springs area (Figure 3) and are the conduits by which discharge flows onto the surface (Guyton and Associates 1979). The bedrock below the northwest side of Spring Lake includes well exposed, deeply incised Early Cretaceous, Comanche Series limestones and marls (Figure 4). Underlying the southeast side of the lake is distinctively younger bedrock composed of Late Cretaceous, Gulf Series marls and shales (Guyton and Associates 1979).

Hydrology

Several large drainage basins move water across the Balcones Escarpment. These are, from west to east, the Nueces, San Antonio, Guadalupe, and Colorado basins as well as a portion of the Brazos basin. These drainages traverse deeply incised canyons across the escarpment, but just below, streams meander through the Rio Grande Plains and more

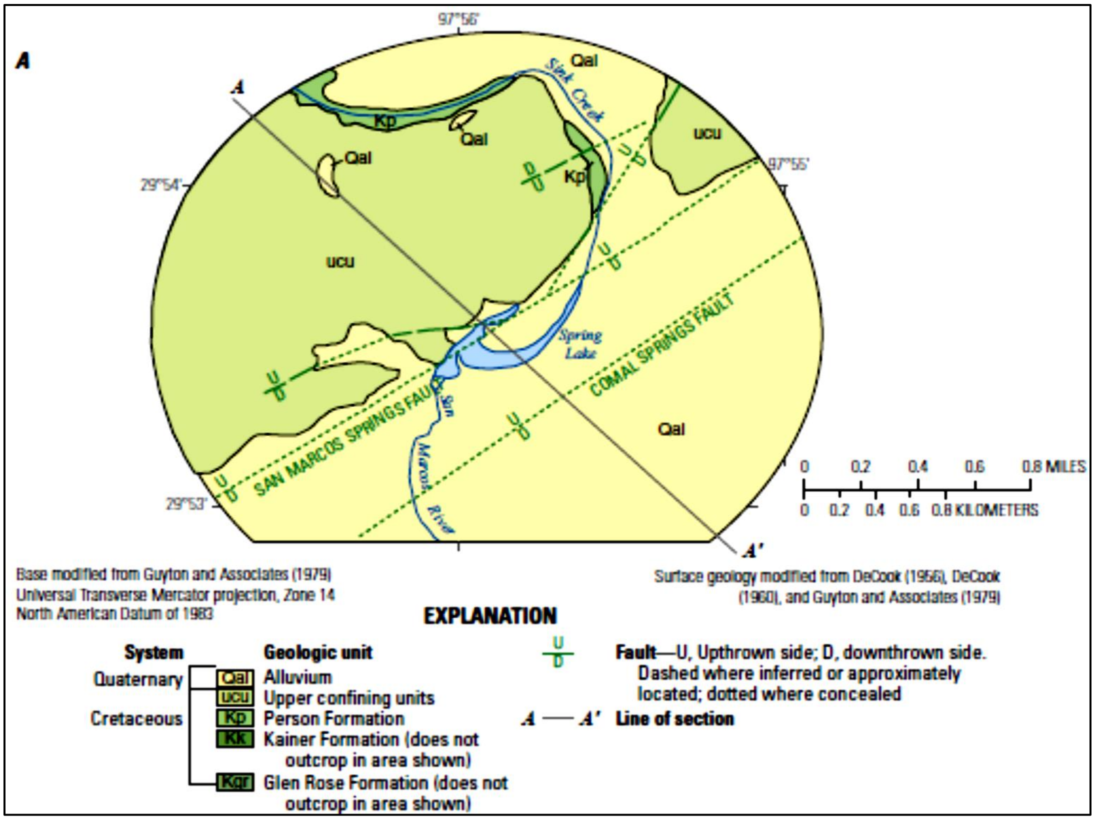

Figure 3 Surface geology around Spring Lake (from Musgrove and Crow 2013)

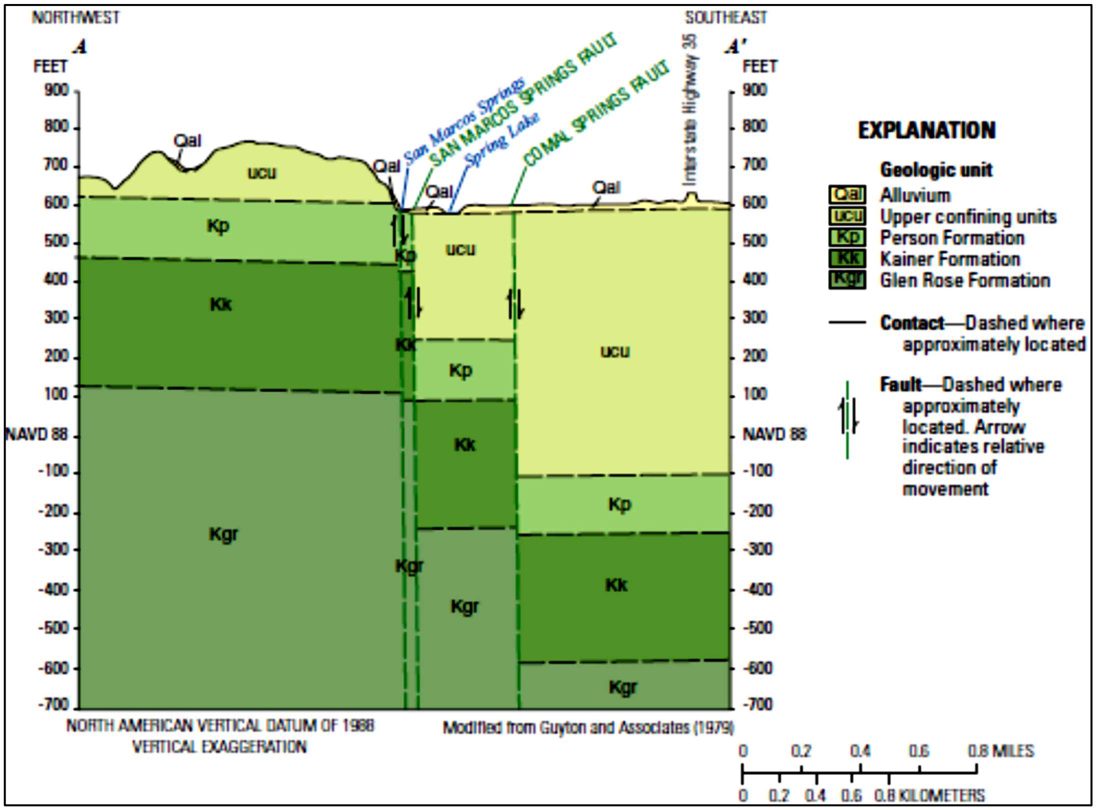

Figure 4. Stratigraphic cross section showing bedrock and faults (from Musgrove and Crow 2013).

gentle slopes and rolling topography of the Gulf Coastal Plain. Central Texas watersheds are profoundly affected by the escarpment with an impact extending both into the atmosphere as well as below the ground surface.

Because the Balcones Escarpment is such a sudden increase in elevation relative to the more gently sloping Gulf Coastal Plain, it creates a meteorological orographic effect. Dominant southeast winds force warm, water-saturated air from the Gulf of Mexico up the ramp of the escarpment and rapidly into cooler atmosphere reducing moisture carrying capacity. The result is a much higher cumulative precipitation along and just above the escarpment relative to surrounding regions (Carr 1967).

Occasionally, the Balcones Escarpment is the line along which polar air masses and tropical low-pressure systems meet. When this happens, extreme temperature and pressure gradients combined with the escarpment's orographic effect and abundance of exposed bedrock can result in record setting deluges. The highest intensity flood ever recorded in the region occurred in 1921 in Thrall, Williamson County with a peak discharge in Brushy Creek of 647,000 ft^3/s from a drainage area slightly over 7 mi^2 resulting from 36.4 inches in 18 hours, a standing world record (Carr 1967, Bomar 1983).

Caran and Baker (1986) put perspective on the magnitude of Central Texas flooding noting that in 1978, during Tropical Storm Amelia, the rate of discharge in the upper Guadalupe near Spring Branch, Comal County exceeded the mean rate of the Nile with only 0.1% of its watershed area. Amelia also set the U.S. record for rainfall in a 3-day period, dropping 48 inches of rain at the Manatt Ranch in Bandera County (Bomar 1983).

During their transit across the Edwards Plateau, many tributaries of Balcones Escarpment drainages lose most or all of their flows through faults and fractures in the recharge zone of the Edwards Aquifer. Through much of the Hill Country the Edwards is an unconfined (open-topped) aquifer. The aquifer becomes confined in Edwards Group limestones overlain by relatively impermeable Georgetown Formation marls, Del Rio Clay, and Buda Formation limestones at the lower edge of the Balcones Escarpment (Woodruff and Abbot 1979). This Late Cretaceous cap allows for the creation of a pressure gradient across a narrow artesian zone at the of the Balcones Escarpment where artesian discharge points such as the Comal Springs and the San Marcos Springs, the first and second largest spring complexes in Texas, occur (Brune 1975).

Although the flow from the San Marcos Springs is less than that of the Comal Springs, the former sits at 15 m lower elevation than the latter. Because the same regional flow supplies both spring complexes (Musgrove and Crow 2012), it is possible for the San Marcos Springs to continue a low discharge after that of the Comal Springs has ceased as occurred during a period of prolonged drought in 1956 (Guyton and Associates 1979).

Modern Climate

In general, the modern climate across the Balcones Escarpment cools slightly to the north and dries considerably to the west. Climate at the central portion of the escarpment containing the San Marcos Springs is classified as sub-tropical, sub-humid, while climate in the western reaches is classified as sub-tropical, semi-arid. Average temperature is the warmest on the western end of the escarpment at $69.7°F$ and coolest in the north at $67.0°F$. West of the escarpment's central bend, winters just below the escarpment become much warmer allowing the average temperature to rise well above $70°F$. Throughout the escarpment, the coolest month is January and the warmest, July (Bomar 1983).

Along the Balcones Escarpment almost all precipitation occurs as rain with only occasional light snows which typically melt within hours of falling. As mentioned above, large rainfall events are relatively common to Central Texas leading to a high variability in actual rainfall amounts from year to year. In order to fully understand Central Texas hydrology, it is critical to keep in mind that the following averages were derived from a period characterized by regular droughts broken by occasional deluges. Average annual precipitation changes across the escarpment with 23.5 inches per year falling above the escarpment, 22.9 inches below the escarpment to the west, and 34.0 inches on and below its central and northern reaches. The least rainy month above the escarpment is January, below the escarpment, March. Throughout the Balcones Escarpment, precipitation spikes on either side of summer, and because midsummer evaporation rates increase dramatically, July and August tend to be the driest months overall (Bomar 1983).

Soils

Alluvial terrace deposits (Qal) composed of eroded gravel, sand, silt, and clay from the Edwards Plateau accumulated at the base of the escarpment in the San Marcos River channel during the Late Pleistocene and Holocene (Fisher 1974). Soils just above Spring Lake on the escarpment are typically classified as Mollisols consisting of Eckert-Rock outcrop complex (ErG) and are shallow, poorly formed, well drained, calcareous clay loams, often gravelly or cobbly. Soils on the southeast side of Spring Lake on top of Qal deposits are classified as Vertisols and consist of Oakallala clay loam (Ok) and Tinn clay (Tn) (Batte 1984). Oakallala clay loam soils are generally composed of an A-B-C soil column. The A horizons are typically dark grayish brown in color and consist of silty, clayey, loamy sediments. B horizons, when present, are generally grayish brown to light yellowish brown, and C horizons are often brown to light yellowish brown and can contain up to 60 percent calcium carbonate. Tinn clay soils are similar to Okallala clay loam, but often contain up to 50 percent coarse fragments. Both soils form in floodplain settings, but Tinn series soils tend to be drier and are found further away from streams than Oakallala series soils.

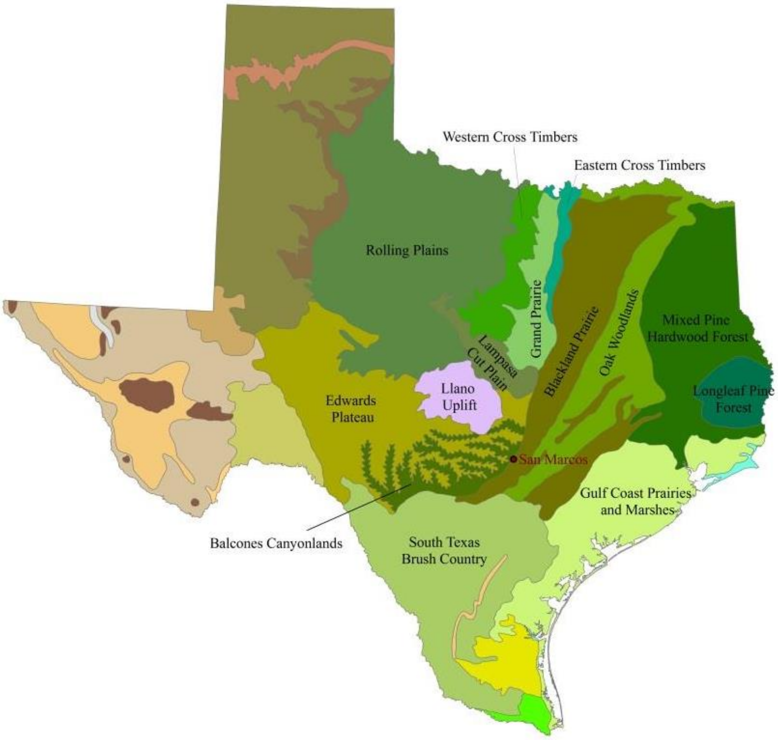

Figure 5. Physiographic regions surrounding the San Marcos Springs.

Flora and Fauna

The Balcones Escarpment represents an *ecotone* or ecological crossroads. Ecotones often contain a more diverse biota than do the individual environmental provinces they separate (Crumly 1994). Especially in the area surrounding the San Marcos Springs (Figure 5) , the sharp contrast in terrain, soils, and moisture availability allows for an intermingling of riverine, grassland-savanna, and woodland flora and fauna not often found together (Blair 1950).

The central and northern portions of the Balcones Escarpment contain biota from both the Edwards Plateau-Hill Country and Blackland Prairie. The native flora is generally savanna supporting tall and short grasses interspersed with patches of drought-resistant woody shrubs and trees such as juniper, Texas oak on uplands. Fingers of riparian forest extend into canyons including trees such as cypress, cottonwood, walnut, and pecan along rivers and streams. Common native fauna include white-tailed deer, coyote, eastern cottontail, white-tailed jackrabbit, raccoon, armadillo, and turkey with rivers and streams supporting cray fish and Guadalupe bass, as well as several endemic species of amphibians and mussels (Blair 1950, Riskind and Diamond 1986). To the west, floral and faunal taxa generally become more xeric-adapted. Flora includes short and mid-grasses with patches of thorny scrub and cacti on uplands; however, riparian forests still thrive along streams (Blair 1950, Riskind and Diamond 1986). In addition to the biotic diversity found in surrounding region, the San Marcos Springs represent critical habitat to several endangered species including Texas wild rice which is endemic to the upper 2 miles of the San Marcos, River.

An important conclusion may be made from the above. The existence of Texas wild rice, a unique and endemic aquatic plant species, is strong evidence to support an assumption that the San Marcos Springs have not completely dried out for a period which must contain the entirety of human presence in North America. Given the location of the springs in an ecotone containing a relatively large variety of ecological resources within a short distance, the site represents an oasis which must have attracted regular visitation by a variety of prehistoric peoples, and the regularity and/or duration of prehistoric human occupations could be expected to have an inverse relationship with regional moisture availability.

Regional Paleoenvironment

Although dramatic transitions in environmental conditions such as those of the Cretaceous are geologically obvious, evidence for more recent small scale fluctuations are more subtle. Paleoclimatic evidence for the environmental change which may have caused shifts in prehistoric human subsistence strategies must always be derived from environmental proxies. Because the modern contexts on which these proxies are based may have been dissimilar in the past, any interpretation is based on at least a few assumptions. Most importantly, researchers must consider the possibility for more than one mechanism which may account for virtually any physical relationship represented in a geologic record (Caran 1998). For the remainder of this Chapter 2, all dates have been approximated and are given in uncalibrated radiocarbon years B.P. (before A.D. 1950) unless otherwise noted.

The fact that the modern environment in Texas is different from that of the Late Pleistocene is demonstrated by paleontological evidence. Several small vertebrates such as the masked shrew, bog lemming, and meadow vole are represented in Pleistocene cave faunas along the Balcones Escarpment, but are now restricted to cooler and/or wetter climates outside Texas. Other burrowing species from the same cave deposits such as the prairie dog still exist in Texas but are restricted to the thicker soils of the Great Plains. (Lundelius 1986; Toomey 1993).

Soil erosion in Central Texas may explain the disappearance of burrowing fauna

(Toomey 1993). Relict, silicate-rich soil remnants are located on some of the uplands in the Edwards Plateau and occasionally hidden in sediment traps such as sink holes and caves (Cooke et al. 2003; 2007). Utilizing changing $^{87}Sr/^{86}Sr$ ratios measured in floral and faunal remains collected in well-dated sediments in Hall's Cave, Kerr County Texas, Cooke et al. (2003; 2007) argued continuous, steady soil erosion occurred in Central Texas from at least 21,000 B.P to 5,000 B.P. This removal of soil cover translated to a loss of habitat for many burrowing fauna (Toomey 1993; Cooke et al. 2007).

Another paleontological climate proxy is the oxygen isotope ratios found in fossil foraminifera of the Gulf of Mexico. These ratios reflect climate change with a stronger chronological control, but at a global rather than regional resolution. When relatively large amounts of water are trapped in polar ice caps, the shells of foraminifera are produced with more isotopically heavy oxygen atoms than during warmer interglacial periods. Leventer et al. (1982) were able to show that oxygen isotope ratios in Gulf of Mexico cores indicated that the volume of glacial meltwater entering the gulf peaked twice in the Late Pleistocene at about 15000 B.P. and again at about 12500 B.P. Climate then stabilized following one last cool period around 11000 B.P.

Two recent studies of fossil plant communities buried in paleosols of east-central and south-central Texas bogs have provided relatively high-resolution models for more localized climate trends in central Texas since the last glacial maximum (Bousman 1998, Nordt et al. 2002). In both studies, proxies indicating the relative dominance of grasses to more woody vegetation were used to estimate past climatic conditions. Grasses, or C_4 plant communities, thrive in warmer, drier habitats, while trees, or C_3 communities, dominate cooler, more moist climates. Bousman (1998) and Nordt et al. (2002) both agree that the extent of woodland vegetation was related to glaciation, but they differ in their interpretations of what ultimately caused fluctuations in vegetation dominance. Bousman (1998) asserts that reduction in moisture availability was probably most influencial, while Nordt et al. (2002) prefers to cite warmer temperatures.

Nordt et al. (2002) used the ratio of stable carbon isotopes in buried soils from near the Medina River in south-central Texas to infer C_4 productivity. Nordt et al. (2002) correlated the dominance of C_4 plant communities in south-central Texas during the Pleistocene with two pulses of glacial meltwater into the gulf of Mexico, arguing for a peak in C_3 plant production and cooler conditions at 13,500 B.P. followed by a warming trend and then a return to cooler conditions at 13,000 B.P. After a peak of C_4 plant dominance and warmer conditions at 11,000 B.P., south-central Texas supported a slightly woodier grassland than today. At 8000 B.P woodland vegetation began to decline with a peak in warmer conditions around 5500 B.P. According to Nordt et al. 2002, grassland dominance and warmer conditions continued in south-central Texas throughout the remainder of the Holocene. Bousman (1998) used palynological evidence from several well dated bog sites in east-central Texas and a modern pollen rain study to estimate the relative dominance of woodland vegetation in east-central Texas (Figure 6). Bousman's (1998) model shows overall trends similar to Nordt et al. (2002), but with more intensive 2nd order fluctuation. Bousman argued for a significant shift to grasslands which marks the beginning of the middle Holocene with a brief return to woodier conditions around 6000 B.P. In the late Holocene he charts a progressive but punctuated return to woodland conditions, with a short increase in the dominance of grasses between 1600 and 1500 B.P. (Bousman 1998).

In summary, Central Texas climate has shifted from relatively cool and/or moist to relatively warm and/or dry over the past 13,000 years. Although lower order climate fluctuation may not be well agreed upon, evidence for major warming/drying phases is strong near 11,000 B.P., 8000 B.P., and 5500 B.P. (Bousman 1998; Nordt et al. 2002). During the same period, a large mass of mature soil was removed from the Edwards Plateau (Toomey 1993; Cook et al. 2003; Cook et al. 2007). Given the location of the San Marcos Springs at the base of the Balcones Escarpment just under the Edwards Plateau, it is likely these major climate trends may be recorded in the sedimentology and geomorphology of the land surrounding Spring Lake.

