Report on a

Geoarcheological Investigation

at the

Palo Alto Battlefield National Historic Site (41CF92)

Cameron County, Texas

S. Christopher Caran, Samuel D. McCulloch, and Jan Jackson
with contributions by
B.M. Albert, PhD, B.M. Winsborough, PhD, and
Isotope Geochemistry Laboratory of the Illinois State Geological Survey

Submitted To:

National Park Service,
Johnson City, Texas

Report No. 1

January 2005

Samuel D. McCulloch, RPA
Principal Investigator

McCulloch Archeological Services LLC, San Marcos, Texas

Report on a

Geoarcheological Investigation

at the

Palo Alto Battlefield National Historic Site (41CF92)

Cameron County, Texas

S. Christopher Caran, Samuel D. McCulloch, and Jan Jackson
with contributions by
B.M. Albert, PhD, B.M. Winsborough, PhD, and
Isotope Geochemistry Laboratory of the Illinois State Geological Survey

Submitted To:

National Park Service,
Johnson City, Texas

Order No. P73500-40016

Report No. 1

January 2005

Samuel D. McCulloch, RPA
Principal Investigator

McCulloch Archeological Services LLC, San Marcos, Texas

TABLE OF CONTENTS

FIGURES iii
TABLES iv
ABSTRACT v
ACKNOWLEDGMENTS vi
INTRODUCTION 1
PROJECT AREA 4
SCOPE OF WORK 5
NATURAL ENVIRONMENT 7
CULTURAL ENVIRONMENT 15
PREVIOUS INVESTIGATIONS 20
METHODS 21
RESULTS 22
Archival Research 22
Field Research 35
Laboratory Processing 62
INTERPRETATION OF THE NATURAL AND CULTURAL LANDSCAPE 73
Paleoenvironmental Interpretation 73
Landscape Modifications 79
Cultural Remains 87
Role of Palo Alto Resaca in the Battle 87
Significance of the Battle of Palo Alto 90
SUMMARY AND CONCLUSIONS 95
EVALUATION 98
Methods 98
Results 99
RECOMMENDATIONS 100

APPENDICES
A. Pollen Analyses 104
B. Diatom Analyses 110
C. Radiocarbon Assays and Carbon Stable-Isotope Analyses 114
D. Major Storms from 1553 to 2004 118
E. Historical Descriptions of the Natural Environment 125
REFERENCES CITED 129

FIGURES

Number		Page
1	Regional Location Map for Palo Alto Battlefield National Historic Site	2
2	Project Area within Palo Alto Battlefield National Historic Site	3
3	Views of the Project Area: Palo Alto Resaca and Along East Bank	4
4	View of the Project Area: Palo Alto Resaca, Including West Ditch	4
5	Natural and Cultural Features at Time of Battle of Palo Alto	10
6	First Sketch Map of Palo Alto Battle by Berlandier	23
7	Sketch Map of Palo Alto Battle by Lt. Dobbins	25
8	Part of 1934 Aerial Photograph Showing Project Area	29
9	Part of 1950 Aerial Photograph Showing Project Area	31
10	Part of 1962 Aerial Photograph Showing Project Area	31
11	Part of 2000 Aerial Photograph Showing Project Area	35
12	Approximate Locations of Backhoe Trenches Excavated During Current Investigation	41
13	Stratigraphic Cross Section through Palo Alto Resaca	43
14	Stratigraphic Profile Exposed in Backhoe Trench 1 (BHT-1)	46
15	Explanation of Symbols Used in Stratigraphic Profiles	47
16	Stratigraphic Profile Exposed in Backhoe Trench 2 (BHT-2)	51
17	Stratigraphic Cross Section through Earthern Berm ("Levee") on East-Southeastern Side of Palo Alto Resaca in BHT-7	53
18	Stratigraphic Profile Exposed in Backhoe Trench 4 (BHT-4)	57
19	Soil Profiles: BHT-1 and BHT-2	58
20	Soil Profiles: BHT-4 and BHT-7	58
21	Radiocarbon Assays and Stable Carbon-Isotope Analyses	64
22	Pollen Diagram	71
23	Formation of a Resaca	74
24	Various Landscape Modifications to Palo Alto Battlefield Since the Battle	81
25	Landscape Modifications to Palo Alto Battlefield Since the Battle Resulting from Ranching and Farming Activities	82
26	Landscape Modifications to Palo Alto Battlefield Since the Battle Resulting from Controlled Collection of Battle Remains by Metal Detectors	83
27	Sketch of Earthworks Constructed Adjacent to Palo Alto Pond, Adapted from Sketch by Lt. Scarrett	86
28	Map Showing Initial Battle Lines Suggested by Haecker and Mauck (1997)	89
29	Composite of Modern Palo Alto Resaca and First Sketch Map by Berlandier	91
30	Composite of Palo Alto Sketch Map by Captain Henry and Modern Palo Alto Resaca	92
31	Composite of Palo Alto Sketch Map by Stewart and Modern Palo Alto Resaca	93
32	Composite of Palo Alto Sketch Map by Lt. Dobbins and Modern Palo Alto Resaca	94

