

SPRING LAKE UNDERWATER GEOARCHAEOLOGY SURVEY

FEBRUARY 2016



Submitted to:
Texas Historical Commission
National Geographic Society
Waite Institute

Submitted by:
Frederick H. Hanselmann



THE MEADOWS CENTER
FOR WATER AND THE ENVIRONMENT
TEXAS STATE UNIVERSITY

SPRING LAKE UNDERWATER GEOARCHAEOLOGY SURVEY

The Meadows Center for Water and the Environment
Center for Archaeological Studies
Texas State University
February 2016

Authors Jacob Hooge, Frederick H. Hanselmann,
Jon C. Lohse, and Daniel Warren

Principal Investigator Frederick H. Hanselmann



THE MEADOWS CENTER
FOR WATER AND THE ENVIRONMENT

TEXAS STATE UNIVERSITY

The following information is provided in accordance with the General Rules of Practice and Procedures, Title 13, Chapter 26, Texas Administrative Code:

1. Type of investigation: Underwater archaeological survey
2. Project name: Spring Lake Underwater Geoarchaeology Survey
3. County: Hays County
4. Principal Investigator: Frederick H. Hanselmann
5. Name and location of sponsoring agency: The Meadows Center for Water and the Environment
6. Texas Antiquities Permit: 5923
7. Published by the Meadows Center for Water and the Environment and the Center for Archaeological Studies, Texas State University, 601 University Drive, San Marcos, Texas, 78666-4616 (2015)

Texas State University is a member of the Texas State University System
Copyright ©2016 by the Meadows Center for Water and the Environment and
The Center for Archaeological Studies at Texas State University
All rights reserved.

No part of this book may be reproduced or utilized in any form or by any means,
Electronic or mechanical, including photocopying, recording,
Or by any information storage and retrieval system
Without permission in writing.

For further information on this and other publications by
the Meadows Center for Water and the Environment, please contact:

THE MEADOWS CENTER FOR WATER AND THE ENVIRONMENT

Texas State University

601 University Drive

San Marcos, TX 78666-4616+

www. <http://www.meadowscenter.txstate.edu/>

ABSTRACT

Archaeologists from the Meadows Center for Water and the Environment and the Center for Archaeological Studies at Texas State University conducted an underwater geoarchaeological survey in Spring Lake in San Marcos, Texas. Work was conducted by Jacob Hooge, Frederick H. Hanselmann, Jon C. Lohse, and Daniel Warren under Texas Antiquities Permit Number 5923, assigned to Principal Investigator Frederick H. Hanselmann.

ACKNOWLEDGEMENTS

Many thanks are due to the National Geographic Society and the Waitt Institute for providing project funding and to Dominique Rissolo and Fabio Amador for support throughout this process.

The authors of this report would like to offer their sincere gratitude to Peter Way and the Way Family Philanthropic Foundation for funding and their steadfast support of this project and archaeology in Texas and elsewhere.

Andrew Sansom and the Meadows Center for Water and the Environment provided in kind support through the use of its barge, access to the springs and the time of its personnel, Aaron Wallendorf, Taylor Heard, Nick Pocknall, and Sam Meacham.

The Center for Archaeological Studies (CAS) provided funding for the coring system and logistical support including vehicles and transportation. Many thanks are owed to Jon C. Lohse, David Yelacic, Bob Woodward, and Andy Grubbs. Additional comments on the results of this research came from C. Britt Bousman, Steve Black, and Michael Collins.

Thanks are owed to co-author Daniel Warren and Jonathan Baker of C&C Technologies for project support and conducting the first geophysical survey.

A major thank you is owed to Jamie Austin, John Goff, and Steffan Saustrap of the University of Texas Institute of Geophysics for conducting a second geophysical survey, in addition to the friendship and camaraderie shared on the short project.

Thank you to Eric W. Hanselmann for editing and formatting this report very professionally despite the last minute notice.

Finally, a major thank you is owed to CAS Project Archaeologist Jacob Hooge, the lead author of this report, who put forth the lion's share of the effort on this project.

CONTENTS

ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	iii
LIST OF FIGURES AND TABLES.....	vi
INTRODUCTION.....	1
PROJECT SETTING AND BACKGROUND.....	2
METHODS.....	6
RESULTS.....	17
INTERPRETATION.....	24
CONCLUSIONS.....	32
REFERENCES CITED.....	33

LIST OF FIGURES AND TABLES

Figure or Table	Description	Page
Figure 1	Physiographic regions surrounding the San Marcos Springs	2
Figure 2	Surface geology around Spring Lake showing approximate location of faults (Musgrove and Crow 2013).	3
Figure 3	Stratigraphic cross section showing bedrock and faults underlying Spring Lake (Musgrove and Crow 2013).	3
Figure 4	Photomosaic of Cypress Point profile exposure highlighting preserved wood.	6
Figure 5	The Meadows Center’s research barge.	7
Figure 6	The EdgeTech SB-424 subbottom profiling system.	8
Figure 7	EdgeTech SB-424 towfish.	8
Figure 8	Towfish deployed.	8
Figure 9	Tracklines surveyed of the bed of Spring Lake.	9
Figure 10	Example of the dataset that delineates the vegetation, surface of the lakebed, subsurface reflector, and acoustic voids.	10
Figure 11	Pneumatic post driver regulator supplying surface supplied compressed air from scuba cylinders.	11
Figure 12	Core tube being driven using pneumatic post driver.	11
Figure 13	Core being extracted using chain-hoist on barge.	12
Figure 14	Chain being secured to the driven core tube.	13
Figure 15	Electric tin shears cutting aluminum core tube.	14
Figure 16	Core 04 opened.	14
Figure 17	Core 04 after sampling.	14
Figure 18	UTIG pole-mounted Knudsen system.	15
Figure 19	UTIG Knudsen chirp sonar system.	15
Figure 20	Dataset from the UTIG survey, demonstrating the varying sediment horizons observed in the low frequency sonar readout.	16
Figure 21	Aerial satellite image of the cross plots.	17
Figure 22	3-dimensional topographic and bathymetric contour of Spring Lake, showing distribution of cross-plots, vertically exaggerated by a factor of 3.	18
Figure 23	Satellite image of the project area showing the horseshoe-shaped Spring Lake and Texas State University’s Bobcat Stadium in the southeast quadrant.	18
Figure 24	Topographic and bathymetric contour map of Spring Lake showing the distribution of the cores, excavations, and profile exposures discussed in this report. Colored lines connecting features correspond to cross-plot sections displayed in 3-dimensions.	19
Figure 25	Stratigraphic cross-plot of Cores 05,03, 07, and 08 (northwest to southeast) in Spring Lake.	20

Figure or Table	Description	Page
Figure 26	Stratigraphic cross-plot of Cypress Point profile and Cores 06, 07, 09, and 04 (southwest to northeast) in Spring Lake.	21
Figure 27	3-dimensional topographic and bathymetric contour map of Spring Lake showing distribution of cross-plots and cores looking north and vertically exaggerated by a factor of 3.	24
Figure 28	Stratigraphic cross-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 from west to east in Spring Lake and across Spring Lake Peninsula.	25
Figure 29	Idealized geologic cross-section of the Sink Creek Valley (modified from Nordt 2010: Figure 6-8).	26
Figure 30	Left - Topographic and bathymetric contour map showing the natural features of Spring Lake. Middle and Right - Progressions showing how the Cypress Point Peninsula could form a levee across the main springs channel.	27
Figure 31	Stratigraphic cross-plot of core D (Nordt 2010), units 3 and 4 (Lohse et al. 2013), and Cores E, L, and M (Nordt 2010) (northeast to southwest) on the Spring Lake Peninsula.	28
Figure 32	Idealized stratigraphic cross-section of the San Marcos Springs (northwest to southeast across the Spring Lake Peninsula)	29
Figure 33	Left - Reconstructed variations in tree cover in east-central Texas (modified from Bousman 1998: Figure 7). Right - Averages rates of aggradation at the San Marcos Springs relative by lateral thickness.	30
Table 1	Published archaeological investigations in and around Spring Lake, San Marcos, Texas.	5
Table 2	Spring Lake subbottom core sample targets.	10
Table 3	C14 ages from cores and the exposed profile in Spring Lake. Calendar ages were calibrated with OxCal-IntCal 2013. DAMS: Direct-AMS, Seattle, UCIAMS: University	22

INTRODUCTION

The San Marcos Springs in central Texas have been a source of fresh water supporting human activity for thousands of years. Previous excavations carried out in Spring Lake during the late 1970s led to exciting archaeological discoveries documenting a long sequence of prehistoric occupation extending through the Paleoindian period, including the recovery of several Clovis projectile points. This initial phase of the new Spring Lake Project seeks to answer questions regarding the paleoenvironment in which some of the earliest inhabitants of North America lived by carrying out the first geoarchaeological survey of the lake. The Spring Lake Geoarchaeology Survey is twofold. First, a geophysical survey utilizing an echosounder and a sub-bottom profiler was carried out in order to study the topography of the lakebed to examine the ancient riverbed of the San Marcos River as related to the springs, and assess the location of potential archaeological deposits. Second, an extensive coring regime was conducted. Following the collection of the core samples, analysis and interpretation of the stratigraphic sequences, coupled with the dating of any material found within the samples, provides much greater insight and understanding of the environment in which the ancient inhabitants of San Marcos, Texas lived. The data acquired will now be used in the development of the overall long-term research design for the Spring Lake Project.