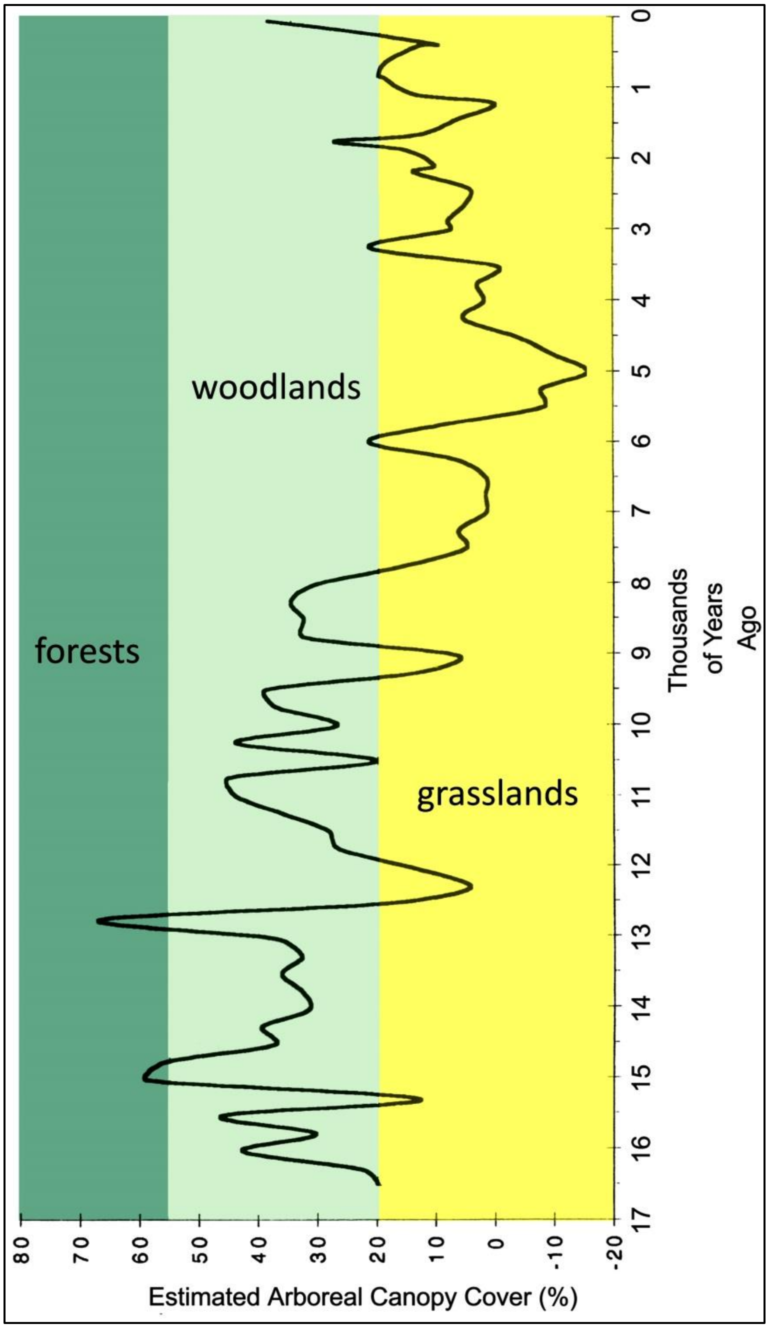

Figure 6. Reconstructed variations in tree cover in east Central Texas. Time is shown in calendar years B.P. (after Bousman 1998).

Regional Cultural Chronology

Cultural chronologies in Texas are not well agreed upon; however, Prewitt (1985) established the widely used system of stages forming the basis of the chronology defined here. The most recent synthesis of the entire prehistoric period in Central Texas comes from Collins (2004). The following cultural chronology is based primarily on that of Collins (2004) with modifications from more recent work (Bousman and Oksanen 2012). All dates have been approximated and are given in radiocarbon years B.P. (before A.D. 1950) unless otherwise stated.

Paleoindian (11,500-8800 B.P.)

The Paleoindian period begins in the Terminal Pleistocene, and is marked by a variety of lanceolate projectile points, notably Clovis and Folsom. Paleoindian subsistence strategies involved big-game hunting by small nomadic groups which likely took advantage of a variety of plant resources in addition to smaller game. Clovis sites include killsites, caches, quarries, and open camp sites. Although present in a variety of contexts throughout North America, Clovis sites often occur on deflated surfaces of uplands and ridges along the Balcones Escarpment. The end of the Paleoindian period is marked by the disappearance of mega-fauna and shifts in technology reflecting a focus on new resources (Collins 2004).

ProtoArchaic (9800-8100 B.P.)

The first stemmed projectile points mark the beginning of the ProtoArchaic. During this period of transition, some groups are still producing lanceolate projectile points and may have been subsisting in a similar manner to Paleoindian societies minus large game hunting, while nearby groups have adapted to economies more characteristic to the Archaic. The end of the ProtoArchaic is marked by the total disappearance of late Paleoindian societies (Bousman and Oksanen 2012).

Early Archaic (8,800-6,000 B. P.)

The Early Archaic period is marked by the widespread adoption of new subsistence strategies involving the use of ground stone tools, hot-rock-cooking technology, and other tools indicating exploitation of a larger variety of resources including plants requiring specialized processing. The distribution of Early Archaic diagnostic tools is relatively sparse; however they occur throughout Texas (Collins 2004).

Middle Archaic (6,000-4,000 B. P.)

Middle Archaic subsistence patterns involved a higher degree of sedentism marked by the increased size of occurrence of large burned rock middens suggestive of an increase in population. Middle Archaic peoples in the Hill Country began to take advantage of nut harvests and produced large varieties of projectile points suggesting seasonality in resource exploitation (Collins 2004).

Late Archaic (4,000-1,200 B. P.)

The Late Archaic in Texas is marked by further population growth and with diagnostic projectile points which are side notched and relatively small (Collins 2004).

Late Prehistoric (1,200 B.P.-420 cal B.P.)

The Late Prehistoric can be subdivided into two phases. The Austin Phase (1200-750 B.P.) is marked by the appearance of Scallorn and Edwards arrow points. Austin phase burials occasionally exhibit evidence of violence suggesting an increase in resource competition. The Toyah Phase (750-420 B.P.) is marked most notably by the appearance of bone-tempered pottery (Collins 2004).

Historic Period (A.D. 1530-Present)

The historic period begins with the arrival of the Spanish in Texas with the earliest record coming from Cabeza de Vaca who was shipwrecked on the Texas coast in A.D. 1528 (Hallenbeck 1940). The first permanent Spanish settlement in Texas was established in San Antonio in 1718, and by 1830, land use across the Balcones escarpment began to have significant effects on the landscape. Most areas above the escarpment have been used as rangeland since the mid-19th Century. By the end of the 19th century, large amounts of soil had disappeared from the uplands and ridges of the Balcones Escarpment. Because of over-grazing and a lack of range fires, most of the native grasses which once held soils on the savanna-grasslands have been removed and replaced by juniper and mesquite (Palmer 1986).

Previous Investigations

There are six numbered archaeological sites within the immediate vicinity of the San Marcos Springs; these are 41HY37, 41HY147, 41HY160, 41HY161, 41HY165, and 41HY306. Archaeological investigations have been conducted at these sites since 1978; however, the frequency of research has greatly increased since the purchase of the property surrounding Spring Lake by Texas State University in 1994. Table 1 shows citations for a majority of archaeological investigations and the cultural components identified at the sites surrounding the San Marcos Springs.

The earliest investigations were conducted by Joel Shiner who began by surveying the river bottom below the dam (41HY161) in1978. Shiner continued his work at the San Marcos Springs through the auspices of Southern Methodist University field schools at 41HY147 through 1984 (Shiner 1983; Takac 1990; Hooge et al. 2013). Shiner was the first to verify the potential significance of the San Marcos Springs by identifying a stone tool assemblage representing Paleoindian through Late Archaic components (Shiner 1981).

Table 1. Published archaeological investigations in and around Spring Lake.

Site	Cultural Components	Citations
41HY37	Historic Burleson homestead; Late Prehistoric and Late Archaic	Bousman and Nickels 2003; Garber and Orlof 1984
41HY147	Late Archaic through Paleoindian, Pleistocene fauna	Lohse 2013; Shiner 1983; Takac 1990, 1991a, 1991b
41HY160	Late Prehistoric through Early Archaic, human remains	Aery 2007; Nickels and Bousman 2010; Garber et al. 1983; Goelz 1999; Leezer et al. 2011; Oksanen 2006; Ramsey 1997
41HY161	Mixed Historic and Archaic, Late Archaic, Paleoindian, human remains, Pleistocene fauna	Ford and Lyle 1998; Garber and Glassman 1992; Jones 2002; Leezer et al. 2010; Ford and Lyle 1998; Lyle et al. 2000; Oksanen 2008 and 2011; Shiner 1979, 1981, 1984; Stull and Hamilton 2011; Yelacic et al. 2008a, 2008b; Stull 2009; Leezer et al. 2010
41HY165	Late Prehistoric through Mid Archaic	Giesecke 1998; Leezer et al. 2011; Ringstaff 2000; Soucie and Nickels 2003; Soucie et al. 2004
41HY306	Late Archaic	Arnn and Kibler 1999

The site of the 41HY147 ‘Terrace Locality’ (Shiner 1981; Shiner 1983) where Shiner spent the majority of his time showed characteristics of both colluvial and high energy alluvial deposition (Shiner 1981; Shiner 1983; Hooge et al. 2013). Shiner (1983) identified three depositional units at the Terrace Locality. Level 1 was a 20-30 cm stratum of grey clay containing Archaic projectile points; Level 2 was a 20-30 cm thick red sand containing Early Archaic and Paleoindian projectile points; and Level 3 was a red clay containing megafauna remains and Paleoindian projectile points. All three depositional units contained limestone boulders and cobbles (Shiner 1983). Hooge et al. 2013 reconstructed several profile sketches from Shiner’s notes which demonstrate the presence of a more complex and likely disturbed sediment profile at the Terrace Locality (Figure 7).

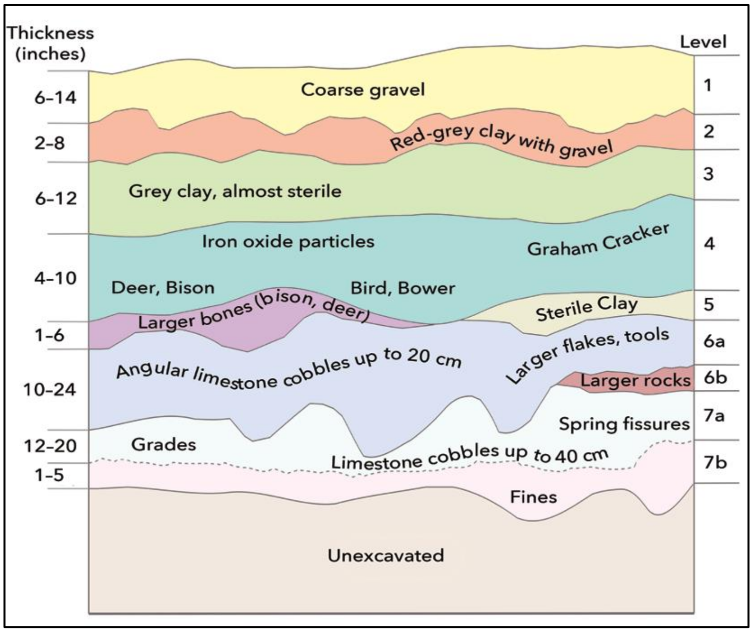

Figure 7. Profile of northeast wall of Terrace Locality excavation. Reconstructed from Joel Shiner’s notes and sketches (from Hooge et al. 2013: Figure 2-5).

Although two previous geoarchaeological assessments were conducted at the San Marcos Springs (Arnn and Kibler 1999; Goelz 1999), the most complete geoarchaeological investigation to date was conducted by Lee C. Nordt in 2001 (Nordt 2010). Nordt collected and analyzed 22 sediment cores as part of an archaeological survey of the upper Spring Lake Peninsula in preparation for the development of the Texas Rivers Center, now the Meadows Center for Water and the Environment (Nickels and Bousman 2010). The cores were taken by a truck-mounted drill rig provided by the Bureau of Economic Geology at the University of Texas and were collected in 5 ft sections. Figure 8 shows the locations of cores taken by Nordt (2010).

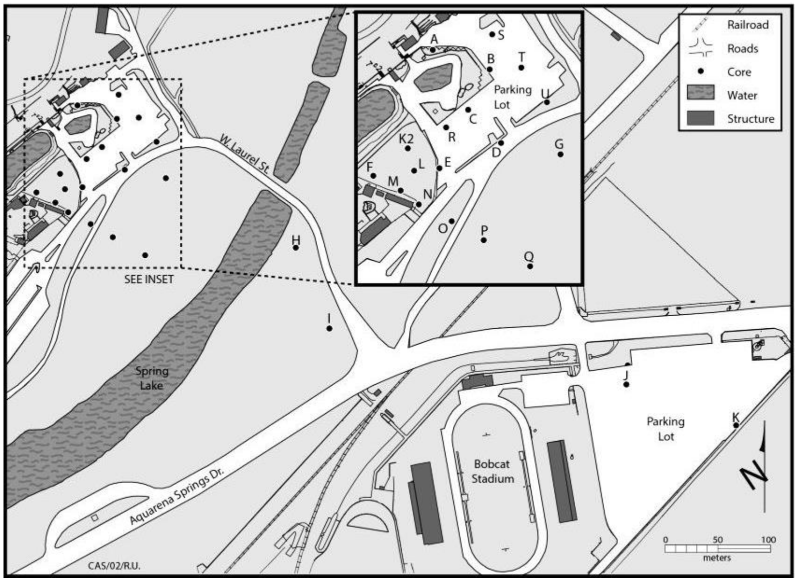

Figure 8. Location map showing distribution of sediment cores taken by Lee Nordt (from Nordt 2010: Figure 6-3).

Nordt identified five unconformably bound depositional units, labeling them A-E from oldest to youngest (Figure 9). Unit A rests unconformably on limestone bedrock and is described as being 2 to 2.5 m thick, consisting of intermingling channel gravels, yellowish brown to brownish yellow overbank deposits, and dark gray to black marsh deposits. Nordt assigned two radiocarbon ages to Unit A marsh deposits, one at 9585±40 B. P.(CAMS 85777) obtained

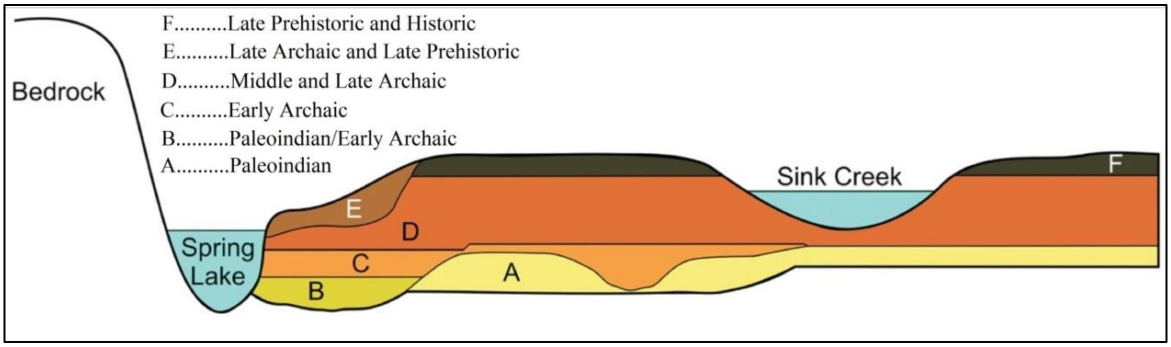

Figure 9. Idealized geologic cross-section of the Sink Creek Valley (modified from Nordt 2010: Figure 6-8).

from plant fragments and a bulk humate date of 11,470±100 B.P. taken by Goelz (1999) (Beta 132062). Unit B is confined to the area surrounding the spring head and was deposited following a termination of floodplain stability and a down cutting of Unit A which extended to bedrock in some places. Unit B also consists of intermingled marsh and overbank deposits and was deposited sometime following 9585±40 B.P. (CAMS 85777) and continued until at least 7365±40 B.P (CAMS 85776). Following a brief period of erosion, Unit C deposits filled down cuts into Unit A nearer to the modern Sink Creek channel. Nordt noted that Unit C also contains interbedded marsh and flood deposits but is unique in that its channel gravels are encased in reddish brown to strong brown mud matrix. Unit C was deposited beginning sometime after 7365±40 B.P (CAMS 85776) and continued no later than 5975±40 B.P (CAMS 85778). Unit D occurred in all cores and unconformably buried all previous units. Unit D consists of dark brown clays grading to strong or reddish brown Bk horizons and is absent of gravelly channel deposits. The deposition of Unit D began sometime after 5975±40 B.P (CAMS 85778), lasting through at least 3300±40 B.P (CAMS 85780). Nordt argued that following the deposition of Unit D, a period of floodplain stability ensued with little to no significant sedimentation. Unit E only occurs near the springhead and Sink Creek and likely represents a fine veneer of Late Archaic and Late Prehistoric deposits. Unit F buries most previous deposits except for near the springhead and consists of mostly post-Historic period fill. Figure 10 shows Nordt's interpretation of the stratigraphy across Spring Lake Peninsula from northwest to southeast, and Figure 11 shows the same down the length of the peninsula from northeast to southwest (Nordt 2010).

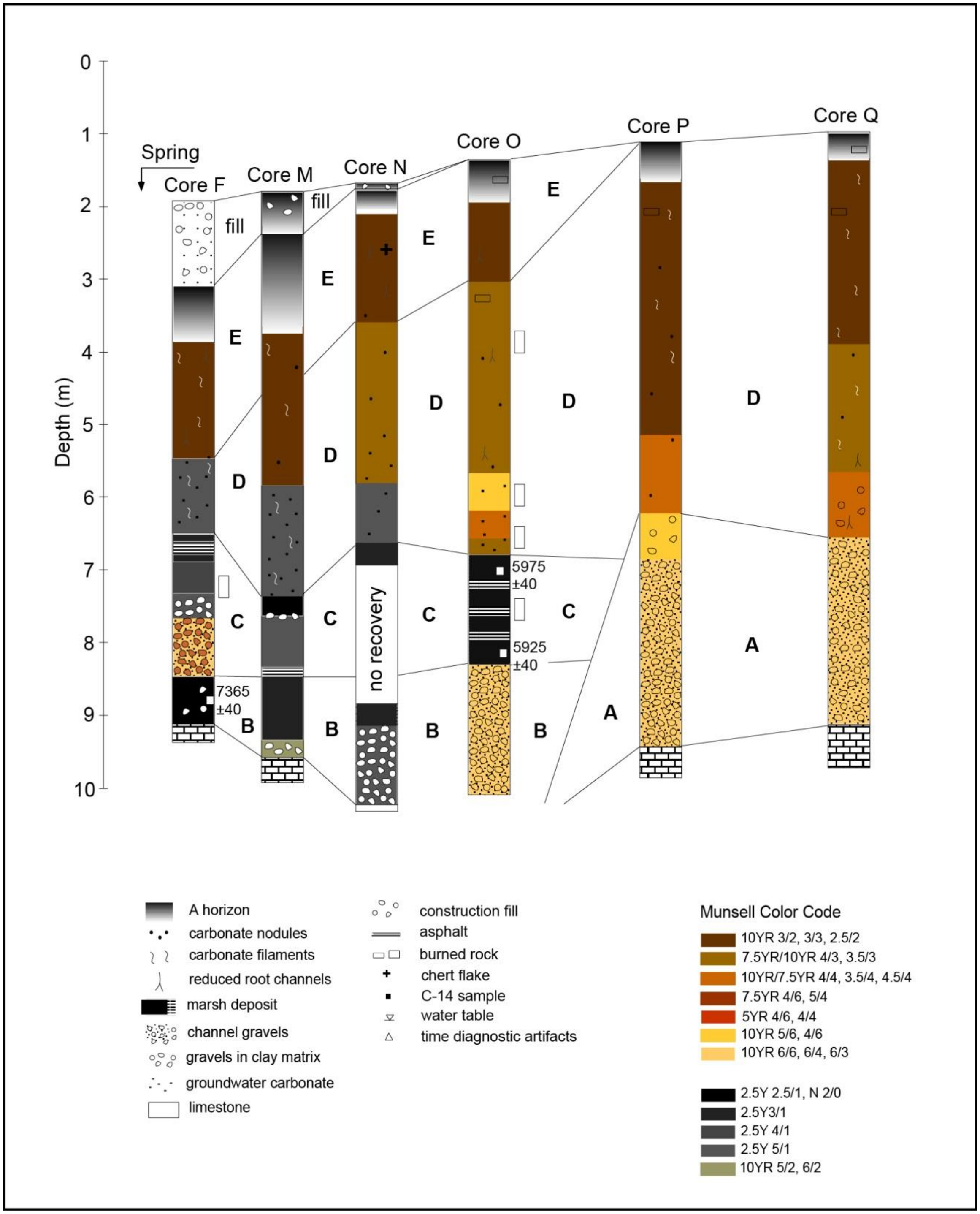

Figure 10. Stratigraphic cross-plot of Cores F, M, N, O, P, and Q taken by Lee Nordt. Lined up from northwest to southeast (from Nordt 2010: Figure 6-5).