TABLES

Number		Page
1	Dimension and Location of each Backhoe Trench across Palo Alto Resaca	41
2	Summary of Stratigraphic Profiles Exposed in Backhoe Trenches at Palo Alto Resaca	42
3	Stratigraphic Profile Exposed at the West-Northwestern End of Backhoe Trench 1 (BHT-1)	45
4	Stratigraphic Profile Exposed at the East-Southeastern End of Backhoe Trench 8 (BHT-8)	48
5	Stratigraphic Profile Exposed at the West-Northwestern End of Backhoe Trench 2 (BHT-2)	50
6	Stratigraphic Profile Exposed in the West-Northwestern and East-Southeastern End of Backhoe Trench 7 (BHT-7)	52
7	Stratigraphic Profile Exposed at the West-Northwestern End of Backhoe Trench 4 (BHT-4)	56
8	Results of Radiocarbon Assays and Carbon Stable-Isotope Analyses	63
9	Relative Pollen Percentages from BHT-4	70
10	Legend for Figure 24 and List of Landscape Modifications at Palo Alto Battlefield National Historic Site after the Battle	80

ABSTRACT

Geoarcheological investigation of the Palo Alto Battlefield National Historic Site, Cameron County, Texas, provided a partial history of landscape evolution and paleoenvironment in the lower Rio Grande delta plain. Examination of stratigraphic profiles (≤ 2.5-m depth) within and adjacent to a resaca revealed a nearly 5000-yr record of vegetation types, sedimentation, soil development, and other geomorphic processes. The resaca is an abandoned channel segment of one of many formerly through-going distributary branches of the Rio Grande that spread across the delta. Key elements of the 1846 Battle of Palo Alto were fought along this resaca, which played a strategic role by restricting movement of troops and artillery. Environmental conditions at the time of the battle, and from the middle Holocene to the present, were reconstructed based on geoarcheological, palynological, and historical evidence. In part, these data indicate that land and water use intensified during the late Nineteenth and Twentieth centuries, altering the battlefield significantly. Changes in the landscape over this period were compiled from vintage maps and aerial photographs. This compilation and the paleoenvironmental reconstruction are the basis for a series of recommendations to restore the site to its historical appearance. The scope of the present investigation was, however, modest. Further studies should be modeled after the current assessment, but cover a larger area and provide a longer and more detailed record. In this way, the National Park Service may fully realize its goals of defining the conformation of the site on 8 May, 1846, the date of the battle, and clarifying the relative impress of natural factors and military tactics affecting the outcome.

ACKNOWLEDGMENTS

Sincere appreciation for support is due to the staff of the National Park Service, especially those at the Palo Alto Battlefield National Historic Site, including Dr. Douglas Murphy, Rolando Garza, Karen Weaver, Rafael Munoz, and Corina Argullin. The assistance provided by Rolando in particular was invaluable in conducting both archival research and field work. We owe special thanks to the Superintendent, Ms. Myrna Palfrey-Perez, and the staff of the National Park Service in Brownsville, and to Marsha Wagner, the Contracting Officer, at Johnson City. Thanks are also extended to the staff members of the historic section of the Texas General Land Office, the Texas State Archives and Library, the Hunter Room of the Library at The University of Texas at Brownsville, the library of the Texas Historical Commission, and the Texas Natural Resources Information System. We want to express appreciation for the backhoe support provided by Mr. Juan Pereida and his crew, Mr. Manuel Zermeno, Jr., and Mr. Arturo Campos. The following individuals or institutions performed specialized analyses, the results of which are presented herein: B.M. Albert, pollen; B. M. Winsborough, diatoms; and Illinois State Geological Survey, Isotope Geochemistry Laboratory, radiocarbon assays and carbon stable-isotope analyses.

INTRODUCTION

In April 2004, the National Park Service (NPS) contracted with McCulloch Archeological Services LLC and Quaternary Analysis Laboratories to conduct a geoarcheological investigation at the Palo Alto Battlefield National Historic Site (PAAL[1]) located north of Brownsville, Cameron County, Texas (Figures 1 and 2). PAAL has been recorded as an archeological site (41CF92) at the Texas Archeological Research Laboratory, the University of Texas at Austin. The battlefield was recognized as a National Historic Landmark and received a Centennial Marker from the Texas Historical Commission in 1936 (Steely 1984:32). One of the goals of NPS is restoration of the cultural landscape to resemble that of May 1846, the time of the first battle of the U.S.-Mexican War. The Palo Alto battle consisted of a series of brief, intense engagements among infantry, cavalry, and artillery units of Mexican and United States forces and militias. The battle took place on the Rio Grande delta plain.