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 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 report details the methods, results, and interpretations of a geoarchaeological investigation of Late Pleistocene and Holocene sediments in order to increase the resolution of understanding of the geoarchaeological record of Spring Lake 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

Due to the unique set of formation processes that 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, natural processes of deposition, erosion, and disturbance of sediments may have been drastically altered. This analysis of multiple core samples taken from within the lake will provide an important stratigraphic context for future archaeological studies by lending a greater understanding to the lake bottom's formation processes. 🌿

PROJECT SETTING AND BACKGROUND

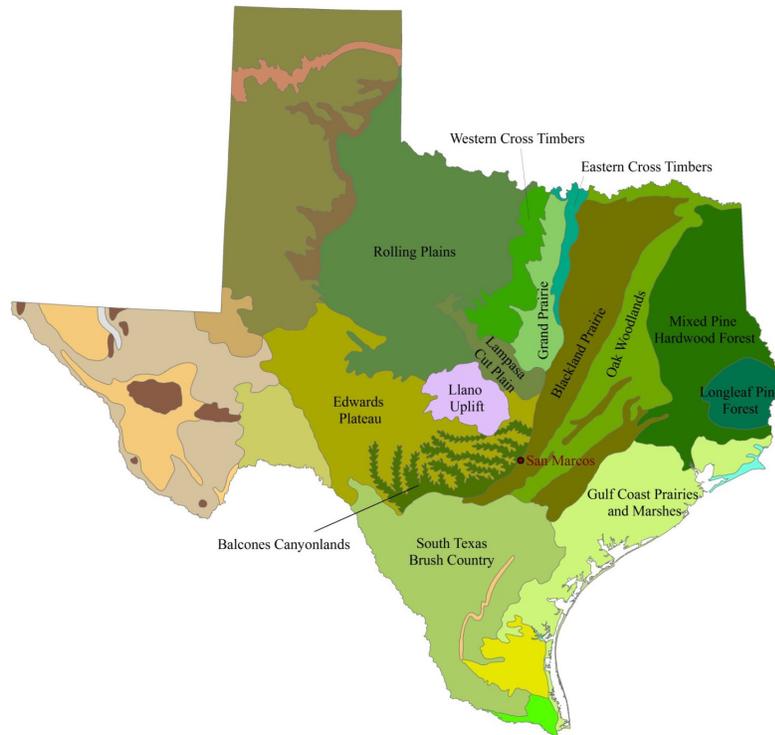


Figure 1: Physiographic regions surrounding the San Marcos Springs.

The San Marcos Springs are situated at the base of the Balcones Escarpment in Hays County, Texas (see Figure 1) and form the uppermost headwaters of the San Marcos River. The springs are now inundated by Spring Lake with approximately 25 percent of discharge issuing 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 Tonkawas, the springs have attracted a human presence for at least 13,500 years (Brune 2005). Today, the San Marcos Springs are home to 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.

Regional Structural 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 seen as a series of en echelon normal faults with slightly southeast dipping to near-vertical displacement (Barnes 1992). Total stratigraphic displacement across the entire fault zone varies with a maximum displacement of 520 meters across a distance of 39 km occurring just north of the bend in Comal County (George et al. 1952). Several faults run through the San Marcos Springs area (see Figures 2 and 3) and are the conduits by which spring discharge flows.

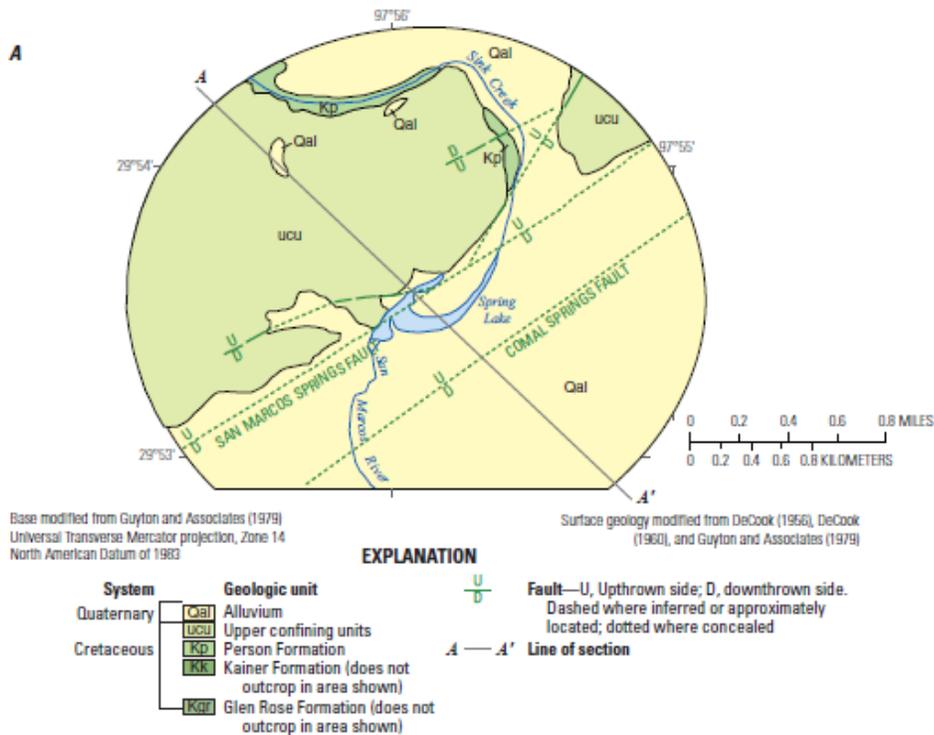


Figure 2: Surface geology around Spring Lake showing approximate location of faults (Musgrove and Crow 2013).

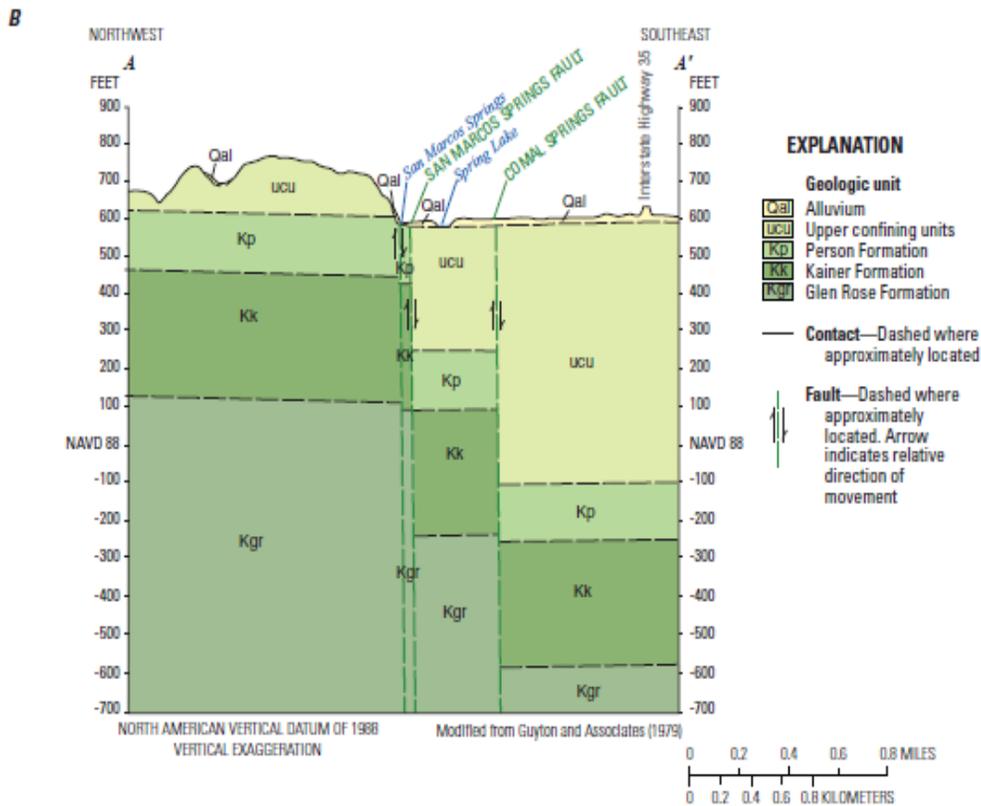


Figure 3: Stratigraphic cross section showing bedrock and faults underlying Spring Lake (Musgrove and Crow 2013).

Hydrology

During their transit across the Edwards Plateau, many tributaries of Balcones Escarpment drainages lose most or all of their flows to faults and fractures of the recharge zone of the Edwards Aquifer. Through much of the Hill Country the Edwards is an unconfined 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 the narrow artesian zone at the base of the Balcones Escarpment at discharge points such as the Comal Springs and the San Marcos Springs, the first and second largest spring complexes in Texas (Brune 1975).

Although the flow from the San Marcos Springs is less than that of the Comal Springs, the former sits at 15 m less 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 Environment

The Balcones Escarpment represents an ecotone or ecological crossroads. Ecotones often contain a more rich diversity of biota than do the individual environmental provinces they separate (Crumly 1994). Especially in the area surrounding the San Marcos Springs (Figure 1), 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).

Average temperature in San Marcos is approximately 69 °F, and precipitation, occurring almost entirely as rain, averages at 34.0 inches/year; however, actual rain amounts from year to year can be highly variable (Bomar 1983). A slight orographic effect caused by the Balcones Escarpment combined with Central Texas often being the meeting point of tropical and polar air masses makes for occasional record-setting floods. 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.

Previous Investigations

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

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; Lyle et al. 2000; Oksanen 2008 and 2011; Shiner 1979, 1981, 1984; Stull and Hamilton 2011; Yelacic et al. 2008
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, Paleoindian	Arnn and Kibler 1999

Table 1: Published archaeological investigations in and around Spring Lake, San Marcos, Texas.

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).

In 2010, the Center for Archaeology Studies (CAS) conducted an archaeological survey of the area surrounding the submarine theater (part of the former amusement park, Aquarena Springs) in order to determine what impacts its removal would have on buried cultural resources (Leezer et al. 2011). CAS identified a complex stratigraphy around the sub, and although radiocarbon dates of bulk sediments proved problematic, a preserved wood fragment collected from the wall of a test unit in front of the sub returned a ^{14}C age of 11390 ± 50 B.P. (Leezer et al. 2011).

Although not yet published, CAS performed the most recent work at the San Marcos Springs in preparation for the installation of a ticket kiosk for the Aquarena Center's glass-bottom boat tours. Four 1x1-m units were excavated to a depth of 300 cm, and artiodactyl and bison bone fragments collected yielded a well-stratified series ^{14}C ages between 6015 ± 20 and 515 ± 15 B.P. (Lohse et al. 2013). 