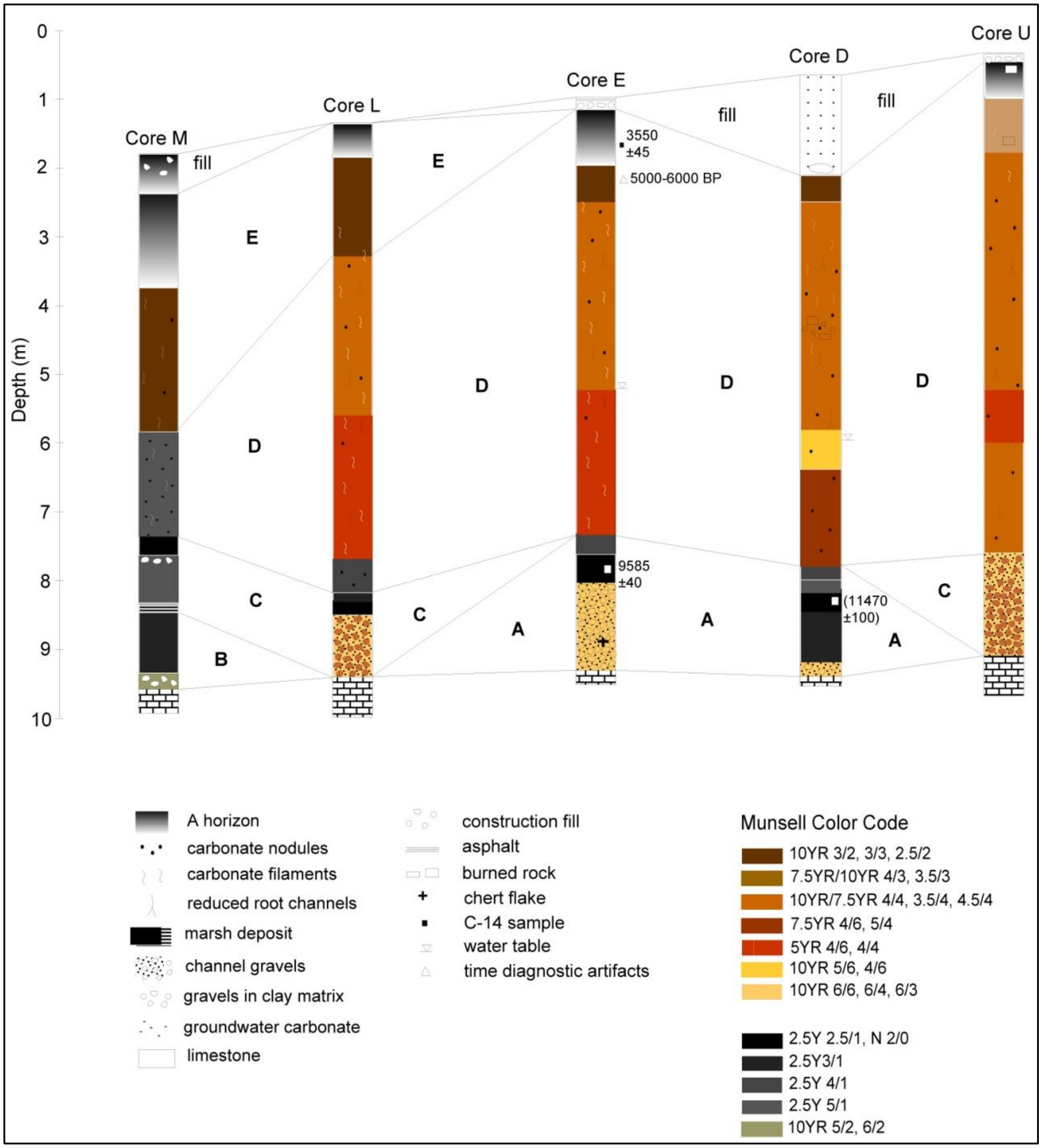

Figure 11. Stratigraphic cross-plot of Cores M, L, E, D, and U taken by Lee Nordt. Lined up from northeast to southwest (from Nordt 2010: Figure 6-7).

In 2010, Center for Archaeology Studies (CAS) conducted an archaeological survey of the area surrounding the submarine theater in order to determine what impacts its removal would have on buried cultural resources (Leezer et al. 2011). CAS collected 8 sediment cores and excavated one 50 x 50 cm test unit in areas immediately adjacent to the submarine theater. Cores were collected by hammering 2¼-inch PVC pipe into the lake bottom and then extracting through either physical force or by chain-hoist. The test unit was excavated using an air-lift; however, sediments were not screened (Leezer et al. 2011).

CAS identified a complex stratigraphy around the sub. In front of the sub (spring side) CAS dated a wood fragment contained in a marsh deposit in Test Pit 1 (Figure 12) at 11,390±50 B.P. (Beta 282624). The marsh deposit was capped by a channel deposit absent at similar depths in cores taken nearby (see Figure 12). Behind the sub (peninsula side) at its northeast corner a bulk sediment sample collected in Core 7 at a depth 3 m above the previously mentioned marsh was dated at 15,980±60 B.P. (Beta 282623) (see Figure 11) (Leezer et al. 2011).

In 2011, CAS excavated four 1 x 1-m units in preparation for the installation of a lift station for a Ticket Kiosk and bathrooms near the north end of Spring Lake (Figure 13) (Lohse et al. 2013). The eastern block of units (see Figure 13) were excavated to a depth of 300 cm. CAS interpreted the stratigraphy as containing 3 depositional units (Figure 14). The lowermost unit, Unit 3 consists of greyish brown clays with gradational carbonate development and is capped by what may represent a truncated A horizon (see Figure 14). Artiodactyl bone fragments at the top of Unit 3 were dated at 6015±20 B.P.

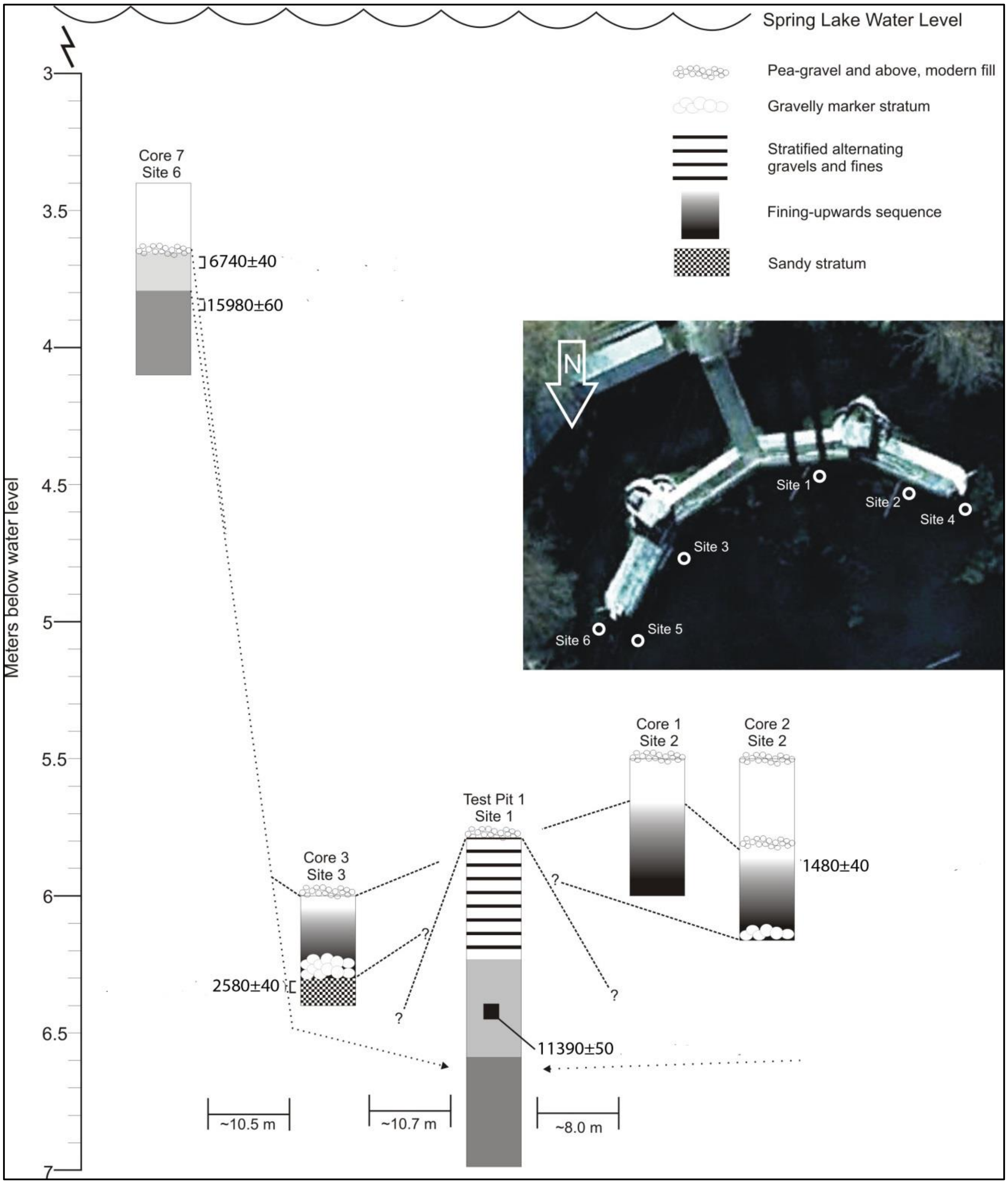

Figure 12. Stratigraphic reconstruction of area surrounding submarine theater. Dates are uncalibrated radiocarbon ages B.P. with errors. (modified from Leezer et al. 2011: Figure 5-22).

Figure 13. Excavation sites for ticket kiosk mitigation. Areas colored in red were shallowly excavated by backhoe. Yellow squares mark excavation unit sites. From Lohse et al. (2013).

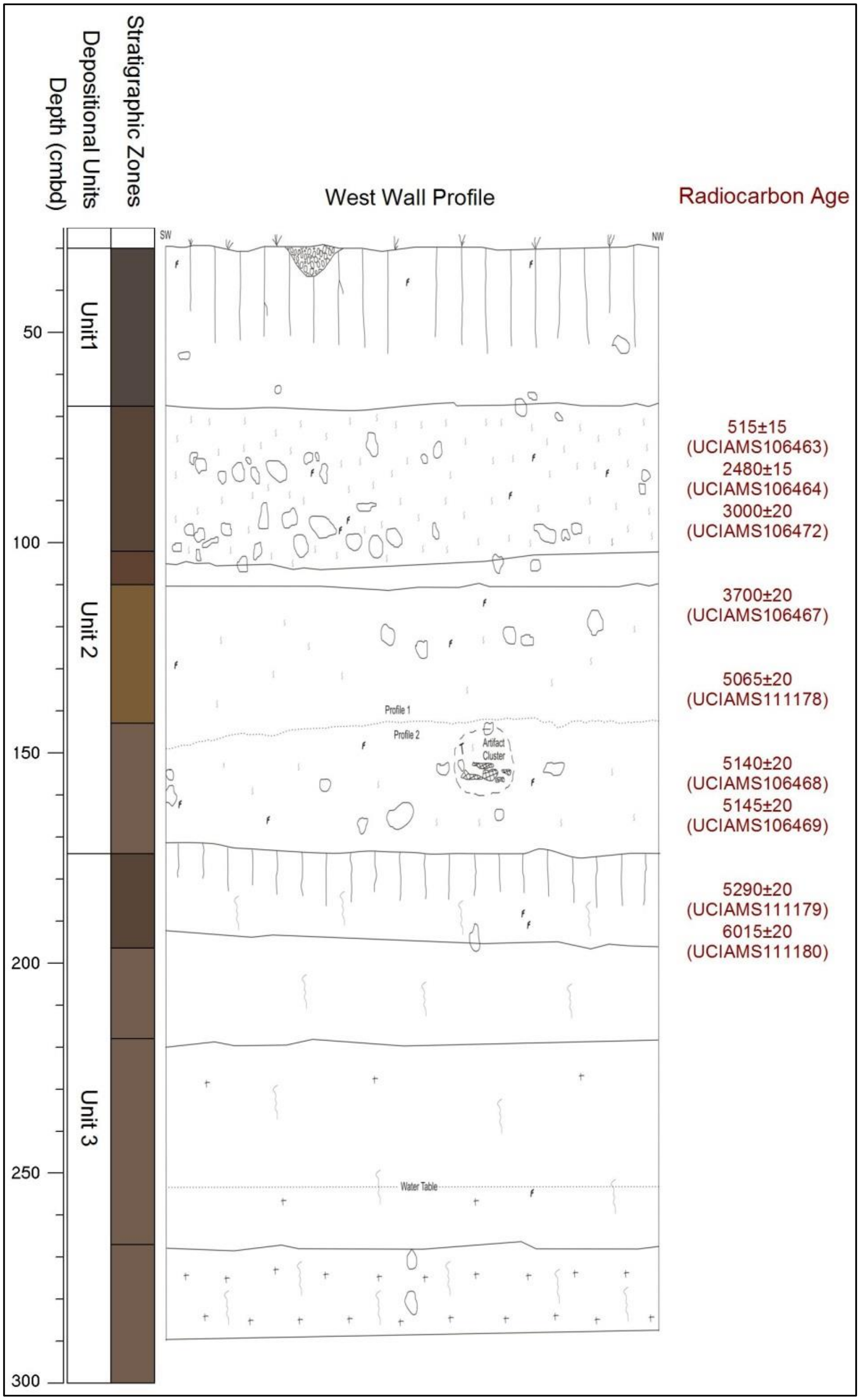

Figure 14. Statigraphic profile from CAS’s Ticket Kiosk Excavation. Shows the west wall of Units 3 and 4 (modified from Lohse et al. 2013). Dates are shown as uncalibrated radiocarbon ages B.P. with errors.

(UCIAMS 111180) and 5290±20 B.P. (UCIAMS 111179). Unit 2 consists of dark brown to yellowish brown clay and is bracketed between bison bone fragment dates of 5145±20 B.P. (UCIAMS 106469) and 515±15 B.P. (UCIAMS 106464) (Lohse et al. 2013).

Taken together, the investigations briefly described above demonstrate clearly that the sediments in Spring Lake have potential to hold *in situ* prehistoric cultural materials, including organics, ranging from Paleoindian to Late Prehistoric; however, several problems are apparent. According to Nordt's (2010) analysis, very little deposition of Paleoindian age remains, having been truncated sometime before 5900 B.P. By Nordt's model the vast majority of intact sediments making up the Spring Lake Peninsula (6 to 8 meters) have been deposited since 5900 B.P. The results of the recent Ticket Kiosk Excavation (Lohse et al. 2013) appear to contradict Nordt's hypothesis, demonstrating that undisturbed deposits as old as 6000 B.P. rest at only 2 meters below the surface. CAS's testing of the sediments around the submarine theater complicates the picture further, showing that organic components of sediments very near the surface date to 16,000 B.P, while more deeply buried wood dates to only 11,400 B.P.

CHAPTER 3

METHODS

In order to address the problems mentioned at the end of the previous chapter, an array of core samples were extracted from sites along the inundated banks of the San Marcos Springs. In addition to examining sediments collected in cores, a naturally cut profile exposure was also observed and described for this analysis.

Fieldwork for this project was conducted between the fall of 2011 and spring of 2013. Laboratory analysis began in the spring of 2012 and continued through the fall of 2013. All depth measurements of features in Spring Lake were observed using a tape measure suspended from a float which was, in effect, an inverted plumbob; error for this method, originating primarily from differences in the force with which divers pulled downward on the tape measure, can reasonably be expected to not exceed 5 cm. Immediately following the recording of any depths, lake level relative to the cement steps at the northeastern tip of Spring Lake was recorded; variation in lake level observed during the course of field-work for this project never exceeded 1 cm.

Profile Exposure

A naturally exposed underwater sediment profile of approximately 4 meters in height was discovered Lake Manager Aaron Wallendorf (Figure 15). According to Wallendorf, the profile was cut at Cypress Point by a flood event in September of 2010. The exposure was near-vertical, slightly concave towards the southeast, approximately 6 meters in total length, and appeared relatively fresh in that very little vegetation or algae had taken root on its face. Because of a difficulty maintaining visibility while attempting

Figure 15. Satellite photo showing the approximate location of the Cypress Point profile. Exposure is just southwest of the mouth of Sink Creek.

to record soil properties underwater, a photomosaic was created by stitching 24 close-up digital photographs taken by a 12 megapixel Canon G10 into a single image using Photoshop. Although the depths of obvious lithostratigraphic contacts were observed and recorded onsite, soil properties including color, large clast size/concentration (gravels/cobbles), and structure were estimated from the photomosaic in the CAS laboratory. Several potentially diagnostic artifacts protruding from the exposure were collected and transported to CAS. Wood samples collected at the Cypress Creek profile for ^{14}C analysis were bagged underwater and kept submerged until they could be properly curated at CAS; those samples selected for radiocarbon dating were prepared by Brendan J. Culleton at the University of Oregon Archaeometry Facility, Eugene following the procedure of Ward and Wilson (1978) and analyzed at the Keck Carbon Cycle AMS Program, University of California at Irvine.

Coring

Following extensive review of underwater sediment coring methodologies and building on experiences gained from the cultural resources survey for the Spring Lake Aquatic Ecosystem Restoration Project (Leezer et al. 2011), as well as experimentation with the coring methods described by Jones et al. (1992), a series of 9 sediment cores was collected by driving aluminum irrigation pipes into lake bed sediments by way of pneumatic post driver (Figure 16). The pipe had an outside diameter of 7.62 cm (3 inches) with a wall thickness of 1.3 mm (0.05 inches) and varied in length from 2.5 to 6 m. The post driver was a Rhino Model PD-55 powered by surface-supplied compressed air and lubricated with vegetable oil in order to avoid contamination of the lake with petroleum-based toxins.


Figure 16. Core tube being driven using pneumatic post driver.

Initially, the locations of cores were to be determined based on the results of a sub-bottom profile survey; however, the data obtained during the survey were largely inconclusive due to the nature of the bottom of Spring Lake. Because of the shallow depth and clear water, aquatic vegetation grows prolifically throughout much of the lake. The highly variable changes in density which occur in the transition from water, to leafy vegetation, to algae, to decomposing organic matter, and finally to alluvium obscure the sub-bottom profile such that distinctive bedding structures remain largely obscured. In the end, coring sites and drive-depth goals were determined primarily based on estimations of sediment thickness given distance to and depth of stream channel colluvium or bedrock exposures.

Before extraction, the base of the exposed pipe was marked and the distance from that mark to the lake surface was recorded. Air tight caps were placed in the open end of the pipes, and the cores were then extracted using a chain hoist secured to an A-frame and suspended through a small access hatch on a shallow-draft barge (Figure 17). As the lower end of the core tube came free of the hole, one of the divers in the water immediately placed a cap over the lower opening, securing it with waterproof adhesive tape. In the case of Core 03, two additional sections were collected by driving a longer second and still longer third pipe down the same hole in order to collect sediments at greater depth; for Core 09, one additional section was taken in the same way. Methods for depth recording and extraction for the additional sections of Cores 03 and 09 were the same as those described above.

Figure 17. Core being extracted using chain-hoist on barge (from Leezer et al. 20011: Figure 4-2).

Mapping

Locations of the Cypress Point profile and all described cores were recorded using a hand-held GPS unit with submeter accuracy held directly over core locations just above the lake surface. GIS information was later downloaded at CAS into a universal map of the project area using ArcGIS software.

Laboratory Procedures

All cores, artifacts, and samples for radiometric dating were carefully collected and stored in appropriate containers in the field and then transported to CAS. Great care was taken to keep the core tubes as vertical as possible before the excess water could be siphoned out of the top and a plug of paper towels could be inserted to help avoid the shifting of sediments during transport to CAS.

Figure 18. Author using electric tin shears to cut aluminum core tube.

Cores were kept sealed and upright at CAS until they could be cut. Time between collection and cutting varied from several days to several weeks, and no samples exhibited significant drying deeper than the top 10 cm prior to being split. Core tubes were cut using electric tin shears (Figure 18) and sediment columns were split using steel wire. Soil/sediment characteristics of core samples including horizon, color, redoximorphic features, carbonate development, structure, and texture were described following the methods of Schoeneberger et al. (2012). Care was taken to only select samples for ^{14}C dating from plant fragments and charcoal which were well-contained within the sediment columns in order to avoid contamination by vertical displacement or vegetable oil. The archaeobotanical identification of charcoal, wood, and plant fragments selected for radiocarbon dating was performed by J. Kevin Hanselka in Austin, Texas; samples were then prepared for AMS ^{14}C dating by Raymond Mauldin at the Center for Archaeological Research, University of Texas, San Antonio (procedure presented in Appendix A) and analyzed by DirectAMS, Seattle.