In developing their General Management Plan, NPS staff noted that Palo Alto Resaca[2] had a prominent but poorly defined role in the battle since engagements apparently necessitated troop movements on both sides of the Resaca. Whether the condition of the Resaca at the time of the battle influenced troop deployment and possible fortification efforts, or affected the conduct of the battle in other ways was uncertain. NPS also noted that large segments of this Resaca were modified in the 20th century by excavating trenches along both banks, apparently to divert water to various stock tanks (small ponds prividing water to livestock). The method used for trench excavation and the disposition of removed soil were unknown. NPS indicated a need for information on how the Resaca was modified and on other changes that occurred over time. To obtain this information, it was determined that a small section of the Resaca should be studied through geoarcheological investigation. Investigators were requested to begin with the excavation of six to eight backhoe trenches across the Resaca. Assessment of exposed soils in these trenches, aided by various analyses, including radiocarbon dating and pollen studies, was planned to help determine the nature of any site modifications and, if possible, to identify the 1846 ground surface. Archival research was conducted to support interpretation of the collected data. Considerable rainfall during late spring and early summer delayed the fieldwork. With consideration to the oncoming hurricane season, NPS personnel continually monitored the area where trenching was to occur and determined that conditions were suitable in early August. The fieldwork was subsequently accomplished on August 11 and 12, 2004, and the analytical results were received by 22 November 2004. The results of the fieldwork, the archival research, and the special analyses are presented in this report.

[1] PAAL is the official National Park Service code designation for Palo Alto Battlefield National Historic Site.

[2] *Resaca* is a Spanish word that may be translated variously. In southern Texas, this term is used to refer to an abandoned channel segment, forming an elongate, narrow, often sinuous, depression, which may contain water. The resaca on the battlefield is shown on Historic-period maps where it is identified as "*Resaca de Palo Alto.*" Neither that name nor the English version, "Palo Alto Resaca," appears on the topographical map covering this area (Geological Survey 1983). The name Palo Alto Resaca has been used in the archeological literature (e.g., Perttula 1999; Perttula and Nelson 1999) in reference to this feature, and that term will be used in this report without quotation marks.