METHODS

Profile Exposure

A naturally exposed underwater sediment profile of approximately 4 meters in height was discovered by Lake Manager Aaron Wallendorf (see Figure 4). According to Mr. Wallendorf, the profile was cut by a flood event in September of 2011. Due to the difficulty of maintaining visibility while using methods prescribed by Schoeneberger et al. (2002), visual observations of the Cypress Point profile were recorded at Center for Archaeology Studies (CAS) using an image created by stitching 24 close-up digital photographs into a photomosaic.

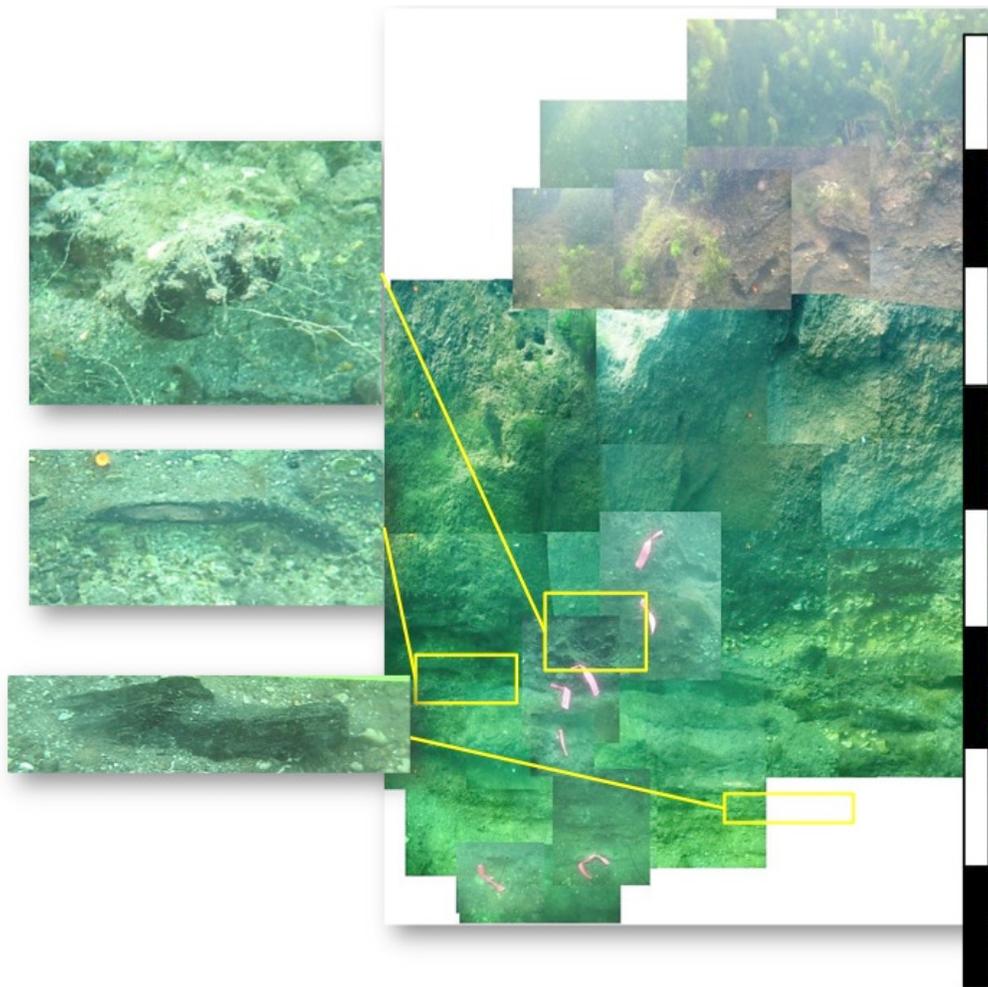


Figure 4: Photomosaic of Cypress Point profile exposure highlighting preserved wood.

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 and analyzed by the University of California at Irvine Keck Carbon Cycle AMS Program, Irvine.

Geophysical Survey 2011

The first geophysical survey was conducted on the Meadows Center's research barge in collaboration with C&C Technologies (now Oceaneering). An EdgeTech SB-424 subbottom profiling systems was utilized in order to map the lakebed and to assess the best potential target areas to take core samples (Figures 5 and 6). The SB-424's sensor or towfish was deployed through the opening in the center of the barge's hull for easy retrieval and cleaning (Figure 5).



Figure 5: The Meadows Center's research barge.



Figure 6: The EdgeTech SB-424 subbottom profiling system.



Figure 7: EdgeTech SB-424 towfish.



Figure 8: Towfish deployed.

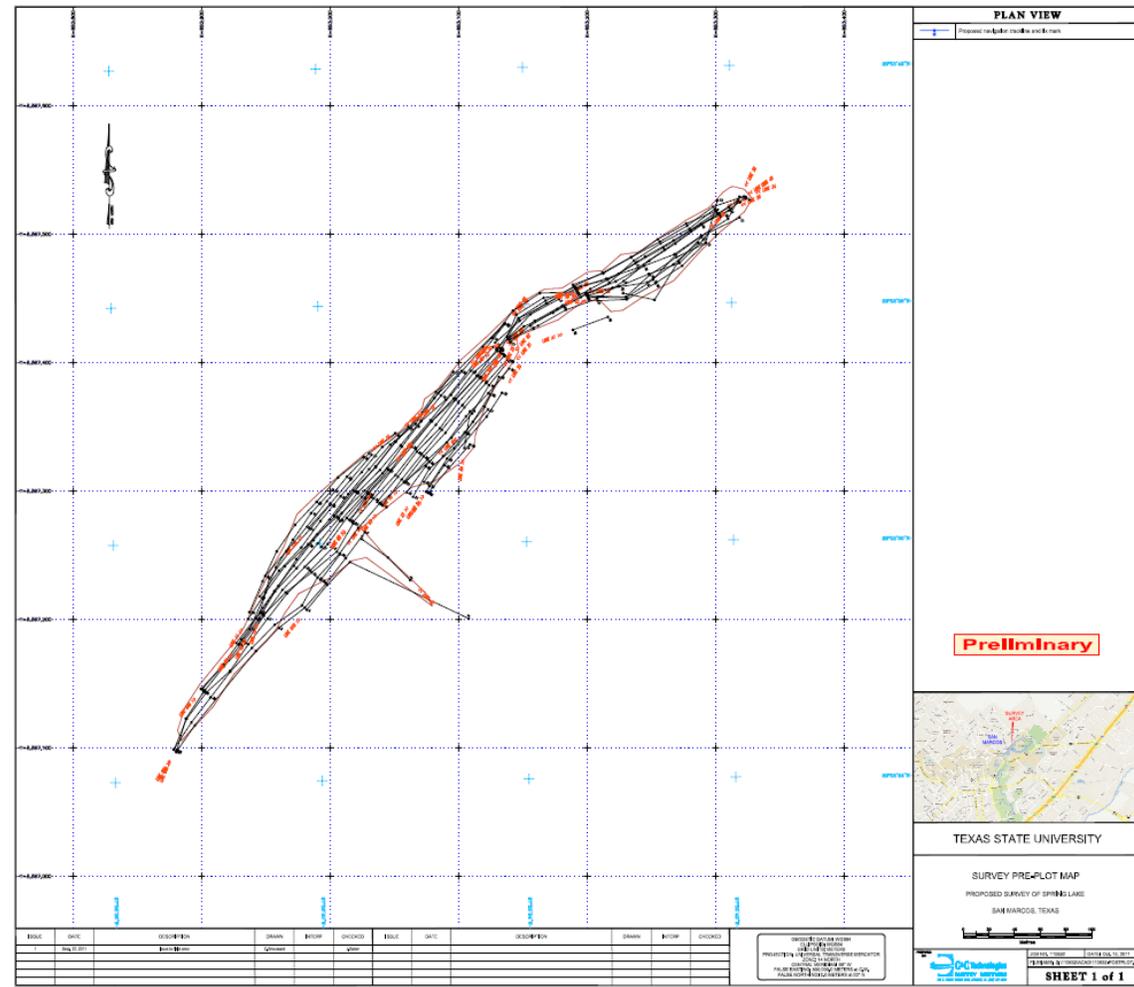


Figure 9: Tracklines surveyed of the bed of Spring Lake.

The SB-424 is a portable 4 – 24 kHz subbottom profiling system. The frequency range of the SB-424 provided the initial attempt to penetrate the prevalent aquatic vegetation found on the lakebed and to obtain adequate imagery of the lake’s subsurface deposits. Positioning was acquired using C-Nav DGPS paired with WinFrog positioning software to track the barge’s location, while the subbottom data was acquired in SEG-Y format. The SEG-Y data was interpreted using Kingdom Suite HIS software. Sound velocities were not recorded in the field, so an average velocity of 1,524 m/s (5,000 ft/s) was used to calculate lake bed and subsurface depths. A total of 58 tracklines were surveyed over the main portion of the lake, the headwaters area, the location known as Deep Hole, and portions of the Training Area (Figure 9). Line spacing varied from 3 – 5 meters due to the density of aquatic vegetation in some areas of the lake.

Utilizing a bathymetric map from the subbottom profiler data, the lakebed was differentiated from the vegetation layer and marked as a horizon on each line. Following the lakebed mapping, the subsurface horizons were selected and any visible subsurface reflectors within the uppermost 10 meters of the lake sediments were mapped as separate horizons on each line (Figure 10).