Instances of *core shortening* (a deficit between drive depth and sample length) resulting from physical compression, sediment thinning, sample loss, and/or sediment bypassing were corrected following the methods of Morton and White (1997). Because of the difficulty in identification, instances of physical compression and sediment thinning were treated as negligible, although both are likely to have occurred to at least a small degree. The first measurement adjustments were made to gaps in the middle of the sample and treated as evidence of sample loss from the bottom of the core tube caused by suction during extraction. The second adjustments were made to the surface elevation and treated as evidence of sediment bypassing. Total depth adjustments due to core shortening varied between 20 and 50 cm.

Stratigraphic Analysis and Modeling

The stratigraphic sequence of deposits observed in cores and the Cypress Point profile was interpreted using a combination of lithostratigraphy and chronostratigraphy.

Unconformable surfaces between lithostratigraphic zones could not often be determined to show evidence of truncation of the lower surface. Therefore, sedimentary units were defined based primarily on superposition and lithostratigraphic characteristics and secondarily by radiocarbon chronology.

Topographic and bathymetric (lake bottom) surface contours were modeled by combining 1-meter resolution TNRIS (Texas Natural Resources Information System) LiDAR data with a bathymetric contour map of Spring Lake showing 2-foot contour intervals (LBG-Guyton and Associates 2004) using a combination of ArcGIS and RockWorks software. 3-dimensional modeling of surface contours and core locations/depths was completed using RockWorks.

CHAPTER 4

RESULTS

Cores from a total of nine locations were collected for this study (Figure 19). They are numbered 01, 02, 03, etc. rather than 1, 2, 3, etc. in order to better distinguish them from cores collected by Leezer et al. (2011) in discussion. The core tube of Core 01 was cut by a handheld circular saw which largely destroyed stratigraphy and spread fine aluminum shavings throughout the sample, ultimately leading to the discarding of the sample as well as the use of electric tin shears as the preferred method for the cutting of core tubes. The provenience data of Core 02 was lost, and so, Core 02 was unfortunately also excluded from this study.

The distribution of Cores 03 through 09 and the Cypress Point profile are depicted in Figure 19 relative to the topography/bathymetry of the area surrounding the San Marcos Springs. Stratigraphy encountered in cores and profile is summarized below beginning with an interpretation of depositional environments represented by the sediments at each location, followed by stratigraphic identification of the distinctive sedimentary zones which exist across locations. A more technical, zone by zone lithology of each core and the Cypress Point profile is presented in Appendix B. Both lithostratigraphic zones and sedimentary units are numbered from top to bottom. For the remainder of this paper, all dates are given in radiocarbon years B.P. (before A.D. 1950) unless otherwise stated.

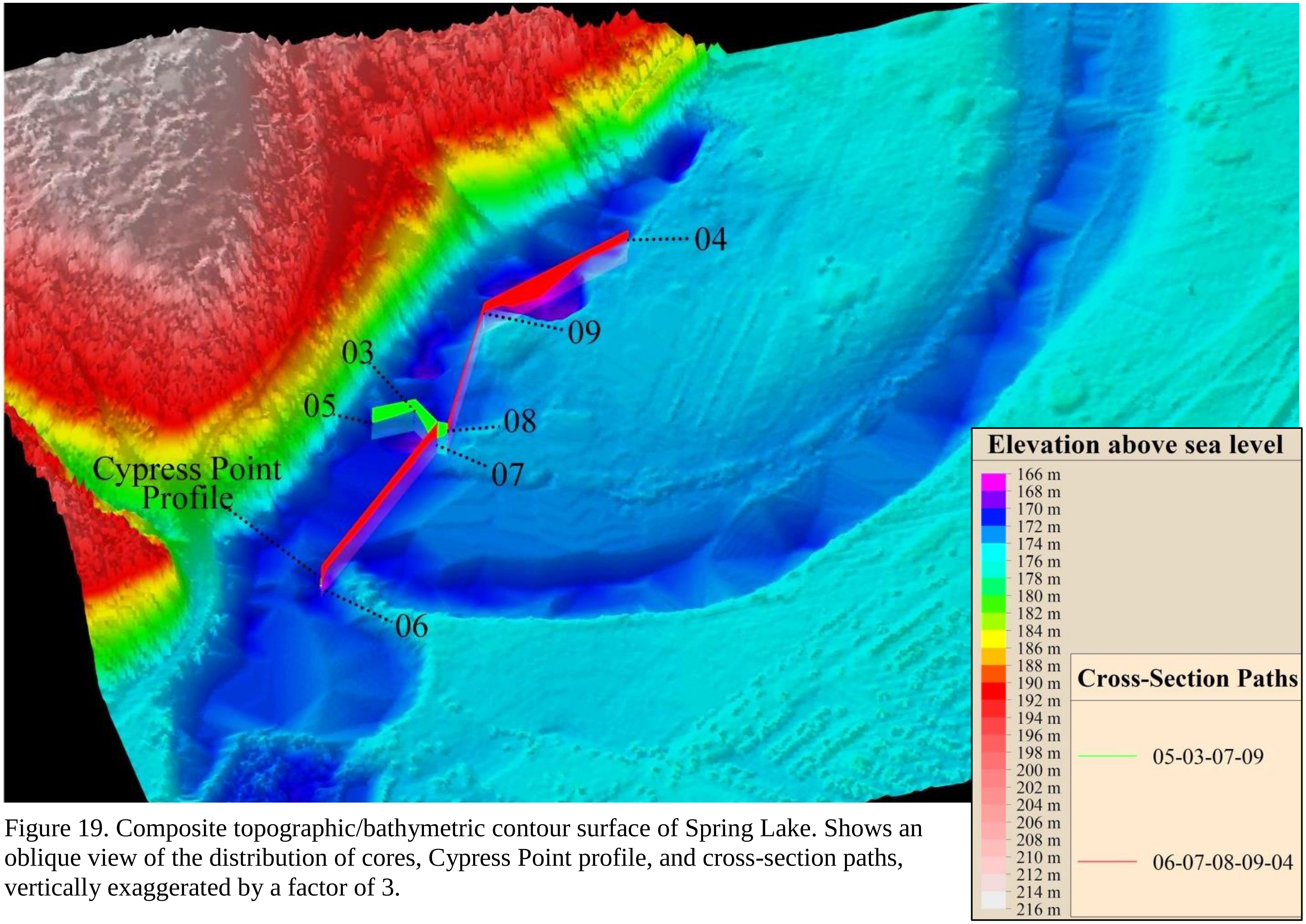

Figure 19. Composite topographic/bathymetric contour surface of Spring Lake. Shows an oblique view of the distribution of cores, Cypress Point profile, and cross-section paths, vertically exaggerated by a factor of 3.

Environments of Deposition Represented in Cores and Profile

Cypress Point Profile

The sediments visible in the Cypress Point Profile were deposited in two very different types of depositional environments. Zones 4 through 8 are composed of interbedded gray to yellowish gray clay matrix supported gravels and gravelly sands; these deposits aggraded in a relatively high energy fluvial environment. In contrast, Zones 1, 2, and 3 represent a more terrestrial alluvial environment with aggradation of clayey overbank deposits showing at least weak structure.

Core 03

Zones 6-16 of Core 03 consist of highly stratified lacustrine sediments. Zones 6, 8, 10, 11, 12, and 14 consist of dark gray to black, organic rich clays and silts which appear to have aggraded slowly in very low energy conditions. Zones 7, 9, 13, 15, and 16 consist of very poorly sorted deposits of multicolored clay rip-up clasts, transported pedogenic $CaCO_3$ clasts, very fragmentary snail shell, and organic debris; these zones represent lacustrine debris-flow deposits, each of which accumulated rapidly in a slackwater environment during during flood events. Zone 5 consists of weakly cross-stratified sand which must have been deposited in a fluvial environment of moderate energy. Sediment in Zones 1-4 has spongy texture and grades upward from more clayey to more sandy to diatomaceous and must have been deposited in a low energy lacustrine environment.

Core 04

Both fluvial overbank and lacustrine deposition occur in Core 04. Zones 11, 12, 13, and 14 are light brown to reddish brown clayey overbank deposits. Zones 11 and 13 were deposited in a relatively higher energy as they contain gravels and transported $CaCO_3$ clasts; Zones 12 and 14 represent an environment of lower energy containing fewer and smaller clasts. Zones 1-10 are dark, organic-rich lacustrine sediments in which Zones 1,2,3,4,5,6, 8, and 9, represent slow limnic aggradation in low energy, and Zones 7 and 10 are lacustrine debris-flow deposits. Zones 1-4 are spongy textured and grade upward from clayey to sandy to diatomaceous**.**

Core 05

All sediments in Core 05 were deposited in a low energy lacustrine environment; they are spongy textured and grade upward from clayey to sandy to diatomaceous.

Core 06

Core 06 was taken from just in front of the Cypress Point profile exposure and most likely is a downward continuation of that profile. Sediments in Zones 2-6 of Core 06 are interbedded yellowish to reddish brown clay matrix supported fluvial channel gravels. Zone 1 most likely represents recent colluviation from the face of the profile wall.

Core 07

Zones 18 and 19 of Core 07 are yellowish to reddish brown clayey overbank deposits. Zone 19 was deposited in a slightly higher energy environment as it contains more and larger clasts than Zone 18. Zones 1-17 represent lacustrine deposition where

Zones 1, 2, 4, 5, 6, 9, 11, and 15 consist of dark, organic-rich, clayey limnic deposits, and Zones 3, 7, 8, 10, 12, 13, 14, 16, and 17 represent more rapidly deposited lacustrine debris-flow deposits.

Core 08

Zones 9 and 10 of Core 08 are yellowish to strong brown clayey overbank deposits. Zone 10 may have been deposited in relatively higher energy as it contains more but not larger clasts than Zone 9. The sediments in Zones 1-8 are lacustrine with Zone 8 representing lacustrine debris-flow and Zones 1-7 consisting of more slowly aggraded organic-rich limnic deposits. Zones 1-4 are spongy textured and grade upward from clayey to sandy to diatomaceous.

Core 09

Zones 7-14 of Core 09 consist of interbedded yellowish to reddish brown clay matrix supported gravels and gravelly sand representing fluvial channel deposition in relatively high energy. Zone 6 sediments are organic-rich, dark gray clayey marsh deposits containing many well-preserved, laminated plant fragments. Zones 1 -5 are spongy lacustrine sediments and grade upward from clayey to sandy to diatomaceous.

Stratigraphy

Alluvial stratigraphy encountered in the Cypress Point profile and cores extracted from the bottom of Spring Lake can be divided into four lithologically distinctive, chronologically similar sedimentary units labeled from youngest to oldest, I, II, III, and IV (Figures 20 and 21). Figure 20 shows a cross-section plot of Cores 05, 03, 07, and 08 oriented across the primary spring discharge channel (see Figure 19), and Figure 21 shows a cross-section plot of the Cypress Point profile and Cores 06, 07, 08, 09, and 04 oriented across the mouth of Sink Creek and up the western bank of the Spring Lake Peninsula (see Figure 19).

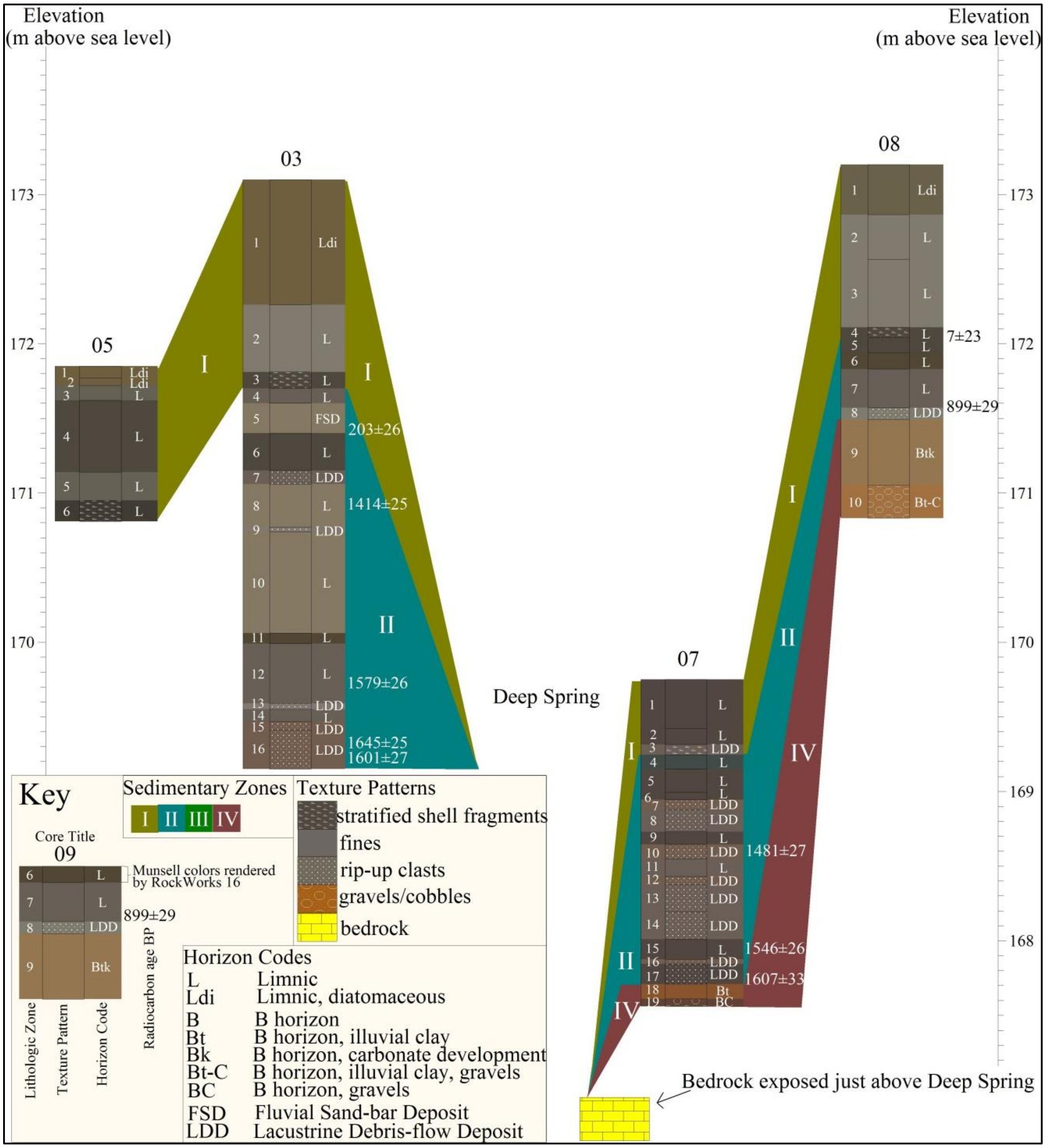

Figure 20. Stratigraphic cross-section plot of Cores 05, 03, 07, and 08. Lined up northwest to southeast in Spring Lake. Uncalibrated raiocarbon dates and errors are plotted adjacent to sample locations.

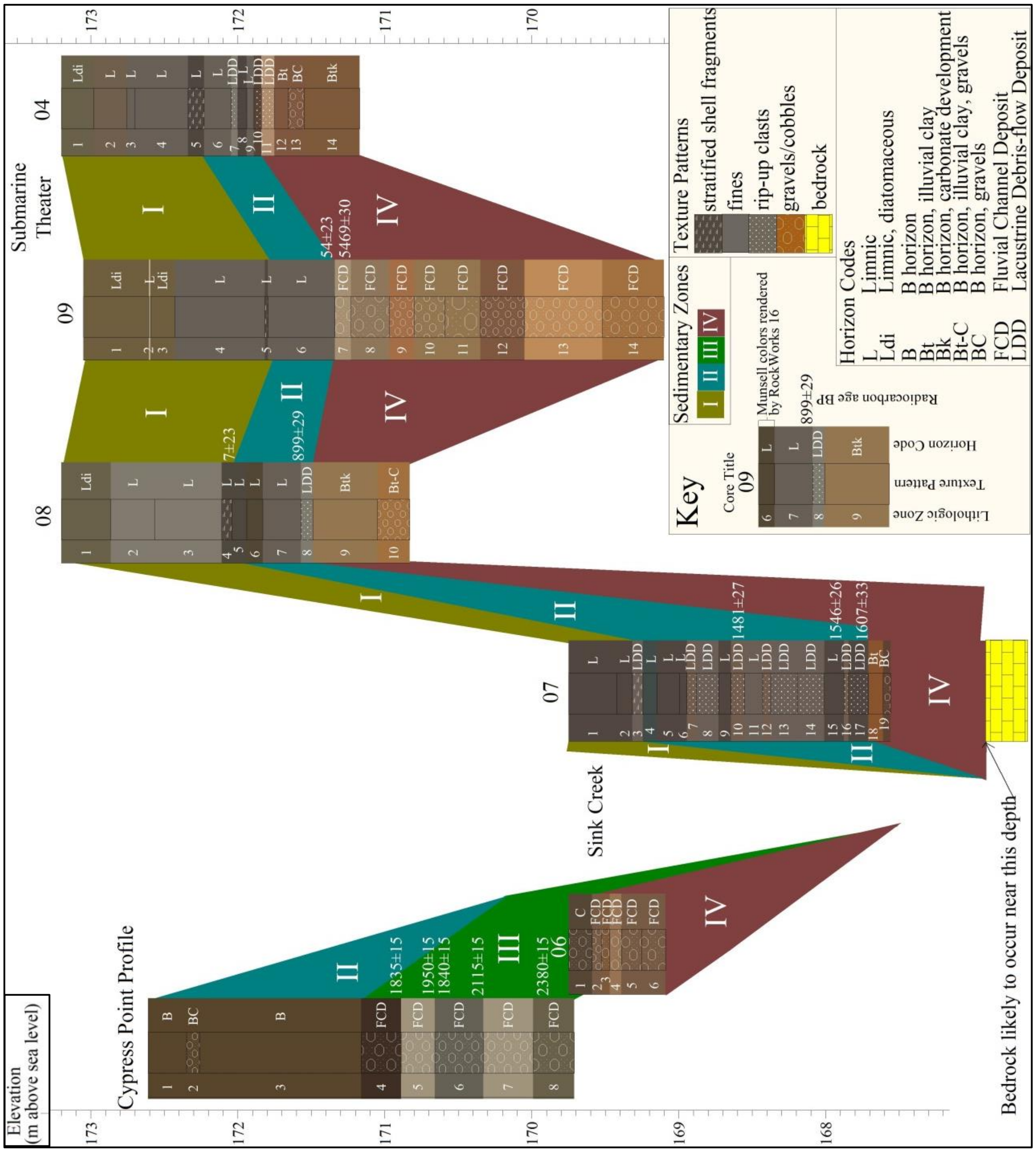

Figure 21. Stratigraphic cross-section plot of profile log and Cores 06, 07, 08, 09, and 04. Lined up southwest to northeast in Spring Lake. Uncalibrated radiocarbon dates and errors are plotted adjacent to sample locations.

The oldest sedimentary unit identified in this study is Unit IV; it occurs in Cores, 04, 06, 07, 08, and 09 (see Figures 20 and 21; Appendix B). A lower boundary for Unit IV was not encountered in cores extracted for this study, however one is likely to occur less than 50 cm below the bottom of Core 07 given that core’s proximity to exposed bedrock near just above the deepest part of the lake (see Figure 20). Unit IVconsists of predominantly reddened clays interbedded with channel gravels and sands supported by reddened clay matrix.

In Cores 06 and 09, Unit IV deposits are entirely fluvial in nature, containing many large cobbles (see Figure 21; Appendix B). For Cores 04, 07, and 08 Unit IV exhibits evidence of pedogenesis, in the form of $CaCO_3$ masses and reddened, compacted clays. Unit IV in Core 04 exhibits a typical progression of $CaCO_3$ development with depth; however, the progression in Cores 07 and 08 appears atypical (Appendix I). Unit IV occurs in Core 08, Zone 9 as a Btk horizon containing $CaCO_3$ masses overlying Zone 10, a gravelly Bt-C horizon distinctively absent of carbonate development. Nearby in Core 09, Zones 8 through 14, Unit IV occurs as a series of matrix-supported channel deposits. The color transition of the matrix clays found in Zones 8, 9, and 10 of Unit 4 in Core 09 are very similar to Zones 9 and 10 of Core 08 with an offset of 10 to 20 cm lower elevation (see Figure 21). Because Core 09 is located nearer the channel’s thalweg, and Core 08 is situated further up-bank, the Unit IV deposits in Cores 08 and 09 may represent, respectively, terrace and channel facies of chronologically linked depositional periods. For all cores in which Unit IV occurs, the top zone shows evidence of truncation, exhibiting wavy to irregular boundaries, and in Cores 04, 07, and 08, the lowest zone of the overlying sedimentary unit exhibits clay rip-up clasts of similar color and texture to the underlying Unit IV zone (Appendix B, Cores 04, 06, 07, 08, 09). Based on charcoal obtained from Zone 7 in Core 09, the deposition of Unit IV continued until at least 5469±30 B. P. (Table 2, DAMS 001781) followed by a period of much-reduced aggradation and at least some amount of truncation.