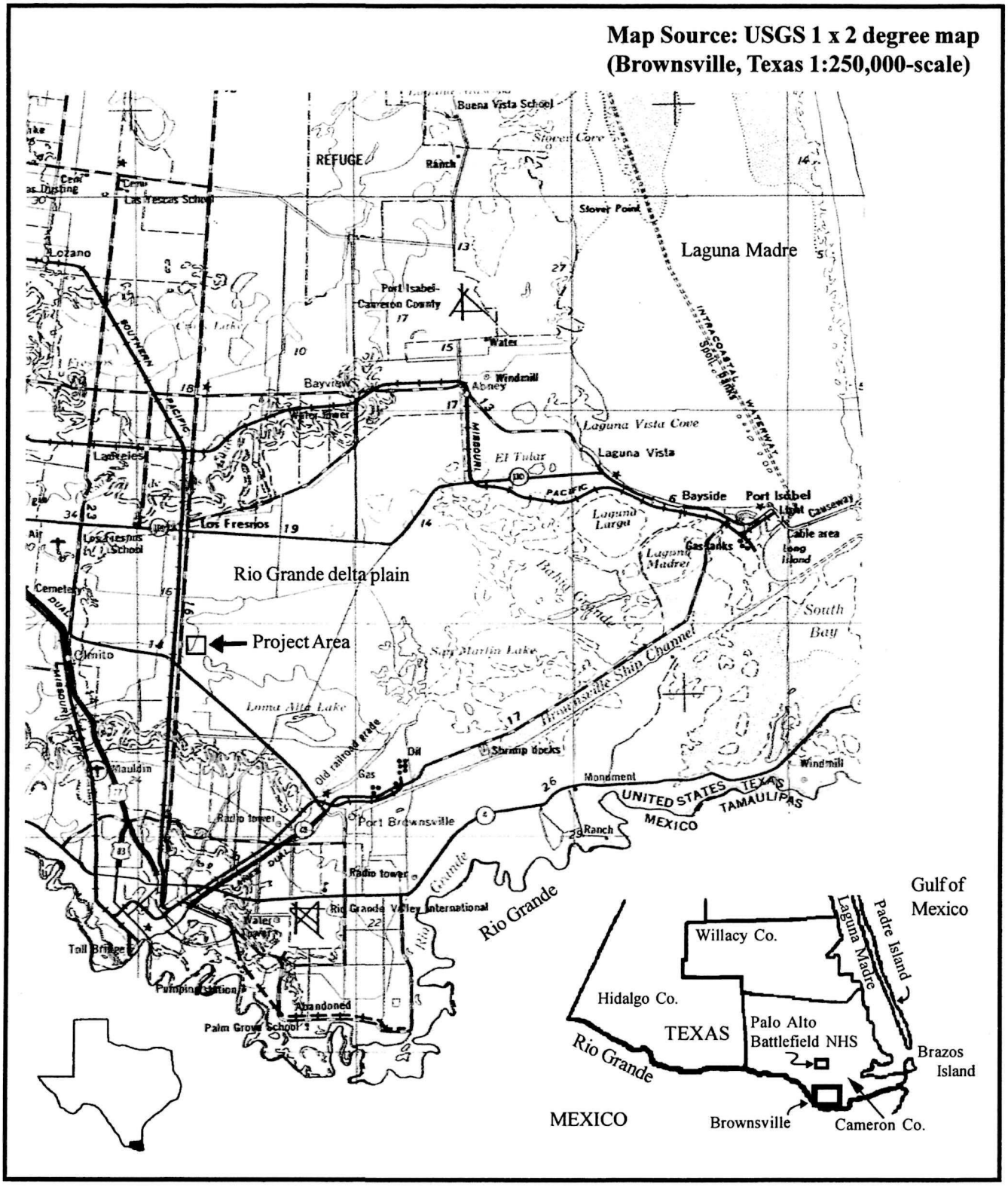


Figure 1. Regional location map for the Palo Alto Battlefield National Historic Site, Cameron County, Texas.