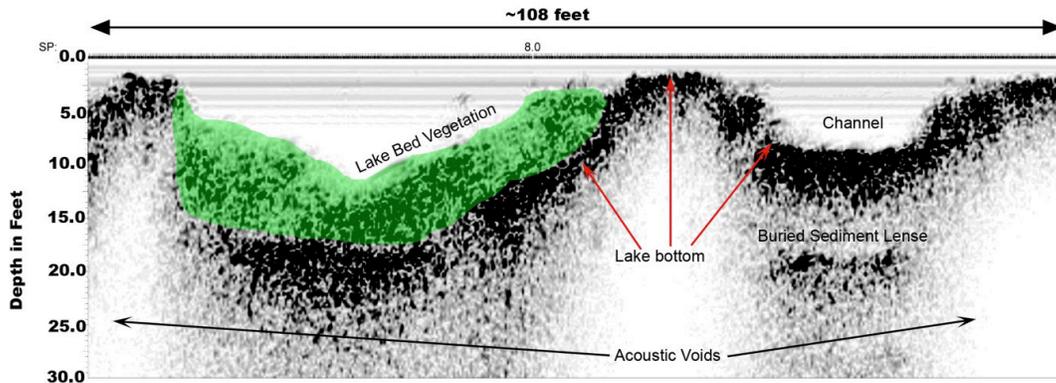


Figure 10: Example of the dataset that delineates the vegetation, surface of the lakebed, subsurface reflector, and acoustic voids.

The lakebed surface and the subsurface horizon data was output from the IHS Kingdom Suite software as X, Y, and Time values. The time values were then converted in depth based on the assumed sound velocity. This is expressed in the following formula:

2-way travel time (seconds) x sound velocity (1524m/s)/2 = depth (m). The conversion of the time values produced a set of X, Y, and Z data for each horizon. The X, Y, and Z data were then converted into a bin file using C&C Technology's proprietary Hydromap software. The bathymetry was processed at a 1-meter bin size. Once the bin file was created, the data set was gridded. Finally, the bin file was gridded in Hydromap using a nearest neighbor algorithm. With the data gridded, Geotiff and DXF contour data were created with the Hydromap software for insertion into project maps. Despite the team's best efforts, issues with the appropriate nautical speed for the towfish, the shallow depths resulting in acoustic voids, and the vegetation, the data collected was not as optimal as desired.

Regardless, 19 targets were selected as the most optimal areas with subsurface horizons from which to take core samples ased on the subbottom profiler data (Table 2). Each area demonstrated subsurface horizons less than three meters below the lake bottom.

WGS 84 UTM 14 North Meters			
LINE	X-COORDINATE	Y-COORDINATE	COMMENTS
101	603141.69	3307405.53	SEDIMENT LENSE AT 3 m
101	603080.78	3307324.79	SEDIMENT LENSE AT 2.4 m
102	603140.12	3307415.09	SEDIMENT LENSE AT 2.3 m
103	603095.09	3307358.11	SEDIMENT LENSE AT 2.1 m
121	603140.75	3307405.37	SEDIMENT WITH HEAVY ORGANIC CONTENT
142	603302.00	3307515.88	SEDIMENT AT 2.0 m
130	603260.20	3307494.90	SEDIMENT AT 4.0 m
130	603302.22	3307519.14	SEDIMENT AT 3.2 m
132A	603134.14	3307417.10	SEDIMENT AT 4.4 m
132	603136.00	3307433.31	SEDIMENT 5.3 m thick
DH1*	603089.66	3307344.72	
DH1	603078.05	3307359.33	
DH2	603080.17	3307340.16	SEDIMENT AT 1.8 m
DH3	603060.31	3307345.89	
DH4	603102.53	3307372.60	SEDIMENT AT 2.3 m
HW1	603309.16	3307506.23	
HW3	603277.45	3307505.26	SEDIMENT AT 1.8 m
HW4	603296.37	3307502.22	SEDIMENT AT 3.5 m
TA1	603210.65	3307432.00	SEDIMENT AT 4.0 m

*DH = Deep Hole, HW = Head Waters, TA = Training Area

Table 2: Spring Lake subbottom core sample targets.

Coring

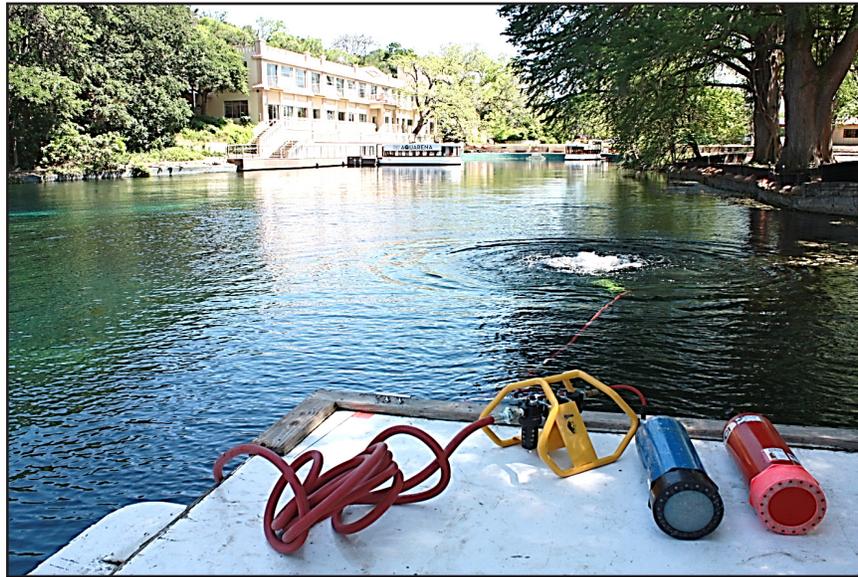


Figure 11: Pneumatic post driver regulator supplying surface supplied compressed air from scuba cylinders.

Following extensive research into underwater sediment coring methodologies and building on experiences gained from the coring methods of Jones et al. (1992) and Leezer et al. (2011), a series of 9 sediment cores were collected by driving aluminum irrigation pipes into lake bed sediments by way of pneumatic post driver (see Figures 11 and 12).

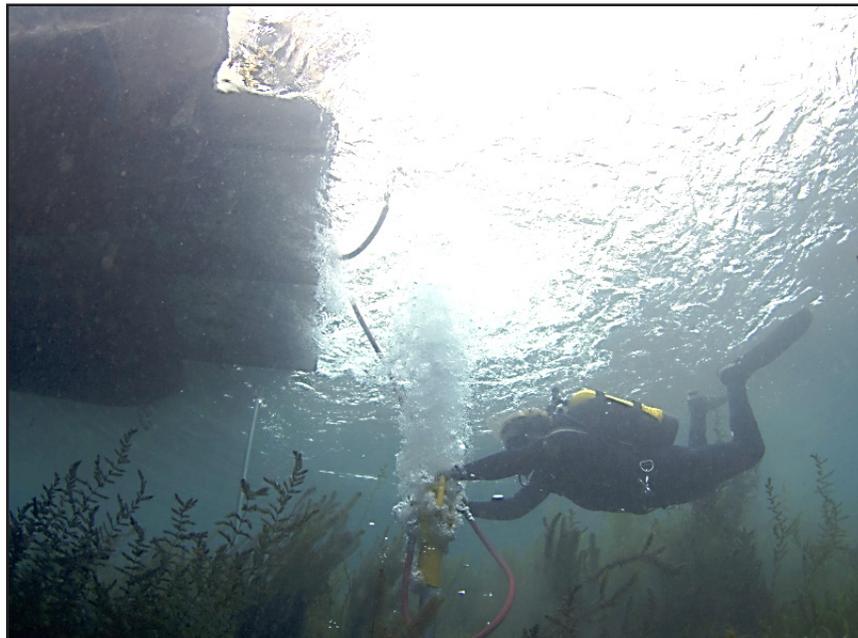


Figure 12: Core tube being driven using pneumatic post driver.

The pipe had an outside diameter of 7.62 cm (3 inch) with a wall thickness of 1.27 cm (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 as per the prohibition of petroleum-based lubricants in Spring Lake. Before extraction, the base of the still-exposed pipe was marked; the distance from that mark to the lake surface was observed using a tape measure suspended from a small float which was in effect an inverted plum-bob. Air/water tight caps were secured in the open end of the pipes, and cores were then extracted using a chain hoist suspended by A-frame through a small access hatch on a shallow-draft barge (see Figures 13 and 14).



Figure 13: Core being extracted using chain-hoist on barge.



Figure 14: Chain being secured to the driven core tube.

As the lower end of the core tube came free of the hole, the diver in the water immediately placed a cap over the lower opening, securing it with waterproof adhesive tape. In the case of Core 3, 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 9, one additional section was taken by the same method.

Laboratory Procedures

Core tubes were cut using electric tin shears (see Figure 15) and sediment columns were split using steel wire. Core samples were described using methods prescribed by Schoeneberger et al. (2002), and instances of core shortening such as physical compression, sediment thinning, sample loss, and sediment bypassing were corrected according to the methods of Morton and White (1997). Care was taken to only select samples for ¹⁴C 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; samples were then prepared for AMS ¹⁴C dating by Raymond Mauldin and analyzed by DiectAMS, Seattle.



Figure 15: Electric tin shears cutting aluminum core tube.



Figure 16: Core 04 opened.



Figure 17: Core 04 after sampling.

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 the Center for Archaeology Studies into a universal map of the project area using ArcGIS software. Modeling of surface contours and subsurface stratigraphy was completed using a combination of ArcGIS and RockWorks software.

Follow-up Geophysical Survey 2014

In May 2014 in collaboration with the University of Texas Institute for Geophysics (UTIG), a second survey was carried out with a low frequency pole-mounted Knudsen, in order to provide a basis for comparison with the previous high frequency survey with the EdgeTech system (Figures 18 and 19).



Figure 18: UTIG pole-mounted Knudsen system.



Figure 19: UTIG Knudsen chirp sonar system.