Unit III is only seen in the Cypress Point profile and marks a period of stream channel aggradation beginning at least as early as 2380±25 B.P. (UCIAMS 95430). Unit III consists of interbedded gray to light yellowish gray clay matrix-supported channel deposits containing large amounts of preserved wood (see Figure 21; Appendix B). It is possible further research may show Unit III to be more appropriately included with Unit IV. Unlike the small twigs abundant in core samples, the preserved wood collected from Cypress Point were fragments of larger branches and may be somewhat older than the depositions in which they are contained. Although Unit III rests on Unit IV deposits, it has tentatively been identified as a distinct unit based on the following observations. No deposits of similar age to Unit III were encountered in cores taken up-stream of the mouth of Sink Creek, and although Unit III consists of coarse textured channel gravels, it lacks the reddened sediments common to Unit IV.

Units III and IV are capped by Unit II which marks a shift from a relatively slow aggradation of channel gravels in a moderately swift current to period of lake high-stand with rapid in-filling of a slack-water environment at some point between 1835±15 B.P. (UCIAMS 95427) and 1645±25 B.P (DAMS 001783) based on the dates of preserved wood and plant fragments collected at Cypress Point and Core 03, respectively. Unit II occurs in Cores 03, 07, 08, and 09 (see Figures 20 and 21; Appendix B) and consists

Table 2. ^{14}C ages from cores and exposed profile in Spring Lake. DAMS: Direct-AMS, Seattle, UCIAMS: University of California at Irvine Keck Carbon Cycle AMS Program, Irvine. For reader convenience, calendar ages showing a 2σ range have been calibrated using OxCal-IntCal 2013; however these calendar ages are not used in any of the following discussion.

Sample Number	Location	Depth (cm)	^{14}C Age B.P.	δ^{13}C ‰	Calendar Age B.P.	Material
DAMS 001773	**Core 03**	163	**203±26**	-25.6	301-0	wood
DAMS 001775	**Core 03**	213	**1414±25**	-26.4	1353-1290	wood
DAMS 001774	**Core 03**	333	**1579±26**	-36.6	1534-1407	wood
DAMS 001783	**Core 03**	373	**1645±25**	-28.8	1613-1420	wood
DAMS 001772	**Core 03**	383	**1601±27**	-25.6	1549-1413	charcoal
DAMS 001782	**Core 07**	110	**1481±27**	-33.7	1409-1310	wood
DAMS 001777	**Core 07**	176	**1546±26**	-28.2	1525-1378	plant fragment
DAMS 001776	**Core 07**	196	**1607±33**	-33.0	1560-1410	wood
DAMS 001779	**Core 08**	111	**7±23**	-23.7	244-36	plant fragment
DAMS 001778	**Core 08**	160	**899±29**	-20.3	911-740	wood
DAMS 001780	**Core 09**	171	**54±23**	-25.5	254-32	wood
DAMS 001781	**Core 09**	180	**5469±30**	-34.0	6310-6208	charcoal
UCIAMS 95427	**Cypress Point Profile**	169	**1835±15**	-	1820-1719	wood
UCIAMS 95426	**Cypress Point Profile**	190	**1950±15**	-	1944-1866	wood
UCIAMS 95425	**Cypress Point Profile**	198	**1840±15**	-	1821-1722	wood
UCIAMS 95428	**Cypress Point Profile**	220	**2115±15**	-	2146-2010	wood
UCIAMS 95430	**Cypress Point Profile**	265	**2380±15**	-	2456-2347	wood
Beta 282624	**Test Unit 1 (Leezer et al. 2011)**	40-45	**11390±50**	-27.2	13332-13106	wood

of highly stratified deposits of organic-rich, dark gray to black limnic sediments interbedded with numerous single-event, lacustrine debris-flow deposits composed of sand to gravel-sized limestone coarse fragments, multi-colored clay rip-up clasts, and many preserved plant, wood, and seed fragments (Appendix B). Unit II deposits also occur in the Cypress Point profile, identified by chronology, but are lithologically distinct from deposits encountered in cores in that they represent a clearly terrestrial B horizon (Appendix B). Given the ^{14}C age of plant and wood fragments collected in Cores 03, 07, and 08, a large majority of Unit II aggradation occurred between 1607±33 B.P. (DAMS 001776) and 1414±25 B.P (DAMS 001775) with a much-slowed accumulation continuing through at least 899±29 B.P. (DAMS 01778) and possibly through 203±26 B.P. (DAMS 01773)

Unit I is the youngest, most widespread, and stratigraphically distinctive phase of deposition in Spring Lake, occurring at the top of all 7 cores (see Figures 20 and 21; Appendix B). Unit I occurs in cores as a near-universal depositional series beginning with a 5 to 10 cm thick very dark gray to black organic rich loam with concentrations of stratified snail shell fragments, overlain by a gray to dark gray sandy loam with reddish-brown oxidized Fe concentrations, and capped by olive brown loamy diatomaceous mats (Appendix B). Although Unit I is lithologically the most recognizable series of zones encountered in cores, its chronology is ambiguous due to problematically young ^{14}C ages of wood and plant fragments collected in and around the shelly marker stratum. A wood fragment collected just above Unit IV in Zone 6 of Core 09 was dated at 54±23 B.P. (DAMS 001780) and a plant fragment collected in Zone 04 of Core 08 was dated at 7±23 B.P. (DAMS 001779). These ages cannot be accurately calibrated because they fall in the range of when the burning of fossil fuels overwhelmed the natural production of ^{14}C in the atmosphere (Taylor 1992). Although in an absence of chronological evidence, Unit I is most likely the lacustrine deposition which began after the inundation of the lake in A.D. 1849. Following this hypothesis, the shelly marker stratum could have resulted from the drowning of terrestrial snails living near the banks upstream of the dam and the oxidation stained sands could mark the clearing of trees and onset of Historic industrialization.

CHAPTER 5

DISCUSSION

The oldest ^{14}C ages of deposition at the San Marcos Springs come from dates of bulk sediment samples (Goelz 1999; Leezer et. al 2011). Nordt (1992) showed that sediment humates tend to date older than charcoal in Central Texas alluvium, and Goudie et al. (1981) demonstrated problems with the dating of lacustrine sediments due to the introduction of older material to the sediment sampled. Given the problematic nature of the sediment dates recorded by Leezer et al. (2011), bulk sediment dates will not be included in this stratigraphic interpretation.

Excluding the apparent ^{14}C age of two bulk sediment samples collected from cores (Beta 132062, Goelz 1999; and Beta 282623, Leezer et al. 2011), the oldest Late Pleistocene deposition yet recorded at the San Marcos Springs was excavated in Test Pit 1 just in front of the submarine theater (Leezer et al.2011). The channel deposits in Core 09 (Appendix B) bear a strong resemblance to those excavated at the top of Test Pit 1 by Leezer et al. (2011), and given the proximity (Figure 22), it is likely that the deposition of Unit IV began before 11390±50 B.P (Table 2, Beta 282624) based on the ^{14}C age of a preserved wood fragment collected from just below the bottom elevation of Core 09 (Figure 23).

The existence of unconformities within Unit IV is obvious in the interbedding of gravelly clays in Cores 06 and 09 and the erratic carbonate presence in Core 08 (Appendix B); these unconformities are suggestive of a period of rapid aggradation of deposits eroded from a nearby source. Given the slightly lower elevation of Core 09 from

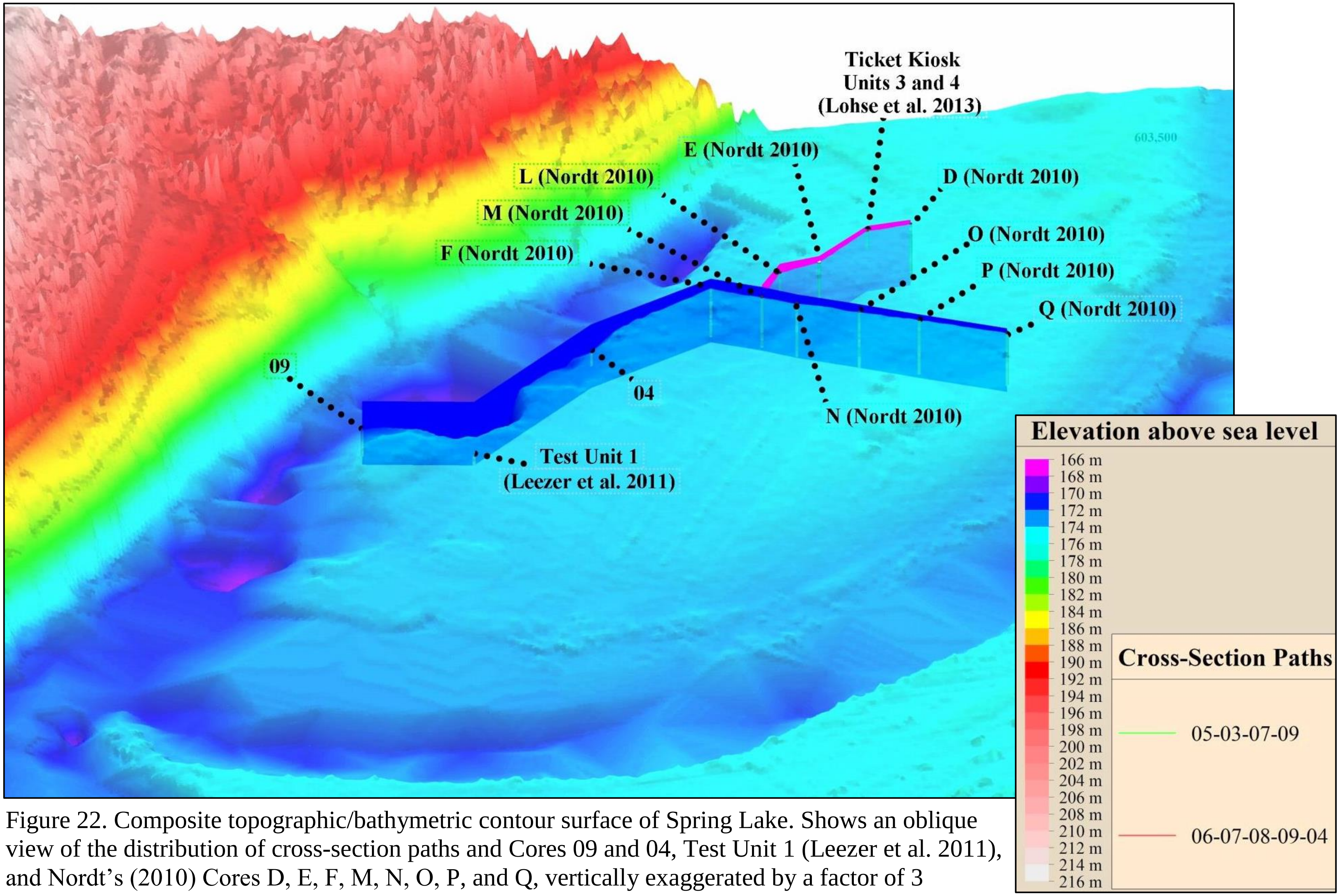

Figure 22. Composite topographic/bathymetric contour surface of Spring Lake. Shows an oblique view of the distribution of cross-section paths and Cores 09 and 04, Test Unit 1 (Leezer et al. 2011), and Nordt's (2010) Cores D, E, F, M, N, O, P, and Q, vertically exaggerated by a factor of 3

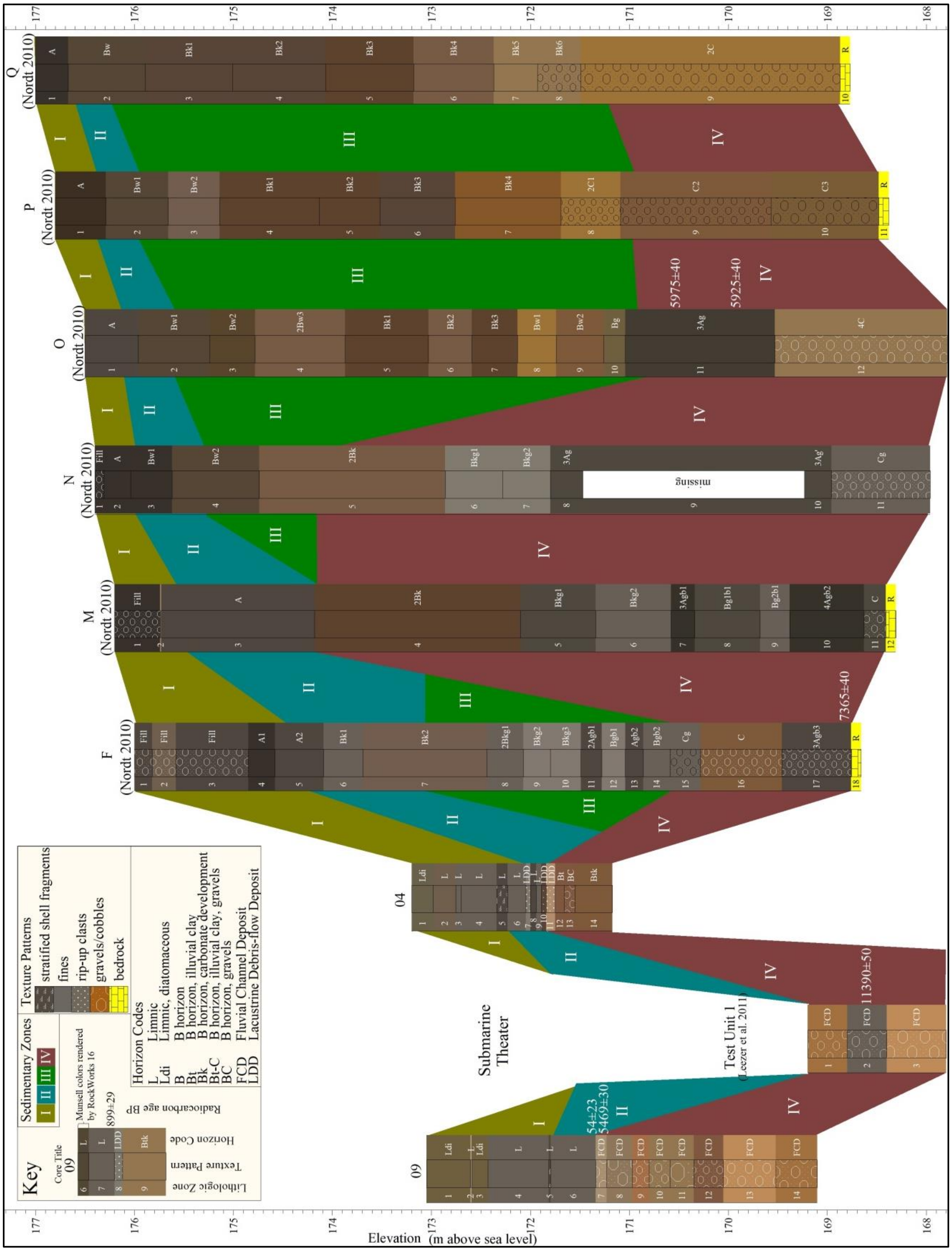

Figure 23. Stratigraphic cross-section plot showing Core 09, Test Unit 1 (Leezer et al. 2011), Core 04, and Nordt's (2010) Cores F, M, N, O, P, and Q. Lined up from west to east in Spring Lake and across the Spring Lake Peninsula.

Core 08, floods traveling down the peninsula would be more likely to deposit gravels on the former and finer grained deposits over the latter. If Unit IV deposits in Cores 08 and 09 are, indeed, different facies of the same depositional episodes, then Unit IV is representative of a period in which freshly eroded mature soils from the nearby uplands of the Balcones Canyonlands and Edwards Plateau were being removed and then rapidly deposited in the San Marcos River Channel. Cooke et al. (2003; 2007) have shown that such was the case at Hall's Cave, Kerr County, Texas. Given the position at the base of the Balcones Escarpment, the reduction of energy which occurs in water moving out of the Balcones Canyonlands onto the Blackland Prairie floodplain makes the springs and the upper San Marcos River channel an ideal sediment trap.

A second factor in catching sediments at the San Marcos Springs is how they would entrap finer grained clays that exist at the top of Unit IV in Cores 04, 08, and 09. If the end of the Pleistocene was marked by deforestation caused by warming and/or drying (Bousman 1998; Nordt et al. 2002), the erosion occurring in the uplands (Cooke et al. 2003; 2007) would also occur at the base of the escarpment. Based on the ^{14}C age of a plant fragment, Nordt (2010) argued that sometime before 9585±40 B.P. (CAMS 85777) only channel gravels existed above the bedrock of much of the lower terrace of the Sink Creek valley with Sink Creek running, perhaps ephemerally, as an anastomosing stream. In this case, fine grained sediments would largely be removed. Nordt (2010) also argued that channel entrenchment occurred through 7,365 B.P., followed by the filling of the Sink Creek valley and construction of the Spring Lake Peninsula occurring after 5900 B.P. In the following model, I propose an alternative hypothesis. Although I agree that major entrenchment of Sink Creek occurred at least until 5,900 B.P. in the middle of the modern peninsula, the construction of at least the northwestern half of the peninsula began roughly by 11,400 B.P. and continued with relatively little truncation until 1414 B.P. In this case, the Unit IV of this study contains all of Nordt's (2010) Units A, B, and C and the majority of Unit D. Although future work will almost certainly show Unit IV to be divisible into several or more distinct depositional phases, the key difference between the following model and that of Nordt is the more ancient age of a large portion of the Spring Lake Peninsula.

A Model for the Formation of Spring Lake Peninsula

The San Marcos Springs can be divided into upper and lower headwaters (Figure 24). The discharges of springheads in the upper headwaters are more dependent on local aquifer flow and are located slightly higher in elevation from the major orifices of the lower headwaters (Musgrove and Crow 2013). It stands to reason that the depositional facies of the upper headwaters would exhibit a greater range in the energy of their environments than those of the lower headwaters without showing a similar variation in the availability of near-to-surface groundwater. One implication of this phenomenon would be that in the vicinity the upper headwaters, stratigraphic markers for climate change could be reversed from normal, whereby periods of drought would lend to sediment aggradation because of still-thriving marsh vegetation acting as a sediment net; a return to wetter conditions would be marked by truncated channel deposits eroded by more energetic spring flow. Extreme droughts would cause regional aquifer flow to subside, causing spring discharge to lose the energy required to remove sediments and debris deposited across the main spring channel by an ephemeral but energetic Sink Creek. Over the course of a drought, increased bed load and organic debris from Sink

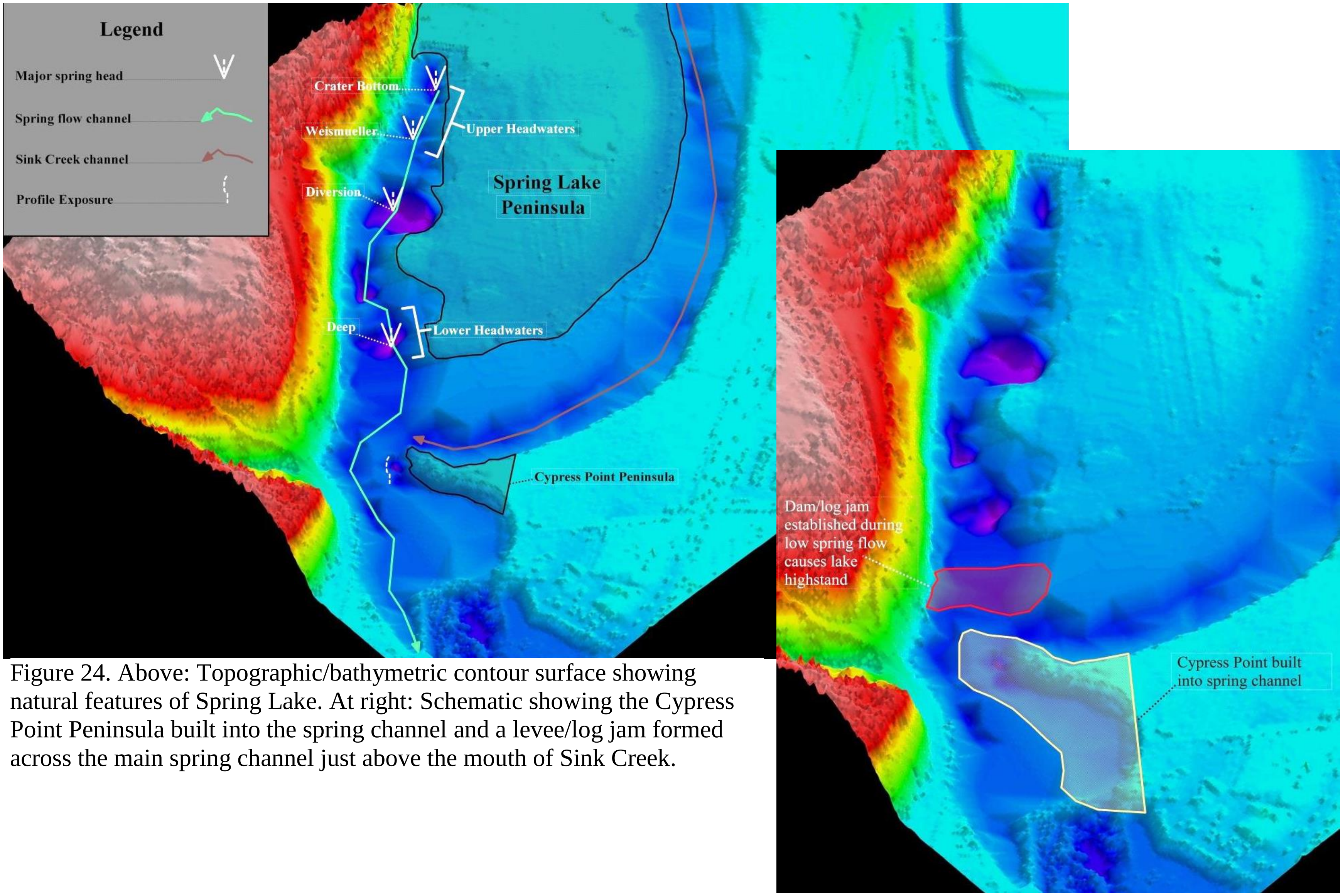

Figure 24. Above: Topographic/bathymetric contour surface showing natural features of Spring Lake. At right: Schematic showing the Cypress Point Peninsula built into the spring channel and a levee/log jam formed across the main spring channel just above the mouth of Sink Creek.