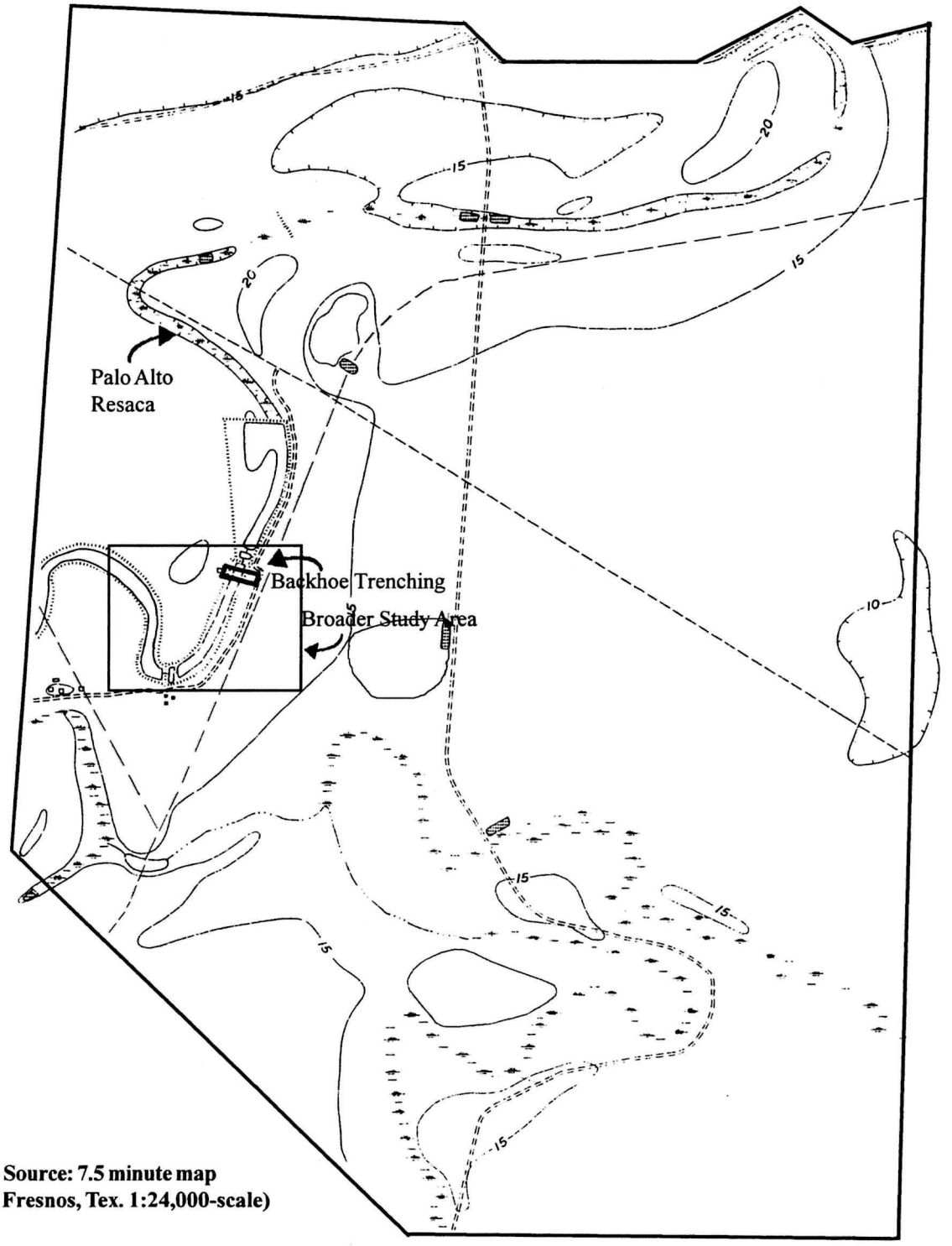


Figure 2. Project area within Palo Alto Battlefield National Historic Site. Field work was conducted within the Palo Alto Resaca, but land-use history and modifications of the landscape were investigated throughout a broader study area. Map perimeter is boundary of Palo Alto Battlefield National Historic Site.

PROJECT AREA

The Palo Alto Battlefield National Historic Site is located approximately 13 km (8 miles) north of Brownsville on a broad, flat prairie that is part of the Gulf Coastal Plain. The battlefield was established as an Historic Site in 1992 with an area of 3,400 acres (1,376 hm^2). The approximate boundary of PAAL is shown in Figure 2. The scope of the current investigation involved three geographic components. All of PAAL was studied in terms of actual battle activities, natural features that played an important role in conducting the battle, and modifications to the landscape that have occurred since the battle. The second component was a relatively broad area selected along Palo Alto Resaca (Resaca de Palo Alto) within which the fieldwork was to be conducted (see Figure 2). Within this area, various elements of the natural environment and modifications to the landscape over time were noted in detail by reviewing aerial photos and maps representing different periods. Consideration of this area provides a better context than would be possible by focusing only on the specific field study area. The third component is the part of Palo Alto Resaca investigated in the field primarily by use of backhoe trenches (see Figure 2). The resaca channel is 56 m (184 feet) wide where the trenching occurred. The upper photo in Figure 3 shows the general area of the resaca facing west from an adjacent road and the lower photo shows the bank of the resaca on the east side. The photo in Figure 4 was taken facing east and shows the resaca channel and an irrigation ditch on the west side of the resaca. The distance across the resaca investigated by backhoe trenching, including the banks and part of the adjacent plain, was 108 m (354 feet).



Figure 3. Above: View of Palo Alto Resaca facing west showing terrain on east side. Below: View of resaca east bank facing north, showing sparse vegetation and open areas.



Figure 4. Facing east, Palo Alto Resaca, with west ditch in lower part of photo.

SCOPE OF WORK

Introduction

The following description served as a statement of the objectives of this project. Among the goals of the National Park Service (NPS) at PAAL is to restore the cultural landscape to an appearance resembling that of May of 1846. The initial focus is on that section of Palo Alto Resaca situated in the western part of the battlefield. The Resaca appears to have played an important role in conducting the battle. Over the years, modifications have been made to the Resaca, apparently to support farming and ranching endeavors. These alterations included excavation of a ditch along each edge of the Resaca. The method of excavation used and the placement of the backdirt are unknown. The specific objectives are to obtain information on the role this Resaca played in the battle, any indication that it was modified during the battle, and how it was modified since the time of the battle. Landscape modifications throughout the battlefield also should be noted.

To address these and related questions, the present investigation will: 1) employ geoarcheological methods to define the nature of the Resaca and its role as a natural barrier during the battle; 2) determine whether the Resaca was deliberately modified before or during the battle; 3) recover and conserve artifacts discovered in the course of the investigation; 4) characterize the historical landscape and local environment; and 5) produce recommendations for restoring the historical appearance and character of the site.

In practice, these objectives will be accomplished by: 1) assessing the geomorphic history of the Resaca, two historically excavated ditches at the Resaca's edges, and two low earthen berms ("levees") adjacent to the ditches, based on the results of field investigations and examination of multiple vintages of aerial photographs and maps; 2) defining the stratigraphy of sedimentary deposits within and near the Resaca; 3) sampling the Resaca deposits for chronological and paleoenvironmental analyses; and 4) using these data to reconstruct surface-water, water-table, and water-quality fluctuations at the site, as well as the flora of this site throughout the period of record.

The scope of work as stipulated by the NPS is summarized below.

Archival Research

1. Conduct a review of historical maps, aerial photographs, publications, and other records that might provide information on the following:
   a. The role of Palo Alto Resaca in relation to the battle.
   b. The landscape and environment that existed at the time of the battle, with particular emphasis on the condition of the Resaca.
   c. Modifications to the landscape that occurred during and since the battle and the locations where these modifications took place.
2. Include in the review those historic cultural materials that exist at NPS in Brownsville, as well as those archived in other locations.