Despite similar interference from the vegetation, this survey yielded better reflection from submerged sediment horizons due to the lower frequency emission and the more stable positioning of the pole-mounted system, giving a better understanding of potential areas for excavation in the lakebed (Figure 20). Even this survey proved problematic due to the acoustic voids in shallow water and interference from vegetation. The results indicate numerous reflective horizons in the sediments surrounding the area of the springs known as “Deep Hole,” making it the prime area of interest. 🌿

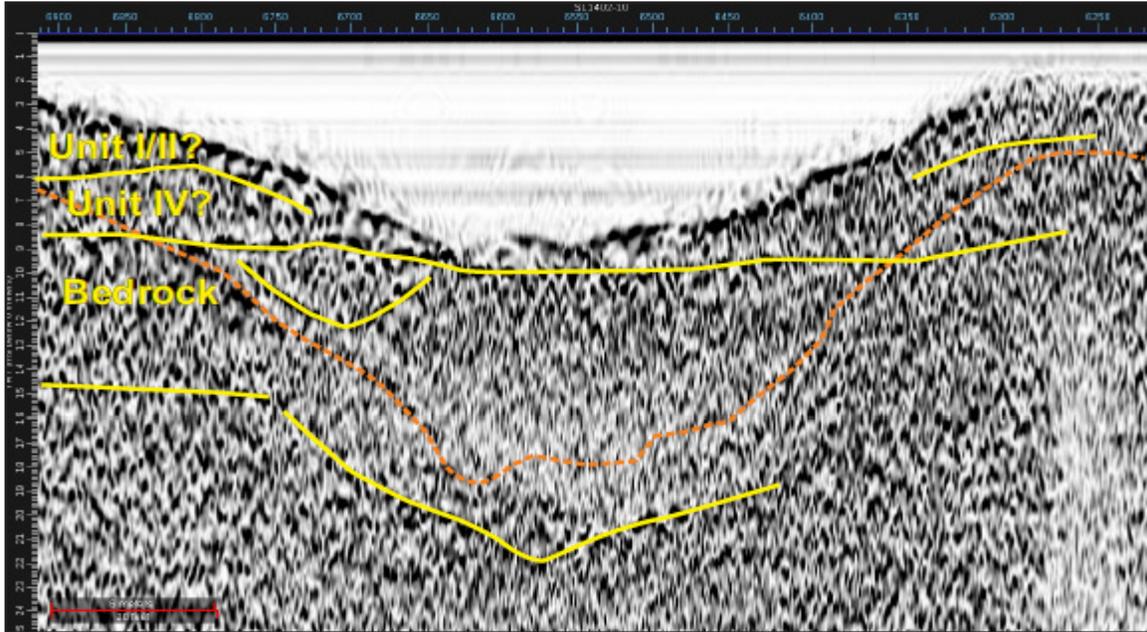


Figure 20: Dataset from the UTIG survey, demonstrating the varying sediment horizons observed in the low frequency sonar readout.

RESULTS

Introduction

Cores from a total of 9 locations were collected for this study. 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 implementation 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 stratigraphy of Cores 03 through 09 in addition to that of the Cypress Point profile is summarized below. All dates have been approximated and are given in radiocarbon years B.P. (before A.D. 1950) unless otherwise stated.

Stratigraphy

Alluvial stratigraphy encountered in the Cypress Point profile and cores extracted from the bottom of Spring Lake can be divided into four unconformably bound allostratigraphic units labeled from youngest to oldest, I, II, III, and IV (see Figures 21 – 26).

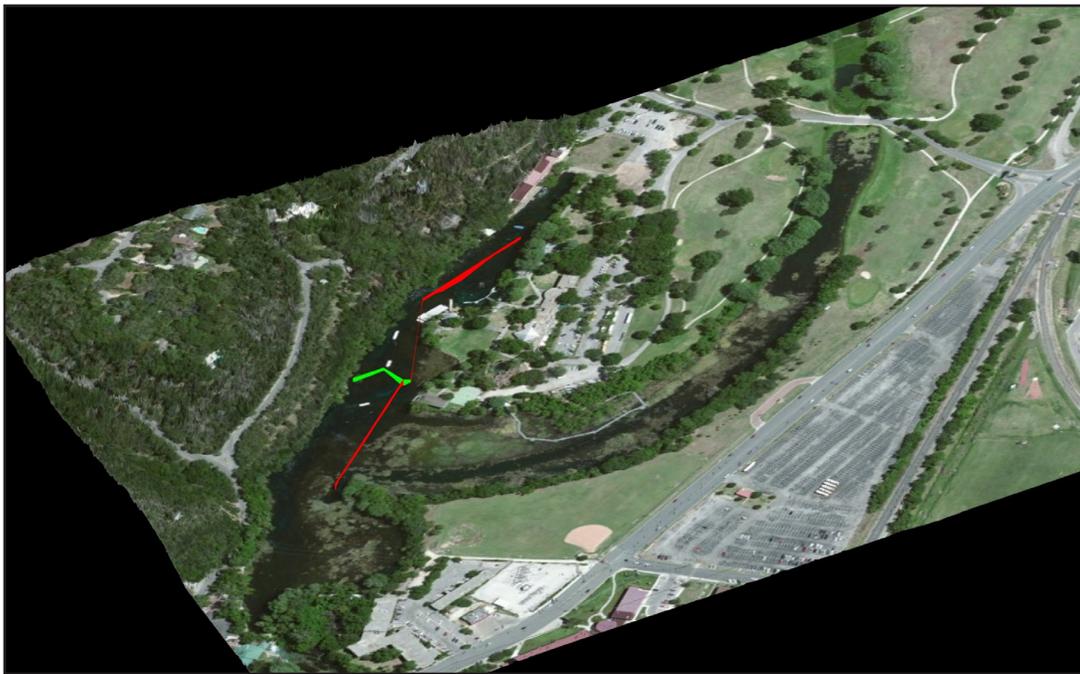


Figure 21: Aerial satellite image of the cross plots.

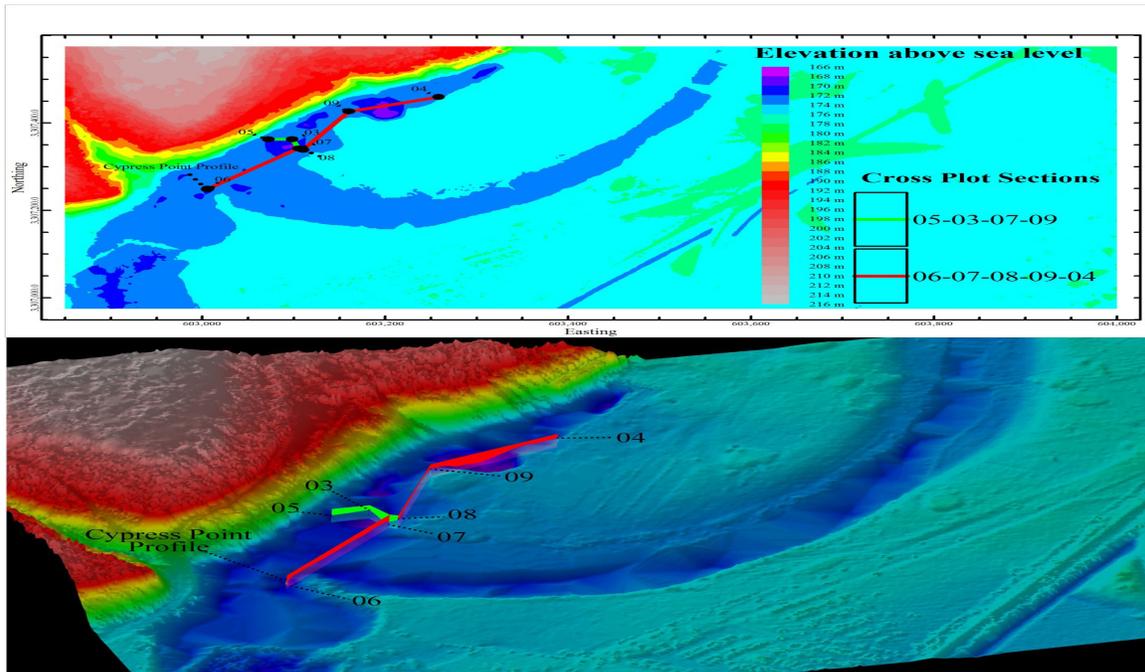


Figure 22: 3-dimensional topographic and bathymetric contour of Spring Lake, showing distribution of cross-plots, vertically exaggerated by a factor of 3.



Figure 23: Satellite image of the project area showing the horseshoe-shaped Spring Lake and Texas State University's Bobcat Stadium in the southeast quadrant.