Creek floods would build a levee across the spring-side stream channel turning the springs into a lake. As the surrounding region dried out, vegetation would be relatively dense within and around the edges of the lake while sparse on the floodplain on the far side of the Sink Creek channel. Upon a return to wetter conditions, both the springs and Sink Creek would begin flowing with greater energy more perennially, resulting in the erosion of the levee across the spring channel as well as the outside bank of Sink Creek. Over time, Spring Lake Peninsula would widen towards the southeast as drought-proof vegetation captured sediment while lengthening towards the southwest as Sink Creek carved further into its relatively dry cutbank.

The process outlined above explains the deposition of Units II and III. Entrenchment of Sink Creek lasting through ~5900 B.P. was followed by aggradation in the Sink Creek channel (Nordt 2010). Beginning some time before 2380 B.P., Sink Creek channel gravels began to extend towards the main spring channel forming the basement of the Cypress Point peninsula. In an absence of sufficiently energetic spring discharge, the Cypress Point peninsula slowly built up as a levee across the main channel (see Figure 24). Spring discharge reached a critical low sometime near 1645 B.P allowing the levee to form a lake over the San Marcos Springs. Once the levee was established, the increased gradient over the springheads further restricted discharge while simultaneously pulling the energy of any water flow that still existed further away from the bottom. Between 1645 B.P. and 1414 B.P., the aggradation of the majority of Unit II occurred throughout the lake. After 1414 B.P., increased spring discharge destroyed the levee and began to remove Unit II from parts of the lake nearest the stream channel as seen in its absence in Core 09 (see Figure 23; Appendix).

Strengthening an argument for a Late Pleistocene construction of Spring Lake Peninsula, the excavation performed by CAS (Lohse et al. 2013) roughly between Nordt's (2010) Cores D and E (see Figure 22) demonstrated that *in situ* deposits dated to 6015±20 B.P. (UCIAMS 111180) existed at a depth of only two meters below surface (Figure 25). Nordt (2010) argued the deposition above an elevation of 170.0 to 170.5 m in Cores D and E began after 5900 B.P. Given this new data (Lohse et al. 2013), the wood sample collected in Test Unit 1 (Leezer et al. 2011), and this study, the deposits of Nordt's Units A, B, C, and much of D must represent a period of frequent to near-continuous aggradation at a relatively high rate from as early as 11,400 B.P. through 5500 B.P. with slowed deposition through at least 1414 B.P. In this case, the marsh sediments encountered in Nordt's study do not represent punctuations of widespread marsh development but rather a narrow, moisture-rich facies, laterally-mobile over time.

Nordt (2010) considered the possibility of Units A, B, and C being facies to Unit D; however, he argued if such was the case, buried paleosols would be present in floodplain alluvium associated in time with each marsh deposit. Although a valid argument in other contexts, the rate at which deposition was occurring in the Sink Creek valley between 11,400 B.P. and 5500 B.P. was immense and most likely too rapid for the landscape stability required for significant soil development. Given the work of Cook et al. (2003; 2007) at Halls Cave, the removal of the Pleistocene soil cover from the uplands of the Balcones Escarpment peaked during the same period. Based on the dates from CAS's ticket kiosk excavation (Lohse et al. 2013) and Nordt's (2010) nearby Core E (see Figure 25), the area just above the upper headwaters accumulated approximately 5 m of fine-grained sediment between 9585 B.P. and 6015 B.P. If the lower 6 to 8 m of

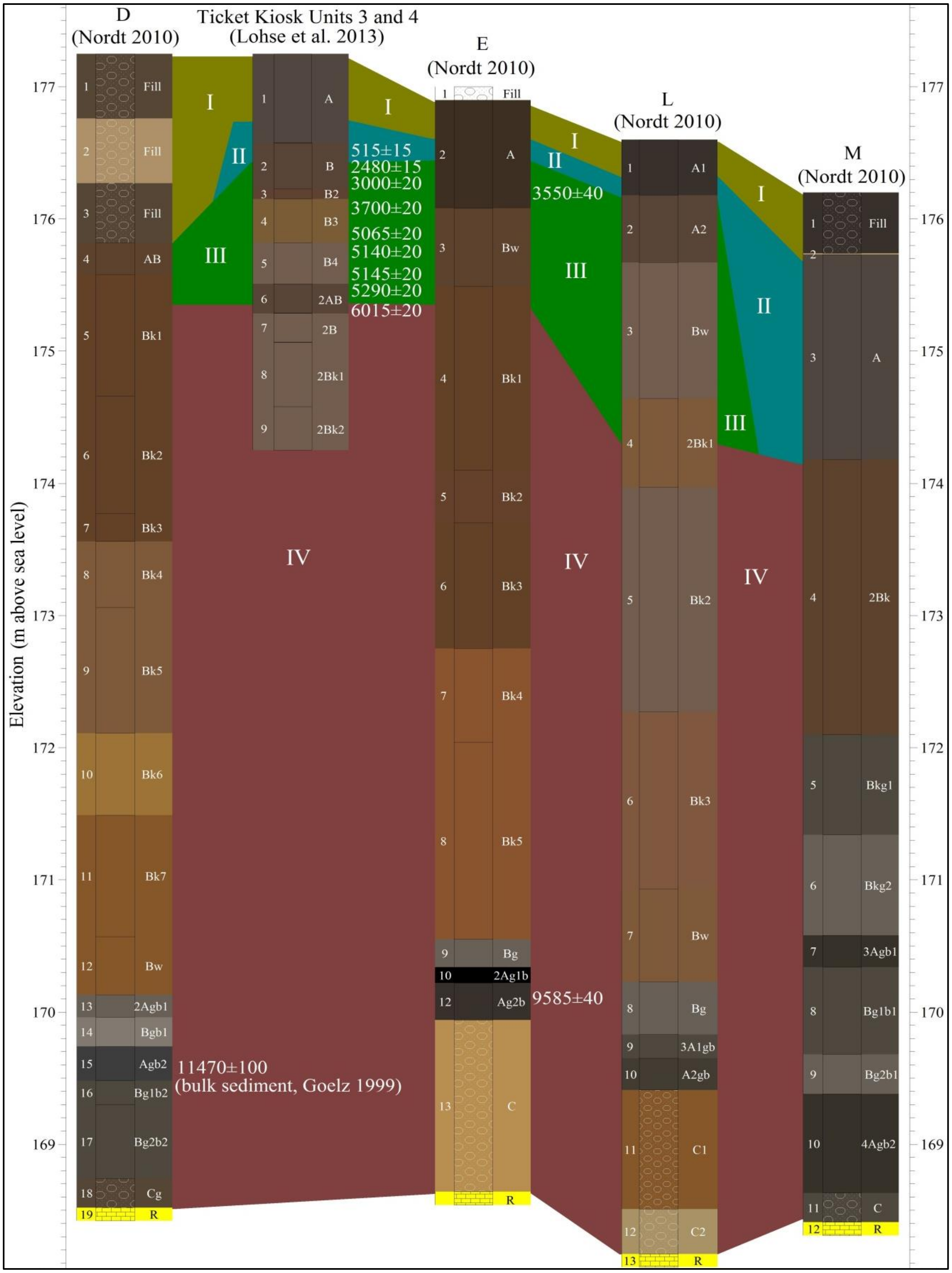

Figure 25. Stratigraphic cross-section plot showing a log of the Ticket Kiosk Excavation (Lohse et al. 2013) and Nordt's (2010) Cores D, E, L, and M. Lined up from northeast to southwest.

sediments forming the Spring Lake Peninsula were composed of freshly-eroded, mature Pleistocene soils, it would also explain why bulk sediment dates such as those obtained by Leezer et al. (2011) were older than expected.

Geoarchaeology

Sediments have been accumulating in the Sink Creek valley and the San Marcos Springs since at least 11,400 B.P., very near the beginning of the Paleoindian period (Figure 26). Given current dates of charcoal, wood and plant fragments, Unit IV and the Units A, B, C, and most of D identified by Nordt (2010), were deposited from as early as 11,390±50 B.P. (Beta 282624) through at least 5469±30 B.P. (DAMS 001781) at an average rate of at least 1.25 mm/year. The northwestern half of Spring Lake Peninsula has the potential to preserve Paleoindian through Early Archaic cultural features including organic material culture; the inundated banks, especially those behind the submarine theater, may exhibit these features on or near to the surface. This is consistent with the excavations performed in Spring Lake by Shiner (1981, 1984, 1983) who demonstrated the presence of Paleoindian and Early Archaic artifacts buried under only 1 to 2 m. Although 41HY147 was most likely the result of secondary deposition, cultural

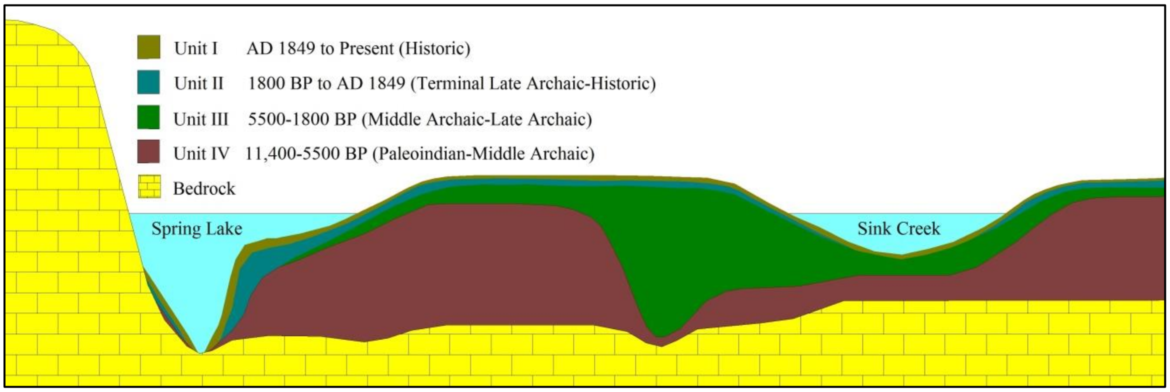

Figure 26. Idealized stratigraphic cross-section of the San Marcos Springs. Showing a view northwest to southeast across the Spring Lake Peninsula and approximate ages of deposition.

activity was clearly present around the San Marcos Springs. Areas on the upper terraces above the early anastomosing stream would have been more attractive locations for Paleoindian occupations; however, the remains of any activity areas associated with these occupations that were located on the early Spring Lake Peninsula may have been preserved in vertically discrete cultural zones given the high rate of sedimentation. Given a more established peninsula towards the end of this period, late Paleoindian and Early Archaic populations would have been more likely to camp nearer the springs.

Following the Late Pleistocene/Early Holocene erosion of mature soils from the uplands of the Balcones Escarpment, alluvial deposition on the Spring Lake Peninsula slowed considerably due to reduced unconsolidated sediment availability. Given a stabilized landscape, Middle and Late Archaic occupations on the peninsula are likely to have occurred with greater frequency, although preserved in deposits with less vertical separation and a higher frequency of disturbance to the sediment column due to pedogenesis and associated turbation processes.

At some time before 2400 B.P. deposition of channel gravels at the mouth of Sink Creek began to extend into the main spring channel. By 1600 B.P. the Cypress Point Peninsula had formed a large enough levee so as to raise the water level, establishing a small lake. Between 1645 B.P. and 1414 B.P., large amounts of organic material collected in the newly formed basin. Although the main spring channel was able to eventually cut through the levee, many of the lake deposits including the organic materials were preserved, yielding a good possibility for the preservation of terminal Late Archaic organic culture.

During the Late Prehistoric the rate of alluvial deposition around the San Marcos Springs was relatively low leaving at most only 10 to 20 cm of sediment. The large majority of deposits forming the topmost 1.0 to 1.5 meters of the modern lake bottom accumulated throughout the lake after 203±26 B.P.; these deposits consist of low-density, diatomaceous sediments which were most likely deposited following the damming of the San Marcos Springs in A.D. 1849.

CHAPTER 6

CONCLUSION

As a drought resistant oasis located at an ecological crossroads in Central Texas, the San Marcos Springs have attracted human occupation since the Late Pleistocene. Although the full range of Central Texas prehistoric culture has not yet been encountered *in situ* at the springs, knowledge of its presence and wishful thinking about the continuously attractive nature of this ecological resource has drawn researchers to San Marcos for over three decades. The recent blitz of archaeology, among other sciences, associated with Texas State University's purchase and ensuing ecological development/restoration of the area surrounding Spring Lake has greatly added to the geoarchaeological understanding of Quaternary sediments surrounding the springs. By contrast, only a small amount of methodical geoarchaeology has been done in the inundated sediments of Spring Lake. Demonstrating the submerged stratigraphy to be complex and possibly much older than previously thought, the recent preparations for the removal of the submarine theater inspired the primary objective of this study. In order to reach a more thorough understanding of the stratigraphic contexts of alluvial deposits now flooded by Spring Lake in a chronologically controlled framework, new underwater geoarchaeological field and lab methods were employed. As in previous chapters, all dates are given in radiocarbon years B.P. (before A.D. 1950) unless otherwise stated.

As a result, four distinctive sedimentary units were identified, examined, and dated. The oldest and most substantial deposition in Spring Lake dates to at least 11390±50 B.P (Beta 282624) and is composed of interbedded poorly developed marsh deposits and rapidly deposited alluvium derived from freshly eroded mature soils originating in the nearby uplands of the Balcones Canyonlands. A rapid and massive sedimentation with a range of coarse, clay matrix-supported channel gravels to fine overbank deposits continued in the area around the San Marcos Springs until at least 5469±30 B.P (DAMS 001781). Given the findings of Cooke et al. (2003; 2007) at Hall's Cave, the deposition of Unit IV is most likely a direct result of the removal of the Pleistocene soil cover from the Edwards Plateau. If the end of Unit IV deposition is linked to the exhaustion of a sediment source rather than a change of moisture availability affecting spring-side vegetation, little truncation can be expected close to the springheads. Nordt (2010) showed that truncation did occur in the middle of Spring Lake Peninsula in sediments recovered from Cores O and N (see Figures 22 and 23). Clearly, given the incision of a stream channel into bedrock to an elevation below the deepest areas of the spring channel, a proto-Sink Creek must have flowed through this paleochannel and migrated laterally, away from the springs. Deposition in Spring Lake following Unit IV was sporadic and most likely tied to drier regional conditions beginning perhaps as early as 2380±15 B.P. (Table 2, UCIAMS 95430) and peaking between 1645±25 and 1414±25 B.P. (Table 2, DAMS 001783 and DAMS 001775). Following 1400 B.P., very little sediment was deposited around the San Marcos Springs until sometime after the onset of the Historic period.

Future Geoarchaeological Research Issues

Further research in Spring Lake could increase the understanding of each sedimentary unit identified in this study. As a complex of multiple depositional facies contained almost entirely below water table, Unit IV will be difficult to access for the purposes of further subdivision by depositional markers. The presence of higher order unconformity is clear in the interzonation of distinctive lithologies deposited over a period of at least several thousand years. At present, the most obvious place to take up this work is the slope from the base of the now-removed submarine theater up to the northwestern bank of the Spring Lake Peninsula. Because of the diversion of spring flow against this slope for the duration of use of the submarine theater, it has only just recently been subjected to limnic deposition. With very little excavation, a series of steps could be cut into the slope exposing a profile of 4 to 5 m beginning at the top of Test Unit 1. Before the removal of the submarine theater, the areas of exposed sediment appeared very similar to Unit IV overbank deposits.

Unit III remains the least understood of this study. If deposition between ~5500 and ~2400 B.P. occurred anywhere other than the old Sink Creek channel identified by Nordt (2010) in the middle of Spring Lake Peninsula, it has been severely truncated. Future underwater studies in Sink Creek or terrestrial cores extracted from the southwestern end of the peninsula could help to clear up this depositional period.

The intentions of this underwater geoarchaeological study were to increase the understanding of inundated alluvial deposits in Spring Lake in order to provide better chronological and stratigraphic context to the research and/or mitigation of cultural resources around the San Marcos Springs. Although this study was limited in scope to the examination and analysis of seven 3-inch wide cores and one exposed profile, by integrating the new results with previous studies it succeeded in documenting the stratigraphic context of a large area of the lake and surrounding alluvial deposits. Further study of other areas of the lake and the surrounding terraces would certainly provide a more complete story; however the above description, analysis, and interpretation broadens the foundation upon which future research may be built.

APPENDIX SECTION

APPENDIX A:

^{14}C SAMPLE PREPARATION PROCEDURES OF RAYMOND MAULDIN

Gloves- non-powder- standard safety glasses etc. when handling acids and bases.

Inspect sample, isolating charcoal to the degree possible-remove any roots-other intrusions with tweezers. If a single large piece, then gently break/ crush to increase surface area/ exposure.

All water should be ultra-pure water (UPW).

Place in reusable test tubes (that have been autoclaved and then heated to 325 C for two to three hours) and sonicate in Ultra-Pure water for 60 min intervals- mark caps, tape to make sure caps stay on. If water is black or dark grey- repeat- pour off water or pipet out- often two layers of material- one that floats near the top and one that is concentrated at the bottom. In this case, pipet water from the middle- add new water and sonicate. Repeat until water is reasonably clear… some samples may take 1 wash, some may take 3 or 4. I generally do not do more than 5 washes- Dry at 50c in heat block-covered.

Remove dried sample and spread out in petri dish. Inspect sample again- Remove any root or adhering material with tweezers if necessary-check under scope- often sand is present- separate out charcoal from sand etc… and put charcoal in new and/or autoclaved test tube. Sand primarily affects the weight.

Place test tube in block at 80c- Add 1N HCL and heat for 20 min-foil tent covered- in clean area.

Rinse at least 4 times with UPW- or more if sample is cloudy- check PH-if close to 7, then proceed. Else, keep rinsing.

Add 0.25N NaOH for 25 min @ 80C- foil covered-in clean area-

Rinse at least 4 times in UPW- some samples are very cloudy/ black/ yellow following treatment- keep washing until water is clear-may take a lot of washes- check ph on discarded water- if close to neutral, proceed.

add 1N HCL for 45 min @ 80C – foil covered-in clean area-

Rinse 6 times- check for neutrality- UPW- keep washing until neutral-

Dry at 50c …in block- covered foil- clean area-

Weigh sample.

Place in new, small glass vials with caps-label- add foil restrictor if needed- place in small plastic bag- pack carefully- assume stuff will be crushed during transport.

APPENDIX B:

PROFILE AND CORE SAMPLE DESCRIPTIONS

Coordinates are given in UTM meters and have been rounded to the nearest whole meter, Datum: WGS-84 (NAD-83), Zone: 14. Surface elevation of cores is height above mean sea level for the upper surface of the core. Due to core shortening from potential instances of physical compression, sediment thinning, sample loss, and sediment bypassing (Morton and White 1997), an error of up to 50 cm may exist in the surface elevation of cores. Soil taxonomy codes are from Schoeneberger et al. (2002) and are defined in Table 3.