Subsurface Investigations

1. In coordination with NPS personnel, select an appropriate section of the Resaca for place ment of backhoe trenches.
2. Excavate a series of six to eight trenches, each five meters in length, distributed over the 100 meter-area so that the Resaca channel and the adjacent banks are represented. Coring could be substituted for some of the trenches, but a minimum of three trenches are to be excavated to validate the coring data, and two of the trenches would need to be placed on each of the Resaca banks.

3. Excavate each trench to a depth of at least five ft (1.5 m) across the length of the trench, and excavate several sections deeper to allow examination of earlier deposits.

4. Prepare a profile of a section of each trench in sufficient detail to allow an interpretation of landscape development in that area. Soil and sediment profile descriptions should use standard Natural Resource Conservation Service and U.S. Geological Survey terminology.

5. Collect one or more samples of bulk soil from the profile for dating, with at least one sample obtained from the Resaca fill and another from either deeper fill or the undisturbed bank sediments. Samples should also be collected from the channel and bank sediments for macrobotanical, pollen, diatom, and/or isotope analysis to aid in determining the potential for environmental reconstruction.

6. Conduct the field activities according to guidelines provided by NPS, including collection and control of recovered artifacts and documentation of fieldwork.

Laboratory Procedures

1. Use standard conservation and stabilization practices for treatment and handling of any recovered artifacts.

2. Catalog all recovered artifacts in accordance with procedures provided by NPS.

3. Conduct an analysis of collected artifacts as prescribed by NPS.

Reporting

1. Provide to NPS for review and approval five draft copies of a brief summary of the results upon completion of the field investigation.

2. Provide five copies to NPS of the approved summary of investigation.

3. Prepare and submit for review and approval five draft copies of a technical report, and a machine-readable copy on Compact Disc media, that contains the following:

a. Descriptions of trench profiles.

b. Reconstruction of area landform development. The reconstruction should indicate resaca filling, location of the original bank, age of sediments, and the mid-nineteenth century condition, to the extent possible.

c. Conclusions regarding the potential impacts, adverse or otherwise, that resaca restoration in this area might have, including possible damage to cultural resources.

d. Recommendations on the best method for restoring the resaca, including future studies that should be undertaken.

4. Present the data to NPS in a format acceptable for submission to the Texas Historical Commission as a part of archeological compliance related to disturbances caused by the resaca restoration project.

5. Provide 25 copies of the final approved technical report to NPS for distribution and a machine-readable copy on Compact Disc media.

6. Provide all drawings in an acceptable electronic Computer Aided Design (CAD) format, or other acceptable digital format.

Curation

1. Deliver all original notes, photographs, drawings, and other project documentation and all recovered artifacts directly to the NPS, unless directed otherwise, and in a form suitable for long-term archival storage as prescribed by NPS .

2. Provide a separate database containing artifact information as prescribed by NPS.

NATURAL ENVIRONMENT

The Regional Setting

The project area is located in the natural region identified by Johnson (1931:133) as the Texas Gulf Coastal Plain. Within this broad classification, the project area is situated in the Lower Rio Grande Valley (ibid.:139). Hatch, Gandhi, and Brown (1990:2, 11) include the area in the Gulf Prairies and Marshes Vegetation Area, specifically within the Gulf Prairies zone, consisting of a nearly flat plain extending inland from the marshes, bays, and estuaries that occur along the coast (ibid.:11). The original vegetation of the Gulf Prairies was a tall grass prairie and post oak savannah (ibid.). Blair (1950:98, 102) places this part of Texas in the Tamaulipan Biotic Province, a moisture-deficient region that extends northward to the Balcones Fault Zone and southward well into Mexico. The climate is classified as semiarid subtropical with warm to hot summers (Griffiths and Bryan 1987:16). The Rio Grande, located to the south, is the only major stream in the region. However, numerous resacas (oxbow lakes, when they contain standing water) are situated throughout the region. The land on which the project area is situated is identified on historical maps as the plain or prairie of Palo Alto (see, for example, Berlandier's map later in this report).

The Prehistoric Environment

The following discussion provides a broad environmental context for some deeper soils and sediments examined in backhoe trenches excavated during this limited investigation. The discussion provides a foundation for future investigations at PAAL where these older deposits are encountered. Information regarding the paleoenvironment was obtained from archeological investigations, geomorphological and pollen studies, and other sources, and a general outline was developed that presents the environmental situation to which South Texas inhabitants adapted over the past 12,000 years or more.