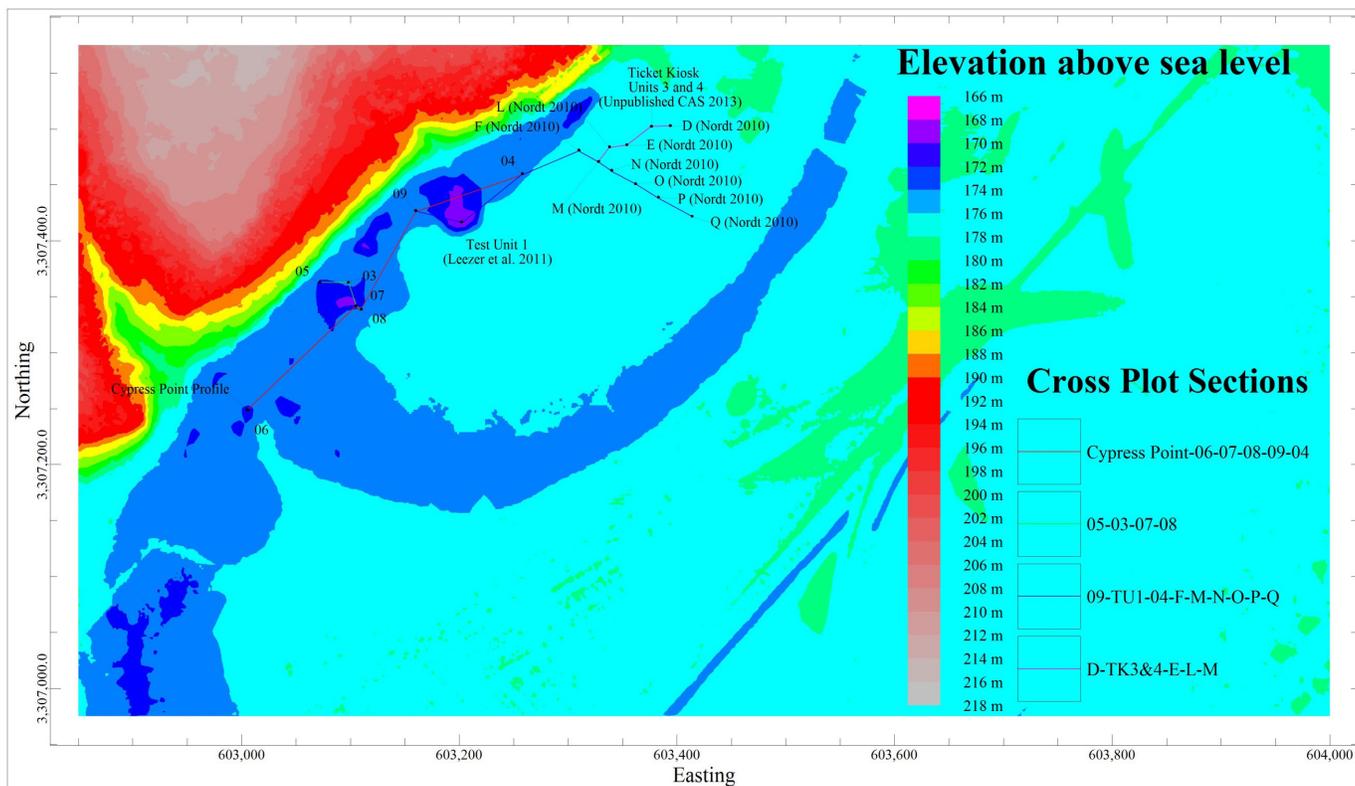


Figure 24: Topographic and bathymetric contour map of Spring Lake showing the distribution of the cores, excavations, and profile exposures discussed in this report. Colored lines connecting features correspond to cross-plot sections displayed in 3-dimensions.

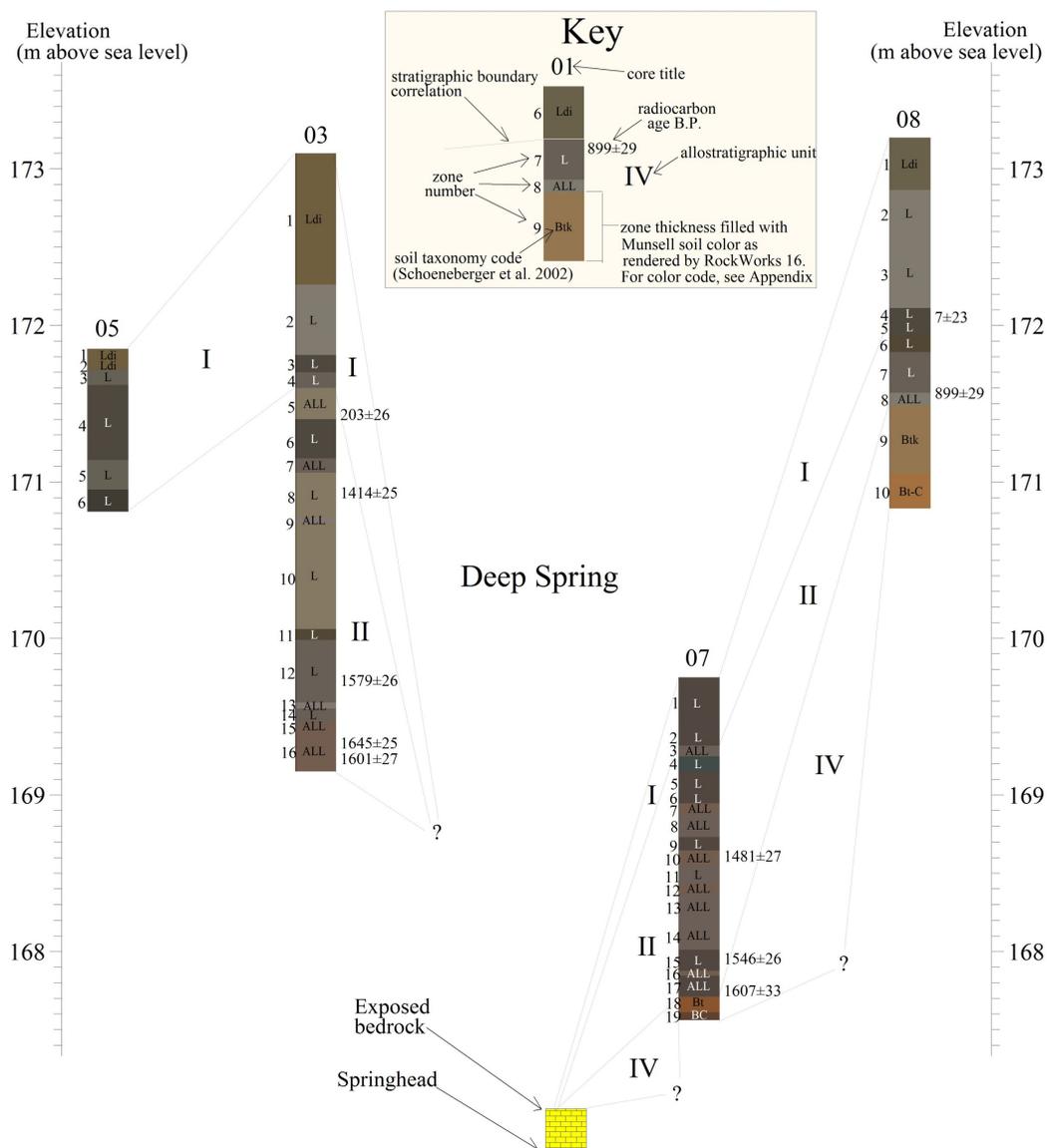


Figure 25: Stratigraphic cross-plot of Cores 05, 03, 07, and 08 (northwest to southeast) in Spring Lake.

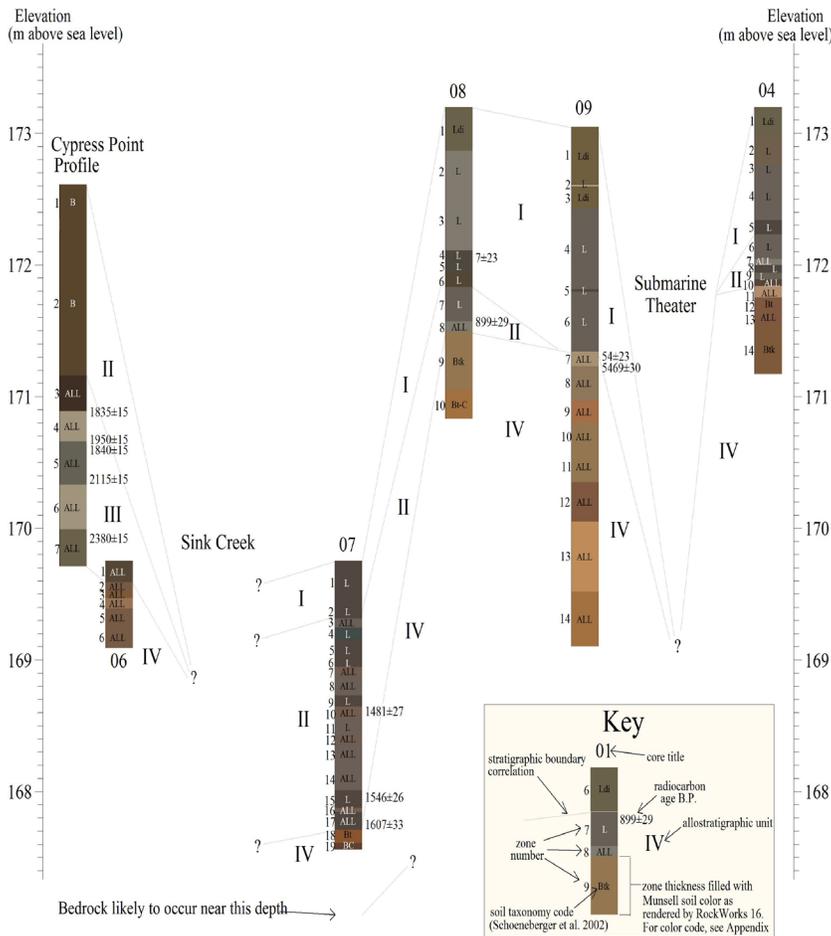


Figure 26: Stratigraphic cross-plot of Cypress Point profile and Cores 06, 07, 09, and 04 (southwest to northeast) in Spring Lake.

Figure 25 shows a cross-plot of Cores 05, 03, 07, and 08 oriented across the primary spring discharge channel (Figures 22 and 24), and Figure 25 shows a cross 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 (Figures 22 and 24). The oldest depositional unit identified in this study is Unit IV; it occurs in Cores, 04, 06, 07, 08, and 09 (Figures 25 and 26). A lower boundary for Unit IV was not encountered; however, its base likely occurs less than 50 cm below the bottom of Core 07 given that core's proximity to exposed bedrock near a springhead (Figure 25). Unit IV is at least 2 to 3 m thick and consists of reddish brown to yellowish brown clays interbedded with channel gravels and sands supported by a clay matrix of similar colors. In Cores 06 and 09, Unit IV deposits are entirely alluvial in nature, containing many large cobbles. For Cores 07, 08, and 09, Unit IV exhibits evidence of pedogenesis, in the form of CaCO₃ masses and reddened compacted clays; however, Unit IV occurs in Core 08, Zone 9 as a Btk horizon containing CaCO₃ 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. Because Core 9 is located nearer the channel's thalweg, and Core 8 is situated above and behind a major spring orifice, 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 appears truncated, exhibiting wavy to irregular boundaries, and in Cores 04, 07, and 08, the lowest zone of the overlying allostratigraphic unit exhibits clay rip-up clasts of similar color and texture to the underlying Unit IV zone.