Table 3. Soil taxonomy codes used in profile and core descriptions (modified from Schoeneberger et al. 2002).

Horizon	**Criteria**
B	Subsurface accumulation of clay, Fe, Al, Si, humus, or $CaCO_3$
BC	Dominantly of B characteristics but contains C horizon attributes
C	Little or no pedogenic alteration
L	Limnic soil materials
Horizon Suffix	**Criteria**
di	Diatomaceous earth
k	Pedogenic $CaCO_3$ accumulation (<50% by vol.)
t	Illuvial accumulation of silicate clay
Non-Pedogenic Deposit Abbreviations	
FCD	Fluvial Channel Deposit
FSD	Fluvial Sand-bar Deposit
LDD	Lacustrine Debris-flow Deposit

Cypress Point Profile Exposure

Location: E603005 N3307249 *Surface Elevation*: 173.1 m

Comments: The descriptions of the individual zones of the Cypress Point profile were made in the lab from a large digital photomosaic, and have been kept simplistic as the images may have been somewhat distorted by the stitching process. Depth measurements were made underwater using a tape measure suspended from a float. The presence of a small spring between the profile and Cypress Point may be responsible for structurally weakening the sediment column leading to its removal by flood waters.

Lithostratigraphic Zone	Sedimentary Unit	Depth to Top (cm below surface)	Depth to Base (cm below surface)	Depositional Environment	Soil Horizon	Description
1	II	0	30	Overbank low energy	B	Massive brownish clay loam.
2	II	30	40	Overbank high energy	BC	Brownish gravelly clay loam.
3	II	40	150	Overbank low energy	B	Massive brownish clay loam.
4	III	150	170	Fluvial channel	FCD	Dark grayish brown gravelly clay
5	III	170	200	Fluvial channel	FCD	Grayish yellow gravelly sandy clay loam
6	III	200	230	Fluvial channel	FCD	Gray gravelly clay
7	III	230	260	Fluvial channel	FCD	Yellowish gray gravelly sandy clay
8	III	260	290	Fluvial channel	FCD	Gray gravelly clay

Core 03

Location: E603098 N3307363 *Lake Bottom Elevation*: 173.1 m

Comments: Core 03 was taken in 3 sections by driving longer core tubes down the same hole. Although the hole partially collapsed as each core was extracted, the stratification of Core 03 enabled the undisturbed, deeper sections to be easily correlated in the lab

Lithostratigraphic Zone	Sedimentary Unit	Depth to Top (cm below surface)	Depth to Base (cm below surface)	Depositional Environment	Soil Horizon	Description
1	I	0	84	Lacustrine limnic	Ldi	Olive brown (2.5Y 4/3) clay loam; spongey texture; 1% shell fragments; very abrupt, smooth lower boundary.
2	I	84	129	Lacustrine limnic	L	Interzonated gray (2.5Y 6/1) and dark gray (2.5Y 4/1) sandy loam; common coarse red (2.5YR 4/6) oxidized Fe staining; preserved wood fragments; 1% shell fragments; very abrupt, smooth lower boundary.
3	I	129	140	Lacustrine limnic	L	Very dark gray (2.5Y 3/1) loam; preserved wood fragments; 30% shell fragments; abrupt, smooth lower boundary.
4	I	140	150	Lacustrine limnic	L	Dark gray (2.5Y 4/1) sandy loam; preserved wood fragments; 3% shell fragments; clear, smooth lower boundary.
5	II	150	170	Fluvial sand bar	FSD	Grayish brown (2.5Y 5/2) sand; preserved wood fragments; 3% shell fragments; abrupt, smooth lower boundary.
6	II	170	195	Lacustrine limnic	L	Very dark gray (2.5Y 3/1) clay loam; preserved wood fragments; 3% shell fragments; abrupt, smooth lower boundary.
7	II	195	204	Lacustrine flood	LDD	Dark gray (7.5YR 4/1) loam; many medium light yellowish brown (2.5YR 6/3) rip-up clasts; 5% coarse fragments up to 7 mm; 1% shell fragments; abrupt, smooth

						lower boundary.
8	II	204	233	Lacustrine limnic	L	Interzonated light brownish gray (2.5Y 6/2) and dark gray (2.5Y 4/1) clay loam; preserved wood fragments; 3% shell fragments; very abrupt, smooth lower boundary.
9	II	233	236	Lacustrine flood	LDD	Gray (7.5YR 5/1) loam; many medium brown (10YR 5/3) rip-up clasts; charcoal fragments; 5% coarse fragments up to 7 mm; 5% shell fragments; very abrupt, smooth lower boundary.
10	II	236	304	Lacustrine limnic	L	Interzonated light brownish gray (2.5Y 6/2) and dark gray (2.5Y 4/1) clay loam; preserved wood fragments; 1% shell fragments; very abrupt, smooth lower boundary.
11	II	304	311	Lacustrine limnic	L	Very dark grayish brown (2.5Y 3/2) loam; high concentration of preserved wood, plant fragments, and seeds; 1% shell fragments; abrupt smooth lower boundary.
12	II	311	351	Lacustrine limnic	L.	Dark gray (2.5Y 4/1) clay loam; preserved wood fragments; charcoal fragments; 1% shell fragments; very abrupt, smooth lower boundary.
13	II	351	355	Lacustrine flood	LDD	Gray (7.5YR 5/1) loam; many fine light yellowish brown (2.5YR 6/3) and brown (7.5YR 4/4) rip-up clasts; 5% coarse fragments up to 5 mm; 3% shell fragments; very abrupt, smooth lower boundary.
14	II	355	363	Lacustrine limnic	L	Dark gray (2.5Y 4/1) clay loam; preserved wood fragments; 1% shell fragments; very abrupt, smooth lower boundary.
15	II	363	369	Lacustrine flood	LDD	Brown (7.5YR 4/2) clay loam; many medium light yellowish brown (2.5YR 6/3) and strong brown (7.5YR 4/6) rip-up clasts; preserved wood fragments; 5% coarse fragments up to 5 mm; 3% shell fragments; clear, smooth lower boundary.
16	II	369	395	Lacustrine flood	LDD	Brown (7.5YR 4/2) loam; many coarse light yellowish brown (2.5YR 6/3) and strong brown (7.5YR 4/6) rip-up clasts; preserved wood fragments; charcoal fragments; 5% coarse fragments up to 7 mm; 3% shell fragments.

Core 04

Location: E603258 N3307460 *Lake Bottom Elevation*: 173.2 m

Comments: Core 04 was taken in two sections by driving a longer pipe down the same hole; however, no additional sediment was collected in the second section.

Lithostratigraphic Zone	Sedimentary Unit	Depth to Top (cm below surface)	Depth to Base (cm below surface)	Depositional Environment	Soil Horizon	Description
1	I	0	22	Lacustrine limnic	Ldi	Olive brown (2.5Y 2/2) loam; spongy texture; preserved wood and plant fragments; 1% shell fragments; clear, smooth lower boundary.
2	I	22	45	Lacustrine limnic	L	Dark grayish brown (10YR 4/2) sandy loam; common coarse red (2.5YR 4/6) Fe oxidation masses; preserved wood fragments; 3% shell fragments; abrupt, smooth lower boundary.
3	I	45	50	Lacustrine limnic	L	Dark gray (10YR 4/1) clay loam; 5% shell fragments; clear, smooth lower boundary.
4	I	50	86	Lacustrine limnic	L	Dark gray (10YR 4/1) clay loam; preserved wood fragments; 3% shell fragments; abrupt, smooth lower boundary.
5	I	86	97	Lacustrine limnic	L	Very dark grey (10YR 3/1) loam; very large amount of preserved wood, seeds, and plant fragments; 30% shell fragments; very abrupt, smooth lower boundary.
6	II	97	116	Lacustrine limnic	L	Dark gray (10YR 4/1) clay loam; preserved wood fragments; 3% shell fragments; abrupt, smooth lower boundary.
7	II	116	120	Lacustrine flood	LDD	Gray (2.5Y 5/1) loam; Many coarse light gray (2.5Y 7/1) and light yellowish brown (2.5Y 6/4) rip-up clasts; 5% shell fragments; very abrupt, wavy lower boundary.

8	II	120	126	Lacustrine limnic	L	Very dark grey (10YR 3/1) clay loam; preserved wood fragments; 3% shell fragments; abrupt, smooth lower boundary.
9	II	126	131	Lacustrine limnic	L	Dark grey (10YR 4/1) clay loam; well-preserved organic matter; 1% shell fragments; clear, wavy lower boundary.
10	II	131	136	Lacustrine flood	LDD	Dark brown (7.5YR 3/2) gravelly loam; common medium yellowish red (5YR 5/6) and strong brown (7.5YR 5/6) rip-up clasts; 5% coarse fragments up to 5 mm; abrupt, wavy lower boundary.
11	IV	136	145	Overbank high energy	BC	Light brown (7.5YR 6/4) gravelly clay; Many coarse reddish yellow (7.5YR 7/6), brown (7.5YR 4/4), strong brown (7.5YR 5/8), yellowish red (5YR 5/8), reddish brown (5YR 5/4), and black (5YR 2.5/1) mottles; 10% coarse fragments up to 10 mm; abrupt, smooth lower boundary.
12	IV	145	154	Overbank low energy	Bt	Reddish brown (5YR 4/4) clay; common medium brown (7.5YR 5/4) mottles; 3% coarse fragments up to 3 mm; very abrupt, smooth lower boundary.
13	IV	154	165	Overbank high energy	C	Reddish brown (5YR 4/4) gravelly clay; common medium reddish yellow (7.5YR 6/6) and black (7.5YR 2.5/1) mottles; 50% coarse fragments up to 30 mm; very abrupt, wavy lower boundary.
14	IV	165	203	Overbank low energy	Btk	Brown (7.5YR 4/4) clay; common medium reddish yellow (7.5YR 7/8) $CaCO_3$ masses, common medium dark brown (7.5YR 3/4), and very dark brown (7.5YR 2.5/1) mottles; common fine gray (2.5Y 5/1) gray root casts; 5% coarse fragments up to 10 mm.

Core 05

Location: E603072 N3307363 *Lake Bottom Elevation*: 171.85 m

Comments: Core 05 was taken from just north of Joel Shiner's main excavation pit at 41HY147. The alluvium, perhaps bedrock, below Zone 06 proved too compact to be penetrated.

Lithostratigraphic Zone	Sedimentary Unit	Depth to Top (cm below surface)	Depth to Base (cm below surface)	Depositional Environment	Soil Horizon	Description
1	I	0	8	Lacustrine limnic	Ldi	Olive brown (2.5Y 4/3) loam; spongy texture; abrupt, wavy lower boundary.
2	I	8	13	Lacustrine limnic	Ldi	Olive brown (2.5Y 4/3) clay loam; common, fine olive brown (2.5Y 4/3) mottles; spongy texture; 0-1% shell fragments; abrupt, wavy lower boundary.
3	I	13	23	Lacustrine limnic	L	Dark gray (5Y 4/1) clay loam; common coarse reddish brown (5YR 4/4) Fe oxidation masses; 0-1% shell fragments; abrupt, wavy lower boundary.
4	I	23	71	Lacustrine limnic	L	Very dark gray (2.5Y 3/1) clay loam; common coarse reddish brown (5YR 4/4) Fe oxidation masses; 0-1% shell fragments; clear, wavy lower boundary.
5	I	71	90	Lacustrine limnic	L	Dark gray (5Y 4/1) clay; 0-1% shell fragments; very abrupt, smooth lower boundary.
6	I	90	104	Lacustrine limnic	L	Black (5Y 2.5/1) clay loam; 15% shell fragments.

Core 06

Location: E603006 N3307249 *Lake Bottom Elevation*: 169.3 m

Comments: Core 06 was taken from about 1 meter out from the base of the Cypress Point Profile in what appeared to be in-place sediment. The depositional environment of Zone I is described as Lacustrine-colluvial because in the lab it appeared to consist of fragments of different zones which may have fallen off the profile face.

Lithostratigraphic Zone	Sedimentary Unit	Depth to Top (cm below surface)	Depth to Base (cm below surface)	Depositional Environment	Soil Horizon	Description
1	I	0	16	Lacustrine colluvial	LDD	Very dark grayish brown (10YR 3/2) loam; common medium yellow (10YR 7/6)and brown (7.5YR 4/4) mottles; 20% coarse fragments up to 30 mm; abrupt, irregular lower boundary.
2	IV	16	23	Fluvial channel	FCD	Brown (7.5YR 4/3) clay; contains charcoal fragments up to 20 mm; 2% coarse fragments up to 30 mm; abrupt smooth lower boundary.
3	IV	23	28	Fluvial channel	FCD	Strong Brown (7.5YR 4/4) loam; bimodal coarse fragments, 10% coarse gravel, 50% medium sand; abrupt wavy lower boundary.
4	IV	28	36	Fluvial channel	FCD	Brown (7.5YR 5/4) loam; Many medium dark gray (7.5YR 4/1) and brown (7.5YR 4/3) mottles; 1 tooth fragment; 40% coarse fragments up to 40 mm; abrupt wavy lower boundary.
5	IV	36	50	Fluvial channel	FCD	Brown (7.5YR 4/3) loam; 70% coarse fragments up to 40 mm; clear smooth lower boundary.
6	IV	50	66	Fluvial channel	FCD	Brown (7.5YR 4/3) loam; 50% coarse fragments up to 40 mm.

Core 07

Location: E603105 N3307342 *Lake Bottom Elevation*: 169.75 m

Comments: The location for Core 07 was chosen up the slope east of Deep Spring by using the core tube as a Jacob's staff held on the exposed bedrock just above the springhead. The drive depth goal was missed by 30 to 40 cm.

Lithostratigraphic Zone	Sedimentary Unit	Depth to Top (cm below surface)	Depth to Base (cm below surface)	Depositional Environment	Soil Horizon	Description
1	I	0	33	Lacustrine limnic	L	Very dark gray (7.5YR 3/1) clay loam; preserved wood fragments; 3% shell fragments; abrupt, wavy lower boundary.
2	I	33	43	Lacustrine limnic	L	Very dark gray (7.5YR 3/1) loam; preserved wood fragments; 1% shell fragments; abrupt, wavy lower boundary.
3	I	43	50	Lacustrine flood	LDD	Dark gray (7.5YR 4/1) sandy loam; many fine light gray (7.5YR7/1) rip-up clasts; preserved wood fragments; 30% shell fragments; abrupt, wavy lower boundary.
4	II	50	60	Lacustrine limnic	L	Greenish black (Gley 1 3/2) loam; preserved wood fragments; 1% shell fragments; abrupt, wavy lower boundary.
5	II	60	76	Lacustrine limnic	L	Very dark gray (7.5YR 3/1) sandy loam; common medium brown (7.5YR 4/2) rip-up clasts; preserved wood fragments; 5% shell fragments; 5% coarse fragments up to 4mm; abrupt, wavy lower boundary.
6	II	76	81	Lacustrine limnic	L	Very dark gray (7.5YR 3/1) loam; preserved laminated plant fragments; 1% shell fragments; abrupt, wavy lower boundary.

7	II	81	87	Lacustrine flood	LDD	Brown (7.5YR 4/2) sandy loam; many coarse light gray (7.5YR 7/1) rip-up clasts; preserved wood fragments; 5% coarse fragments up to 7 mm; 1% shell fragments; abrupt, irregular lower boundary.
8	II	87	102	Lacustrine flood	LDD	Dark gray (7.5YR 4/1) sandy loam; many medium light gray (7.5YR 7/1) rip-up clasts; preserved wood fragments; 5% coarse fragments up to 7 mm; 1% shell fragments; abrupt, wavy lower boundary.
9	II	102	111	Lacustrine limnic	L	Very dark gray (7.5YR 3/1) loam; preserved wood fragments; charcoal fragments; 1% shell fragments; abrupt, wavy lower boundary.
10	II	111	120	Lacustrine flood	LDD	Brown (7.5YR 4/2) sandy loam; many medium light gray (7.5YR 7/1) rip-up clasts; preserved wood fragments; 2% coarse fragments up to 4 mm; abrupt, irregular lower boundary.
11	II	120	132	Lacustrine limnic	L	Dark gray (7.5YR 4/1) clay loam; preserved wood fragments; 3% shell fragments; very abrupt, smooth lower boundary.
12	II	132	138	Lacustrine flood	LDD	Brown (7.5YR 4/2) sandy loam; many coarse light brown (7.5YR 6/3) and light gray (7.5YR 7/1) rip-up clasts; 10% coarse fragments up to 15 mm; 1% shell fragments; very abrupt, smooth lower boundary.
13	II	138	156	Lacustrine flood	LDD	Dark gray (7.5YR 4/1) sandy loam; fining upward sequence of many medium to fine light gray (7.5YR7/1) rip-up clasts; preserved wood fragments; vertically oriented gray (7.5YR 6/1) chert flake; 5% coarse fragments up to 5 mm; 1% shell fragments; abrupt, wavy lower boundary.
14	II	156	174	Lacustrine flood	LDD	Dark gray (7.5YR 4/1) sandy loam; many coarse light gray (7.5YR 7/1) and brown (7.5YR 4/2) rip-up clasts; preserved wood fragments; 5% coarse fragments up to 7 mm; 1% shell fragments; abrupt, wavy lower boundary.
15	II	174	188	Lacustrine limnic	L	Very dark gray (7.5YR 3/1) clay loam; preserved wood fragments; 2% shell fragments; abrupt, smooth lower boundary.

16	II	188	191	Lacustrine flood	LDD	Brown (7.5YR 4/2) sandy loam; common medium light brown (7.5YR 6/3) rip-up clasts; preserved wood fragments; 5% coarse fragments up to 5 mm; 1% shell fragments; abrupt smooth lower boundary.
17	II	191	204	Lacustrine flood	LDD	Very dark gray (7.5YR 3/1) clay loam; many coarse light gray (7.5YR 7/1), light brown (7.5YR 6/3), and strong brown (7.5YR 5/6) rip-up clasts; preserved wood fragments; charcoal fragments; 5% coarse fragments up to 20 mm; 2% shell fragments; abrupt, irregular lower boundary.
18	IV	204	214	Overbank low energy	Bt	Yellowish red (5YR 4/6) clay; 10% coarse fragments up to 30 mm; clear, smooth lower boundary.
19	IV	214	219	Overbank high energy	BC	Dark reddish brown (5YR 3/3) gravelly clay; 30% coarse fragments up to 40 mm.

Core 08

Location: E603110 N3307339 *Lake Bottom Elevation*: 173.2 m

Comments: The location for Core 08 was chosen up the slope east of Core 07 by using the core tube as a Jacob's staff held at the surface of Core 07. The drive depth goal was missed by 1 to 1.5 m.

Lithostratigraphic Zone	Sedimentary Unit	Depth to Top (cm below surface)	Depth to Base (cm below surface)	Depositional Environment	Soil Horizon	Description
1	I	0	34	Lacustrine Limnic	Ldi	Olive gray (5Y 4/2) clay loam; preserved wood and plant fragments; spongey texture; 3% shell fragments; abrupt, smooth lower boundary.
2	I	34	64	Lacustrine limnic	L	Interzonated gray (2.5Y 6/1) and dark gray (2.5Y 4/1) clay loam; preserved wood and plant fragments; 5% shell fragments; clear, smooth lower boundary.
3	I	64	109	Lacustrine limnic	L	Interzonated gray (2.5Y 6/1) and dark gray (2.5Y 4/1) sandy loam; common coarse red (2.5YR 4/6) oxidized Fe staining; preserved wood and plant fragments; 3% shell fragments; very abrupt, smooth lower boundary.
4	I	109	116	Lacustrine limnic	L	Very dark gray (2.5Y 3/1) loam; preserved wood fragments; 30% shell fragments; abrupt, smooth lower boundary.
5	II	116	126	Lacustrine limnic	L	Very dark gray (2.5Y 3/1) clay loam; preserved wood fragments; charcoal fragments; 3% shell fragments; abrupt, smooth lower boundary.

6	II	126	137	Lacustrine limnic	L	Very dark grayish brown (2.5Y 3/2) loam; high concentration of preserved wood, plant fragments, and seeds; 1% shell fragments; abrupt smooth lower boundary.
7	II	137	163	Lacustrine limnic	L	Dark gray (2.5Y 4/1) clay loam; preserved wood fragments; charcoal fragments; 1% shell fragments; very abrupt, irregular lower boundary.
8	II	163	171	Lacustrine flood	LDD	Gray (5Y 5/1) loam; many coarse pale brown (2.5Y 8/3) and yellow (2.5Y 7/8) rip-up clasts; 10% coarse fragments up to 10 mm; very abrupt, wavy lower boundary.
9	IV	171	215	Overbank low energy	Btk	Yellowish brown (10YR 5/4) clay; common coarse olive yellow (2.5Y 6/8) $CaCO_3$ masses; 5% coarse fragments up to 20 mm; clear, wavy lower boundary.
10	IV	215	237	Overbank high energy	BtC	Strong brown (7.5YR 5/6) gravelly clay; 20% coarse fragments up to 20 mm.