Climate - The climate of the Holocene appears to have changed gradually from the more mesic conditions at the end of the Pleistocene to the semi-arid conditions of the present. However, there have been numerous fluctuations in this general trend including wet and dry and warm and cold periods which may have lasted up to hundreds of years (cf. Boyd and Perttula 2000:15-16). Butzer (1982:23-27) describes these as superimposed variations in climate having different orders of intensity and duration, and Norwine (1978:12) characterizes the climate as consisting of "cycles on cycles on cycles." Norwine states further (ibid.:12-13) that there have been six to eight distinct climatic stages since the last glacial epoch.

In reviewing data on the paleoenvironment of South Texas, as elsewhere, the different orders of variation should be kept in mind, especially with regard to the sources of data used in environmental interpretations. Inferences drawn from two or more paleoenvironmental indicators may differ, resulting in inconsistencies in the environmental reconstruction. Some indicators, such as soil erosion or deposition, may exhibit quick responses to environmental change. On the other hand, movement of some faunal species to warmer or cooler environments may have been delayed through temporarily successful adaptions within local habitats. In the 1998 volume of *Plains Anthropologist*, journal of the Plains Anthropological Society, Bousman and Brown (1998) introduced a series of papers selected from several presented at an earlier symposium on paleoclimatic research in Texas. In one, Caran (1998) discusses factors to be considered when attempting to reconstruct the paleoenvironment. He notes the need to establish controls over the data being considered, including stratigraphic context, chronology, and various biases which might be inherent in the data.

Examples of suggested climatic changes from earlier studies include the long drought or Altithermal period, from 7500 to 4000 B.P. (5550 to 2050 B.C.; Early to Middle Archaic), proposed by Antevs (1955), and a brief mesic period from 3000 to 2000 B.P. (1050 to 50 B.C.; late Middle Archaic to Late Archaic) documented for West Texas by Baker and Penteado-Orellana (1977).

Unfortunately, these studies were conducted with little or no chronological control. More recent studies tend to support or refine some of the suggested climatic changes and to indicate other periods of climate variation. For example, pollen data from a bog in Central Texas suggests a long dry period from about 7500 to 3500 BP. that might be a local reflection of the Altithermal (Bousman 1998:210). Ricklis and Cox (1998:132-133) report that stratigraphic and mollusk evidence indicates a warming and drying trend in the early Holocene until sometime between 5000 and 3000 B.P. followed by a cooler, more mesic period. Further study of climate change during these years is clearly needed; however, using chronologically controlled paleoenvironmental data with consideration to other factors, changes of varying duration within an overall warming and drying climate seem evident throughout the period since the end of the Pleistocene.

Hydrology - Investigations of the Late Quaternary hydrology of the lower Rio Grande valley have addressed coastal processes, ground water, and riverine flooding. During the Wisconsin glacial maximum, 18,000 BP, sea level along the Texas coast was 130 m below present mean sea level (MSL), but rose quickly as the continental glaciers melted, reaching MSL by the middle Holocene, about 5300 BP (Paine 1991). As sea level rose during this period, the seaward portion of the ancestral Rio Grande delta was progressively drowned. Lohse (1958) described the Holocene evolution of the present delta, concluding that the main flow axis of the Rio Grande had shifted repeatedly, crossing the entire delta plain. Pryor et al. (1975) stated that the river delta's distributary channel system has operated for the past 5000 to 7000 years. Brown et al. (1980) presented an extensive review of the coastal and deltaic environment and the dominant processes operating there, but provided only a general chronology of events. Records pertaining to tropical storms, hurricanes, and major floods of the historic past were compiled from multiple sources for the present investigation (see Appendix D). Baker (1965) assembled data regarding groundwater conditions (local water-table elevations and water quality) on the U.S. side of the border. The principal near-surface aquifers are Pleistocene and Holocene fluvial-deltaic and delta-plain deposits.

Vegetation - Studies such as those by Bryant and Shafer (1977) and Bryant and Holloway (1985) indicate forest cover vegetation in South Texas prior to 10,000 B.P. The forest gradually changed to a mixed grassland and savannah climax vegetation, with a continued presence of dense arboreal species along stream borders (ibid.). This distribution apparently persisted until early Historic times, with several possible periods of change from woodlands to grasslands and back within this longer period.

Fauna - Among paleofauna changes especially significant for archeological studies, apart from the loss of megafauna toward the end of the Pleistocene, is the presence of bison at varying times during the Late Pleistocene and the Holocene. For example, Huebner (1991:351-353) reviewed several lines of evidence that indicated a climate change about 1000 B.P. (A.D. 950) toward more arid conditions, with an increase in short grasses over the previous tall grasses and arboreal species. Tall grasses were a favorable food source for bison, which moved into South Texas a short time later.