Sample Number	Location	Depth (cm)	¹⁴ C Age B.P.	Calendar Age B.P.	Material
DAMS 001773	Core 03	163	203±26	301-0	wood
DAMS 001775	Core 03	213	1414±25	1353-1290	wood
DAMS 001774	Core 03	333	1579±26	1534-1407	wood
DAMS 001783	Core 03	373	1645±25	1613-1420	wood
DAMS 001772	Core 03	383	1601±27	1549-1413	charcoal
DAMS 001782	Core 07	110	1481±27	1409-1310	wood
DAMS 001777	Core 07	176	1546±26	1525-1378	plant fragment
DAMS 001776	Core 07	196	1607±33	1560-1410	wood
DAMS 001779	Core 08	111	7±23	244-36	plant fragment
DAMS 001778	Core 08	160	899±29	911-740	wood
DAMS 001780	Core 09	171	54±23	254-32	wood
DAMS 001781	Core 09	180	5469±30	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

Table 3: C14 ages from cores and the exposed profile in Spring Lake. Calendar ages were calibrated with OxCal-IntCal 2013. DAMS: Direct-AMS, Seattle, UCIAMS: University of California at Irvine, Keck Carbon Cycle AMS Program.

Based on charcoal obtained from Zone 7 in Core 09, the deposition of Unit IV continued until at least 5469±30 B. P. (Table 3, DAMS 001781). Unit III is only seen in the Cypress Point profile (Figure 26) and marks a period of stream channel aggradation beginning at least as early as 2380±25 B.P. (Table 3, UCIAMS 95430). Unit III consists of interbedded gray to light yellowish gray clay matrix-supported channel deposits containing large amounts of preserved wood (Figure 4). Unit III is capped by Unit II which marks a shift from slower, high-energy deposition to more rapid, slackwater in-filling at some point between 1835±15 B.P. (Table 3, UCIAMS 95427) and 1645±25 B.P. (Table 3, DAMS 001783) based on the dating of preserved wood and plant fragments collected at the Cypress Point profile and Core 03, respectively. Unit II occurs in Cores 03, 07, 08, and 09 (Figures 25 and 26) and consists of highly stratified deposits of organic-rich, dark gray to black marsh and lake sediments as well as numerous single-event

overbank deposits composed of small limestone coarse fragments, multi-colored clay rip-up clasts, and many preserved plant, wood, and seed fragments. Unit II deposits also occur in the Cypress Point profile, but are unique from those encountered in cores in that they represent a well-formed B horizon. Given the ^{14}C age of plant and wood fragments collected in Cores 03 and 08, a majority of Unit II aggradation occurred between 1645 ± 25 B.P. (Table 3, DAMS 001783) and 1414 ± 25 B.P. (Table 3, DAMS 001775) with a much-slowed accumulation continuing through at least 899 ± 29 B.P. (Table 3, DAMS 01778) and possibly through 203 ± 26 B.P. (Table 3, DAMS 01773)

Unit I represents both the youngest and most widespread phase of deposition in Spring Lake, occurring at the top of all 7 cores (Figures 25 and 26). The top three zones of Unit I occur 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, followed by a gray to dark gray sandy loam with reddish-brown oxidized Fe concentrations, and capped by olive brown loamy diatomaceous mats. The lower boundary of Unit I is more ambiguous. ^{14}C ages in Unit I are problematically young with a wood fragment collected just above the contact of Unit I and Unit IV in Core 09 dated at 54 ± 23 B.P. (Table 3, DAMS 001780) and a plant fragment collected in the shelly marker stratum dated at 7 ± 23 B.P. (Table 3, DAMS 001779). ❄

INTERPRETATION

Stratigraphy

The oldest ^{14}C ages of deposition at the San Marcos Springs come from dates of bulk sediment samples. 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.

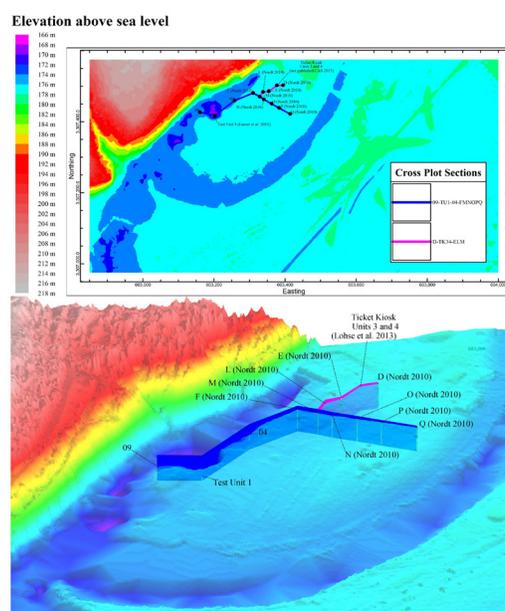


Figure 27: 3-dimensional topographic and bathymetric contour map of Spring Lake showing distribution of cross-plots and cores looking north and vertically exaggerated by a factor of 3.

Excluding the ^{14}C age of bulk 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 a test pit just front of the submarine theater (Leezer et al. 2011). The channel deposits in Core 09 bear a strong resemblance to those excavated at the top of Test Pit 1 by Leezer et al. (2011), and given the proximity (see Figures 24 and 27), it is likely that the deposition of Unit IV began before 11390 ± 50 B.P. (Beta 282624) based on the ^{14}C age of a preserved wood fragment collected from just below the bottom elevation of Core 09 (see Figure 28). 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; these unconformities are suggestive of a period with a high sedimentation rate of deposits eroded from a nearby source. Given the slightly lower elevation of Core 09 from Core 08, floods traveling down

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) 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, we propose an alternative interpretation. Although we 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 during the early Paleoindian period and continued with relatively little truncation through at least the Late Archaic. 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 (see Figure 29).

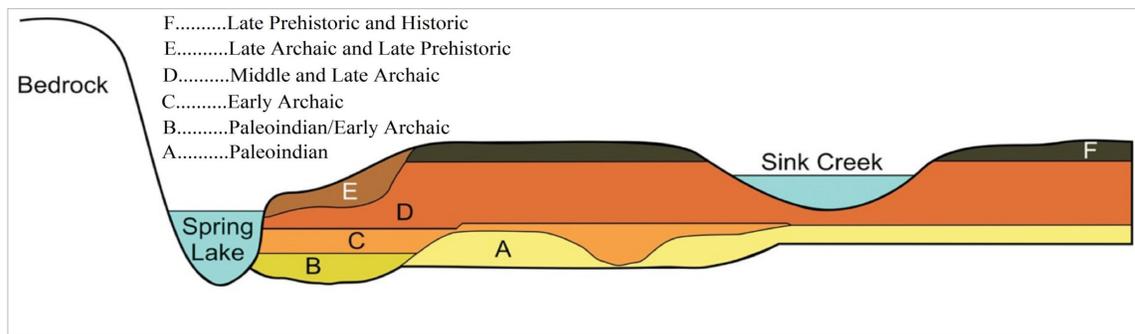


Figure 29: Idealized geologic cross-section of the Sink Creek Valley (modified from Nordt 2010: Figure 6-8).

A Model for Spring Lake Peninsula

The discharges of springheads in the upper headwaters are more dependent on local aquifer flow and are located slightly upgradient from the major orifices of the lower headwaters (see Figure 30) (Musgrove and Crow 2013). It stands to reason that the depositional facies of the upper headwaters (Figure 30) 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-the-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 deposited across the main spring channel by an ephemeral Sink Creek. Over the course of a drought, increased bed load from Sink 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.

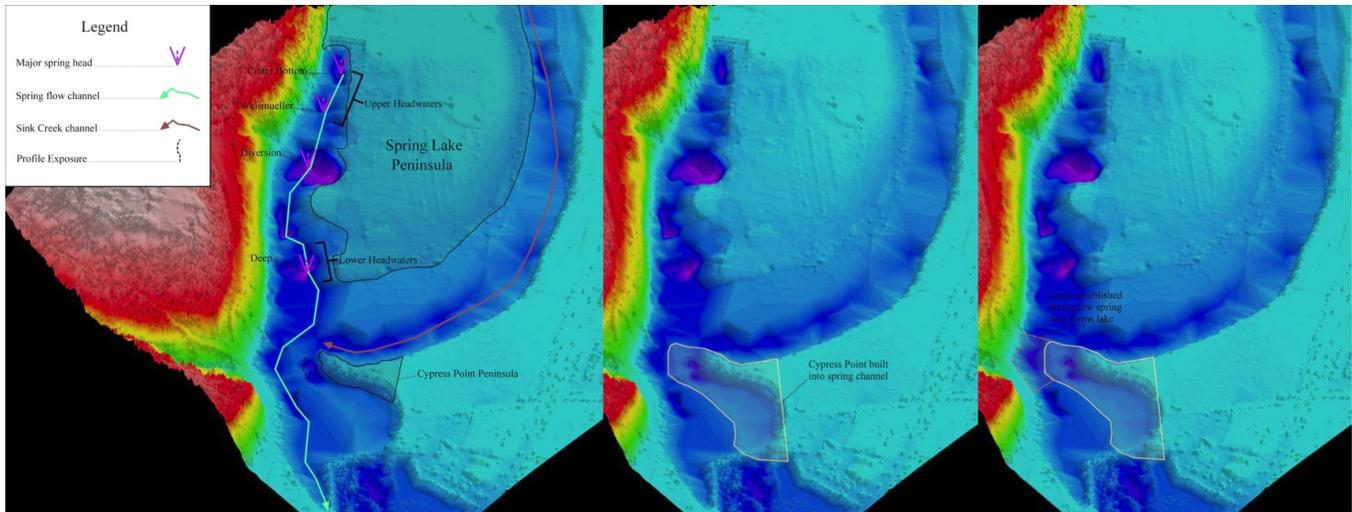


Figure 30: Left - Topographic and bathymetric contour map showing the natural features of Spring Lake. Middle and Right - Progressions showing how the Cypress Point Peninsula could form a levee across the main springs channel.

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 a levee across the main channel (Figure 30). 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. Following 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 (Figure 26).