Core 09

Location: E603160 N3307427 *Lake Bottom Elevation*: 173.05 m

Comments: Core 09 was taken in two sections by driving a longer pipe into the same hole. The second section was the longest continuous core sample extracted at 4 m total length; however, only the lower 1.9 m represented additional sample collection with approximately 0.5 m lost out of the bottom of the tube during extraction.

Lithostratigraphic Zone	Sedimentary Unit	Depth to Top (cm below surface)	Depth to Base (cm below surface)	Depositional Environment	Soil Horizon	Description
1	I	0	44	Lacustrine limnic	Ldi	Olive brown (2.5Y 4/3) clay loam; preserved wood and plant fragments; spongey texture; 1% shell fragments; abrupt, wavy lower boundary.
2	I	44	45	Lacustrine limnic	L	Light gray (2.5Y 7/2) clay; abrupt, wavy lower boundary.
3	I	45	62	Lacustrine limnic	Ldi	Olive brown (2.5Y 4/3) sandy loam; preserved wood and plant fragments; 1% shell fragments; clear, smooth lower boundary.
4	I	62	124	Lacustrine limnic	L	Dark gray (2.5Y 4/1) sandy loam; few coarse reddish brown (5YR 4/4) Fe oxidation staining; preserved wood fragments; 3% shell fragments; very abrupt, wavy lower boundary.
5	I	124	126	Lacustrine limnic	L	Very dark gray (2.5Y 3/1) loam; preserved wood fragments; 40% shell fragments; very abrupt, wavy lower boundary.
6	I	126	171	Marsh	L	Dark gray (2.5Y 4/1) silty clay; very well preserved laminated plant remains; 3% shell fragments; very abrupt, wavy lower boundary.

7	IV	171	182	Fluvial channel	FCD	Pale brown (10YR 6/3) gravelly sand; charcoal fragments; chert flake; possible burned rock fragment; 30% coarse fragments up to 40 mm; clear, wavy lower boundary.
8	IV	182	208	Fluvial channel	FCD	Brown (10YR 5/3) gravelly clayey sand; charcoal fragments; many coarse yellow (10YR 7/6) and yellowish red (5YR 4/6) mottles; 30% coarse fragments up to 50 mm; abrupt, wavy lower boundary.
9	IV	208	225	Fluvial channel	FCD	Yellowish red (5YR 5/6) gravelly sand; 20% coarse fragments up to 5 mm; clear, wavy lower boundary.
10	IV	225	246	Fluvial channel	FCD	Light yellowish brown (10YR 5/4) gravelly sand; 30% coarse fragments up to 10 mm; clear, wavy lower boundary.
11	IV	246	270	Fluvial channel	FCD	Light yellowish brown (10YR 5/4) gravelly sand; 50% coarse fragments up to 100 mm; abrupt, wavy lower boundary.
12	IV	270	300	Fluvial channel	FCD	Reddish brown (5YR 4/4) sandy clay; 30% coarse fragments up to 7 mm; clear, irregular lower boundary.
13	IV	300	353	Fluvial channel	FCD	Reddish yellow (7.5YR 6/6) gravelly sandy clay; 30% coarse fragments up to 30 mm; abrupt, wavy lower boundary.
14	IV	353	395	Fluvial channel	FCD	Strong brown (7.5YR 5/6) gravelly sandy clay; 40% coarse fragments up to 40 mm.

REFERENCES CITED

Abbot, P. L. and C. M. Woodruff Jr.

1986 Preface: The Balcones Escarpment. In *The Balcones Escarpment: Geology, Ecology, and Social Development in Central Texas*. Abbot and Woodruff eds. Geological Society of America Annual Meeting, San Antonio, TX.

Aery, D.A.

2007 *Organization of Lithic Technology in Archaic Texas: An Example from 41HY160 in San Marcos, Texas*. Unpublished Master's thesis, Texas State University San Marcos.

Arnn, John W. III and Karl W. Kibler

1999 *Archeological Survey and Geomorphological Assessment for the Proposed Spring Lake Water Line, Hays County, Texas*. Technical Reports No. 41. Prewitt and Associates, Inc., Austin.

Barnes. V. E.

1992 *Geologic Map of Texas*. Bureau of Economic Geology, University of Texas.

Batte, C.C.

1984 *Soil Survey of Comal and Hays Counties, Texas*. United States Department of Agriculture, Soil Conservation Service, in cooperation with the Texas Agriculture Experiment Station.

Blair, F. W.

1950 *The Biotic Provinces of Texas*. Texas Journal of Science Vol. 2 No .1 pp. 93-117.

Bomar G. W.

1983 *Texas Weather*. University of Texas Press, Austin, Texas.

Bousman C. Britt

1998 Paleoenvironmental Change in Central Texas: the Palynological Evidence. Plains Anthropologist Vol.43 No.1, pp. 201-219.

Bousman, C. Britt, and David L. Nickels, editors

2003 *Archaeological Testing of the Burleson Homestead at 41HY37, Hays County, Texas*. Archaeological Studies Report No. 4. Center for Archaeological Studies, Texas State University San Marcos.

Bousman, C. Britt, and Eric Oksanen

2012 The Protoarchaic in Central Texas and Surrounding Areas. *From the Pleistocene to the Holocene: Human organization and Cultural Transformations in Prehistoric North America*. C. Britt Bousman and Bradley J. Vierra, eds. Texas A&M University Press. pp. 197-232.

Brune, Gunnar

1975 Major and Historical Springs of Texas. Texas Water Development Board Report 189, p. 94.

2005 *Springs of Texas*, Vol.1 Texas A&M University Press, College Station.

Caran, S. Christopher

1998 Quaternary Paleoenvironmental and Paleoclimatic Reconstruction: A Discussion and Critique, with Examples from the Southern High Plains. Plains Anthropologist, Vol. 43, No. 164, pp. 111-124.

Caran, S. C. and V.R. Baker

1986 Flooding along the Balcones Escarpment, Central Texas. In *The Balcones Escarpment: Geology, Ecology, and Social Development in Central Texas*. P. L. Abbot and C. M. Woodruff eds. Geological Society of America Annual Meeting, San Antonio, TX. pp. 1-14.

Carr, J. T. Jr.

1967 *The Climate and Physiography of Texas*. Texas Water Development Board. Report 53.

Casby-Horton, S., S. Clift, J. Douglass, and L. Kiniry

2008 *General Soil Map of Texas*. USDA Natural Resources Conservation Service in collaboration with Bureau of Economic Geology, University of Texas.

Collins M. B.

2004 Archaeology in Central Texas. In *The Prehistory of Texas*. T. Perttula ed., Texas A&M University Press. pp. 101-126.

Cooke ,J. L., L. A. Stern,J. L. Banner, and L. E. Mack

2007 Evidence for the silicate source of relict soils on the Edwards Plateau, Central Texas. *Quaternary Research*, Vol. 67, pp. 275-285.

Cooke ,J. L., L. A. Stern,J. L. Banner, L. E. Mack, T. W. Stafford, and R. S. Toomey

2003 Precise timing and rate of massive late Quaternary soil denudation. *Geology*; October, v. 31, no. 10, p. 853-856.

Crumly, C. L.

1994 *Historical Ecology: Cultural Knowledge and Changing Landscapes*. School of American Research Press, Santa Fe, NM.

Fisher, W.L.

1974 Geologic Atlas of Texas: Seguin Sheet. Bureau of Economic Geology, University of Texas at Austin.

Ford, Owen A. and Anthony S. Lyle

1998 *Archaeological Investigation of a Spring Lake Lot for Joe's Crab Shack Parking*. Archaeological Survey Report No. 277, Center for Archaeological Research, University of Texas at San Antonio.

Garber, James F., S. Bergman, B. Dickinson, R. Hays III, J. Simpson, and J. Stefanoff

1983 Excavations at Aquarena Springs, San Marcos, Texas. *La Tierra* 10:2:28-38.

Garber, James F. and David M. Glassman

1992 *Excavation of Human Remains from the Fish Pond Site, 41HY161, in San Marcos, Hays County, Texas*. Department of Sociology and Anthropology, Southwest Texas State University.

Garber, James F. and M. D. Orloff

1984 Excavations at 41HY37: an Archaic site on the Balcones Escarpment in San Marcos, Texas. *La Tierra* 11:3:31-37.

George, W.O., S. D. Breeding, and W. W. Hastings

1952 *Geology and ground-water resources of Comal County, Texas*. USGS Water-Supply Paper 1138.

Giesecke, J.

1998 *Faunal Analysis from 41HY165: an Independent Study*. Manuscript on file at Anthropology Department, Southwest Texas State University, San Marcos.

Goelz, M.

1999 *Geoarchaeological Assessment of the Texas Rivers Center, San Marcos Springs, Hays County, Texas*. Technical Reports, Number 40, Prewitt & Associates, Inc., Austin.

Goudie, Andrew, Malcom Anderson, Tim Burt, John Lewin, Keith Richards, Brian Whalley, and Peter Worsley

1981 *Geomorphological Techniques*. George Allen & Unwin, London.

Guyton, W.F. and Associates

1979 *Geohydrology of Comal, San Marcos, and Hueco Springs*. Austin Tex., Texas Department of Water Resources Report 234, p. 85.

Hallenbeck, C.

1940 *Alvar Nuñez Cabeza de Vaca: The Journey and Route of the First European to Cross the Continent of North America, 1534-1536*. Arthur C. Clark Publishing, Glendale, California.

Hooge, Jacob, Carole Leezer, Fritz Hanselmann, and Jon C. Lohse

2013 Underwater Excavations at 41HY147. in *Underwater Arachaeology at 41HY147, the Terrace Locality at Spring Lake*. edited by Jon C. Lohse. Center for Archaeological Studies Report No. 28. Texas State University.

Jones, Brian, Kenton F. Phimester, Ian G. Hunter, and Paul Blanchon

1992 A Quick, Inexpensive, Self-contained Sediment Coring System for Use Underwater. *Journal of Sedimentary Petrology*, Vol. 62, No. 4, pp. 725-728.

Jones, Richard

2002 *Archaeological Trench Monitoring Near Prehistoric Site 41HY161, Hays County, Texas*, Technical Report No. 3, Center for Archaeological Studies, Texas State University-San Marcos.

Kimmel, Jim

2006 *The San Marcos: A River's Story*. Texas A&M University Press,.

Klemt, W. B., Knowles, T. R., Elder, G. R., and Sieh, T. W.,

1975 *Ground-Water Resources and Model Applications for the Edwards (Balcones Fault Zone) Aquifer*. Texas Water Development Board Open File Report.

LBG-Guyton Associates

2004 *Evaluation of augmentation methodologies in support of in-situ refugia at Comal and San Marcos Springs, Texas*: Report prepared for the Edwards Aquifer Authority [variously paged].

Leventer, A., D. F. Williams, and P. Kennett

1982 Dynamics of the Laurentide Ice Sheet During the Last Deglaciation: Evidence from the Gulf of Mexico. *Earth and Planetary Science Letters, Vol.* 59, pp. 11–17.

Leezer, Carole, Julian A. Sitters, and Sarah Scogin

2010 *Archaeological Assessment and Monitoring for Construction of a New Boiler Station at Jowers Center and Sewell Park, Texas State University-San Marcos, Hays County, Texas*, Technical Report No. 38, Center for Archaeological Studies, Texas State University-San Marcos.

Leezer, Carole, David Yelacic, Jon C. Lohse, and Frederick Hanselmann

2011 *Results of Cultural Resources Survey for the Spring Lake Section 206 Aquatic Ecosystem Restoration Project.* Archaeological Studies Report No. 22, Center for Archaeological Studies, Texas State University-San Marcos.

Lohse, Jon C., Editor

2013 *Underwater Arachaeology at 41HY147, the Terrace Locality at Spring Lake*. Archaeological Studies Report No. 28, Center for Archaeological Studies, Texas State University-San Marcos.

Lohse, Jon C., Amy E. Reid, David M. Yelacic, and Cinda L. Timperley

2013 *Data Recovery and Analysis at the Texas State University Ticket Kiosk Project, Located at 41HY160, Spring Lake, Hays County, Texas*. Archaeological Studies Report No. 32, Center for Archaeological Studies, Texas State University-San Marcos.

Lundelius, E. L. Jr.

1986 Vertebrate Paleontology of the Balcones Fault Trend. In *The Balcones Escarpment: Geology, Ecology, and Social Development in Central Texas*. P. L. Abbot and C. M. Woodruff Jr. eds. Geological Society of America Annual Meeting, San Antonio, TX.

Lyle, A. S., C. E. Horrell. S. A. Tomka, and D. A. Cargill

2000 *Archaeological Testing at the Headwaters of the San Marcos River: Southwest Texas University Raw Water Supply Project*. Archaeological Survey Report No. 293, Center for Archaeologcial Research, The University of Texas at San Antonio.

Musgrove, MaryLynn and Cassi L. Crow

2012 *Origin and Characteristics of Discharge at San Marcos Springs Based on Hydrologic and Geochemical Data (2008-10), Bexar, Comal, and Hays Counties, Texas*. United States Geological Survey, Scientific Investigations Report 2012-5126.

Morton, Robert A. and William A. White

1997 Characteristics of and Corrections for Core Shortening in Unconsolidated Sediments. *Journal of Coastal Research*. Vol. 13, No. 3, pp. 761-769

Nickels, David L., and C. Britt Bousman

2010 *Archaeological Testing at San Marcos Springs (41HY160) for the Texas Rivers Center, Texas, Hays County, Texas*. Archaeological Studies Report No. 13. Center for Archaeological Studies, Texas State University-San Marcos.

Nordt, Lee C.

1992 *Archaeological Geology of the Fort Hood Military Reservation, Fort Hood, Texas*. Archaeological Resource Management Series, Research Report Number 25. United States Army, Fort Hood.

2010 Geology, Landscape Evolution, and Geoarchaeology at Spring Lake. In *Archaeological Testing at San Marcos Springs (41HY160) for the Texas Rivers Center, Hays County, Texas*, by David L. Nickels and C. Britt Bousman. Archaeological Studies Report No. 13, Center for Archaeological Studies, Texas State University-San Marcos.

Nordt, L. C., T. W. Boutton, J. S. Jacob, and R. D. Mandel

2002 C4 Plant Productivity and Climate—CO2 Variations in South-Central Texas During the Late Quaternary. *Quaternary Research* Vol. 58, pp. 182-118.

Oksanen, Eric

2006 *Proposed Fiber Optic Conduit Route at the Aquarena River Center and Golf Course, San Marcos, Hays County, Texas*, Technical Report No. 22, Center for Archaeological Studies, Texas State University-San Marcos.

2008 Archaeological Investigations at the Icehouse Site, 41HY161: a Revaluation of Early Archaic Technology, Subsistence and Settlement along the Balcones Escarpment and Central Texas. Unpublished Master’s thesis, Department of Anthropology, Texas State University-San Marcos.

Oksanen, Eric, Barbara Meissner and C. Britt Bousman

2011 *Archaeological Investigations at the Ice House Site, 41HY161: Early Archaic Technology, Subsistence, and Settlement along the Balcones Escarpment, Hays County, Texas*. Archaeological Studies Report No. 14. Center for Archaeological Studies, Texas State University-San Marcos.

Palmer, C. E.

1986 Land Use and Cultural Change along the Balcones Escarpment: 1718-1986. In *The Balcones Escarpment: Geology, Ecology, and Social Development in Central Texas*. P. L. Abbot and C. M. Woodruff Jr. eds. Geological Society of America Annual Meeting, San Antonio, TX.

Prewitt, E. R.

1985 From Circleville to Toyah: Comments on Central Texas Chronology. *Bulletin of the Texas Archaeological Society*, Vol. 54, pp. 201-238.

Ramsey, Dawn

1997 *Archaeological Survey of Aquarena Springs Park, Hays County, Texas*. Manuscript on file at Anthropology Department, Southwest Texas State University, San Marcos.

Ringstaff, C. W.

2000 *A Study of Landform Evolution and Archaeological Preservation at Site 41HY165, San Marcos, Texas*. Unpublished Master's thesis, Department of Geography, Southwest Texas State University, San Marcos.

Riskind, D. H. and D. D. Diamond

1986 Plant Communities of the Edwards Plateau of Texas : an Overview Emphasizing the Balcones Escarpment Zone Between San Antonio and Austin with Special Attention to Landscape Contrasts and Natural Diversity. In *The Balcones Escarpment: Geology, Ecology, and Social Development in Central Texas*. P. L. Abbot and C. M. Woodruff Jr. eds. Geological Society of America Annual Meeting, San Antonio, TX. pp. 20-32.

Schoeneberger, P. J., D. A. Wysocki, E. C. Benham, and W.D Bronerson, and Soil SurveyStaff

2012 *Field Book for Describing and Sampling Soils, Version 3.0*. Natural resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Shiner, Joel L.

1979 *Survey and Testing of the Ice House site: San Marcos, Hays County, Texas*. Unpublished manuscript, Southern Methodist University, Dallas.

1981 History, Economy, and Magic at a Fresh Water Spring. In *The realms of gold, Proceedings of the Tenth Conference on Underwater Archaeology*, edited by W. A. Cockrell, pp. 202-203. Fathom Eight, San Marino, California.

1983 Large Springs and Early American Indians. *Plains Anthropologist* 28:99:1-7.

1984 A Reply to Johnson and Holliday. *Plains Anthropologist* 29:103:71-72.

Soucie, Shawn, and David L. Nickels

2003 *Archaeological Monitoring of a Tree Planting Project and Installation of the Front Door Welcoming Drive for Texas State University-San Marcos, Hays County, Texas.* Technical Report No. 11, Center for Archaeological Studies, Texas State University-San Marcos.

Soucie, Shawn, David L. Nickels, Kevin L. Shubert, and Colby J. Mischefsky

2004 *Archaeological Trench Monitoring at the Aquarena Springs Golf Course, San Marcos, Hays County, Texas.* Technical Report No. 16, Center for Archaeological Studies, Texas State University-San Marcos.

Stull, Kyra, and Michelle D. Hamilton

2011 Descriptive Analysis of Three Individual Remains from Zatopec, with Comparative Analysis of Two Additional Sets from 41HY161; Chapter 8: Bioarchaeological Analysis of Human Remains from Zatopec. In *Prehistoric Life, Labor, and Residence in Southeast-Central Texas: Results of Data Recovery at 41HY163, the Zatopec Site, San Marcos, Texas.* Jon C. Lohse, editor, Archaeological Studies Report No. 18, Center for Archaeological Studies, Texas State University-San Marcos.

Takac, Paul R.

1990 *“Homes Bases” and the Paleoindian/Archaic transition in Central Texas*. Paper presented at the 55th Annual SAA Meeting, Las Vegas.

1991a Underwater Excavations at Spring Lake: a Paleoindian Site in Hays County, Texas. *Current Research in the Pleistocene* 8:46-48.

1991b *Paleoindian Occupations at Spring Lake, Hays Co., Texas*, Dissertation Research Proposal. Submitted to the Faculty, Department of Anthropology, Southern Methodist University, Dallas.

Taylor, F. B., R. B. Haily, and D. L. Richmond

1966 *Soil Survey of Bexar County, Texas*. United States Department of Agriculture, Soil Conservation Service, Washington D.C.

Taylor, R. E., A. Long, and R. Kra (eds)

1992 *Radiocarbon After Four Decades. An Interdisciplinary Perspective*. Springer-Verlag, NY.

Toomey, Rickard S., III

1993 *Late Pleistocene and Holocene Faunal and Environmental Changes at Hall’s Cave, Kerr County, Texas*. Unpublished Ph.D. dissertation, Department of Geography, University of Texas at Austin.

Ward, G. K., and S. R. Wilson

1978 Procedures for Comparing and Combining Radiocarbon Age-Determinations – Critique. *Archaeometry*, Vol. 20, pp. 19-31.

Woodruff, C. M., Jr. and P. L. Abbott

1979 Drainage-Basin Evolution and Aquifer Development in a Karstic Limestone terrain, South-Central Texas, USA: Earth Surface Processes V. 4, pp. 319-334.

Woodruff, C. M. Jr. and P. L. Abbott

1986 Stream Piracy and Evolution of the Edwards Aquifer Along the Balcones Escarpment, Central Texas. In *The Balcones Escarpment: Geology, Ecology, and Social Development in Central Texas*. Abbot and Woodruff eds. Geological Society of America Annual Meeting, San Antonio, TX. pp. 77-90.

Yelacic, David M., R. Zac Selden, and Jon C. Lohse

2008 *Results of Archaeological Monitoring at the Fish Ponds, Texas State University-San Marcos, Hays County, Texas*. Technical Report No. 33, Center for Archaeological Studies, Texas State University-San Marcos.