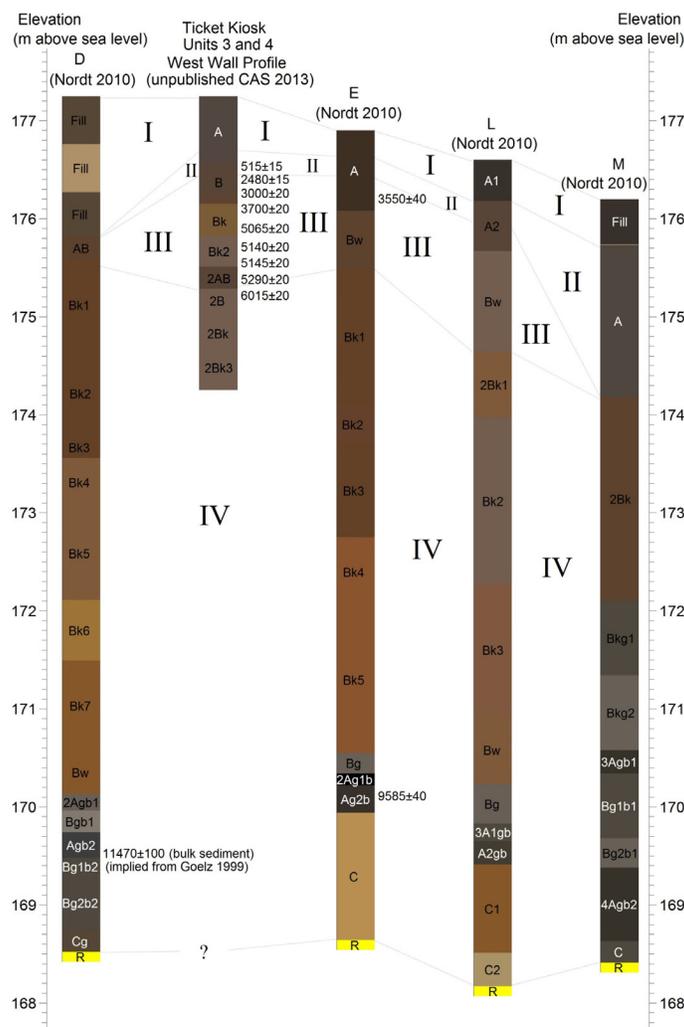


Figure 31: Stratigraphic cross-plot of core D (Nordt 2010), units 3 and 4 (Lohse et al. 2013), and Cores E, L, and M (Nordt 2010) (northeast to southwest) on the Spring Lake Peninsula.

Strengthening an argument for a Paleoindian period construction of Spring Lake Peninsula, the excavation performed by CAS (Lohse et al. 2013) roughly between Nordt's (2010) Cores D and E (Figure 25) demonstrated that in situ deposits dated to 6015 ± 20 B.P. (UCIAMS 111180) existed at an elevation of approximately 175.3 m above sea level (Figure 31). 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 deposition at a relatively high rate of sedimentation from as early as 11390 B.P. until 5900 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 11390 B.P. and 5900 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) Core E, 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 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 problematic and older than expected.

Geoarchaeology

The Sink Creek valley and the San Marcos Springs have been collecting alluvial sediments since the beginning of the Paleoindian period (see Figure 32). Given current dates of charcoal and plant and wood fragments, Unit IV and the Units A, B, C, and most of D identified by Nordt (2010), were deposited from as early as 11390±50 B.P. through at least 5469±30 B.P. at an average rate of at least 1.25 mm/year (see Figure 33). 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 activity was clearly present around the San Marcos Springs. Areas on the upper terraces would have been more attractive locations for Paleoindian occupations; however, the remains of any activity areas which 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.

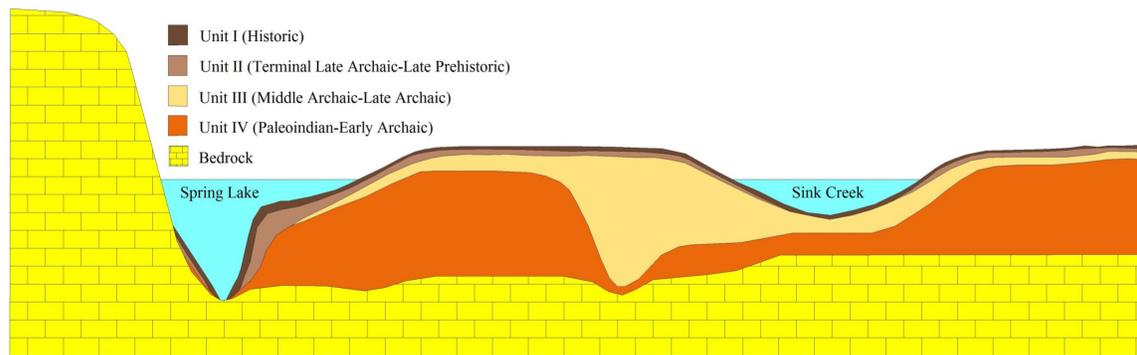


Figure 32: Idealized stratigraphic cross-section of the San Marcos Springs (northwest to southeast across the Spring Lake Peninsula showing modifications to the model presented by Nordt (2010).

Following the Late Pleistocene/Early Holocene emptying of mature soils from the uplands of the Balcones Escarpment, alluvial deposition on the Spring Lake Peninsula slowed considerably. 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.

At some time before 2480±15 B.P. deposition of channel gravels at the mouth of Sink Creek began to extend into the main spring channel. By 1645±25 B.P. the Cypress Point Peninsula had become enough of a levee so as to raise the water level, forming a small lake. Between 1645±25 B.P. and 1414±25 B.P., large amounts of organic material collected in the newly formed lake. 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 to the preservation of terminal Late Archaic organic culture.

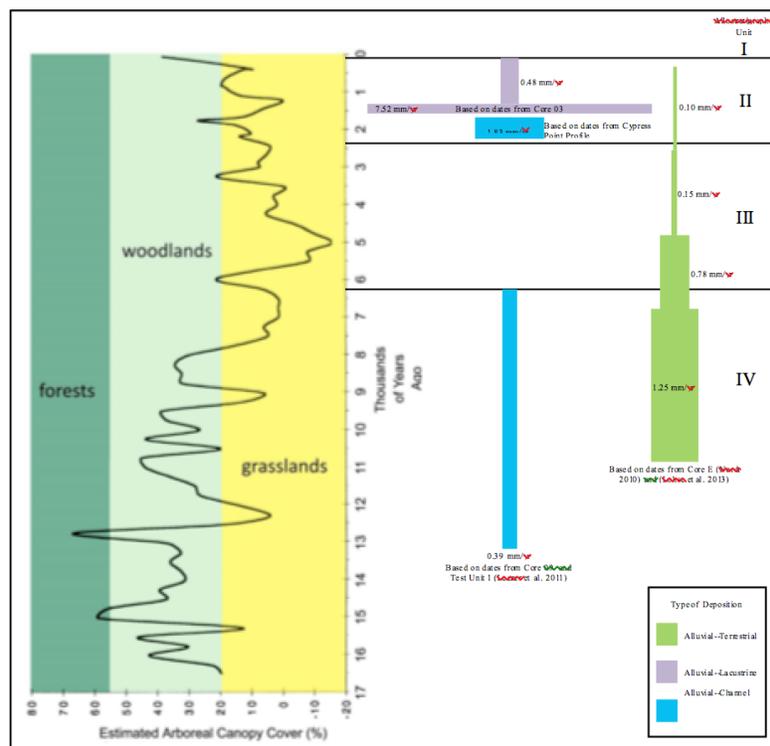


Figure 33: Left - Reconstructed variations in tree cover in east-central Texas (modified from Bousman 1998: Figure 7). Right - Averages rates of aggradation at the San Marcos Springs relative by lateral thickness.

During the Late Prehistoric the rate of deposition around the San Marcos Springs was relatively low leaving at most 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. 🌿

CONCLUSIONS

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 a result, four allostratigraphic units were identified, examined, and dated. The oldest and most substantial deposition in Spring Lake dates from at least as early as 11390 ± 50 B.P (Beta 282624, Leezer et al. 2011). 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 emptying of the Pleistocene soil cover from the Edwards Plateau. If the end of Unit IV deposition is tied more to the exhausting of a sediment source rather than a change in moisture availability to spring-side vegetation, little truncation can be expected close to the springheads. Nordt (2010) has shown that truncation did occur in the middle of Spring Lake Peninsula under the localities of Cores O and N; clearly, given the truncation of bedrock in this area to an elevation near to and possibly lower than the deepest areas of the spring channel, a proto-Sink Creek must have filled in this area and moved outward, 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 3, UCIAMS 95430) and peaking between 1645 ± 25 and 1414 ± 25 B.P. (Table 3, DAMS 001783 and DAMS 001775). Following 1400 B.P., very little sediment was deposited around the San Marcos Springs until the construction of Spring Lake Dam in the mid-19th century.



REFERENCES CITED

- 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.
- 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. B.
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 Burlison Homestead at 41HY37, Hays County, Texas*. Archaeological Studies Report No. 4. Center for Archaeological Studies, Texas State University San Marcos.
- Brune, Gunnar
1975. Major and Historical Springs of Texas. Texas Water Development Board Report 189, p. 94.
- 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.
- 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.
- 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.
2005. *Springs of Texas*, Vol.1 Texas A&M University Press, College Station.
- 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.
- Jones, Brian, Kenton F. Phimester, Ian G. Hunter, and Paul Blanchon
1992. *A Quick, Inexpensive, Self-contained Sediment Coring System for Use Underwater*. Department of Geology, University of Alberta. Edmonton, Alberta T6G 2E3, Canada.
- 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.
- 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].
- 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 H. 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 Archaeology at 41HY147, the Terrace Locality at Spring Lake. Center for Archaeological Studies Report No. 28. Texas State University.

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.

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 Archaeological 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.

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.

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

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.

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.

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.

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

2002. *Field Book for Describing and Sampling Soils, Version 2.0*. 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.

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

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.