The Early Historic Environment

Climate - The general trend in South Texas climate during the Holocene was toward conditions prevalent today, but there apparently were a number of transitory and minor fluctuations, as noted above, including the period from about 1550 to around 1850, known as the Little Ice Age (Norwine 1978:12; see also Schneider and Londer [1984:114-117]). Others have suggested that the Little Ice Age began somewhat sooner, lasting from A.D. 1300 to about 1850 (Fagan 2000). The Little Ice Age represented a time of somewhat colder and wetter conditions than shortly before or after that period, and may have had an important effect on vegetation, fauna, and human inhabitants, especially in regions such as South Texas (Foster 1995:10, 228). Many early traveler's accounts mention considerable amounts of rainfall, often resulting in swollen rivers, and, at times, large amounts of snow with much colder temperatures than normal.

The following account may be associated with the Little Ice Age or may be an anomaly in the usual weather pattern, or may result from some variable such as high elevation. José Enrique de la Peña, in northern Mexico while en route to the Alamo in February 1836, stated that the rain turned to snow one evening and, by dawn, was knee-deep (Peña 1975:26-28). The snow continued, although more lightly, until the following late afternoon (ibid.:28). On the other hand, in their discussion of South Texas droughts during the past few centuries, Boyd and Perttula (2000:16) reference studies of tree rings and other data sources showing several periods of little moisture and warmer temperatures alternating with colder, wetter years. Thus, even the early Historic period is represented by cyclic or at least variable climate patterns. The Palo Alto battle occurred in 1846, at the end of this fluctuating climatic period. Haecker and Mauck (1997:29) note there had been heavy rains just before the battle. These might have been an expression of the period of changing climate, or simply a heavy rain such as still occurs there periodically.

Landscape - Several maps of PAAL and surrounding area from 1846 provide information on the landscape of that time (see also, Appendix E). Prominent natural features common to most of these maps included Palo Alto Pond, Palo Alto Resaca, a large circular depression within the battlefield usually identified as a marsh area, and several small hills along the southeast edge of the battlefield (see Figure 5). The most prominent cultural feature is the road leading north to Point (Port) Isabel and south to Matamoros, Mexico. Usually two branches were shown off this road. One southwest of the battlefield extends toward the northwest, identified as the road to Point Isabel during the rainy season. The other road is north of the battlefield and branches northwest, usually unidentified but in one case given as the road to San Antonio. A map in Baxter and Killen (1976:Figure 1) shows both these roads connecting to a generally east-west road leading eastward to Point Isabel and west, probably to San Antonio, after turning northward.

Flora - South Texas vegetation at the time of European contact was apparently an upland grassland savannah with occasional mottes of trees, and streams bordered by a dense growth of trees and shrubs (Appendix E). The extent of the grasslands seems to be indicated by Weniger (1984a:188) in an account by William McClintock in 1846 of a grass fire, probably somewhere in Starr County, resulting in blackened stretches of 20 or 30 miles. Although this report is up river of the current project area, it seems to refer to the year of the Palo Alto battle as a dry period for the general area. However, as noted previously, Haecker and Mauck (1997:29) state there had been heavy rains just before the battle, May 8, 1846 (see also Weaver 1999:23). According to Abbe Domenech, 1851, the route from Isabella Point (Point Isabel) to Brownsville follows the bay for some distance and then "turning to the left it enters a vast marshy plain, indented with natural salt-pits", which joins with Palo Alto toward the northwest extremity where the battle took place (Weniger 1984:27). During the same trip, in what is now Cameron County, the Abbe Domenech also reported passing over "glades and prairies" where the ground was so soft it could cause men and horses to sink and disappear, also referred to as "shaking prairies" (ibid.:11). The location within the County was not given. Weniger questions whether this might have been a fine sandy soil that could form something like quicksand after rains, or if it could refer to "old *resacas* so choked with partly decayed plant material that horse and rider could sunk into them?" (ibid.). Weaver (1999:2) notes that historical descriptions of the battlefield show it covered with "high, spiky grass", probably *Spartina spartinae*, known locally as sacatal or sacahuistle. Sometimes referred to as Gulf Cordgrass, this grass grows best on moist, clay soils located on coastal flats and brackish marshes (Hatch and Pluhar 1993:87). Accounts from participants in the battle indicated the grass was several feet high (Weaver 1999:24).

For various reasons, including the Spanish introduction of cattle, sheep, and goats into the region, vegetation changed to the mesquite shrubland found in South Texas today. As an example of the amount of livestock in one area, Chipman (1992:169) references an inspection trip to Camargo (in Tamaulipas, Mexico, across from Rio Grande City) by José Tienda de Cuervo in 1757, where he found 17 ranches within a five league radius containing an estimated 6,500 horses, 2,600 cattle, and 72,000 sheep.

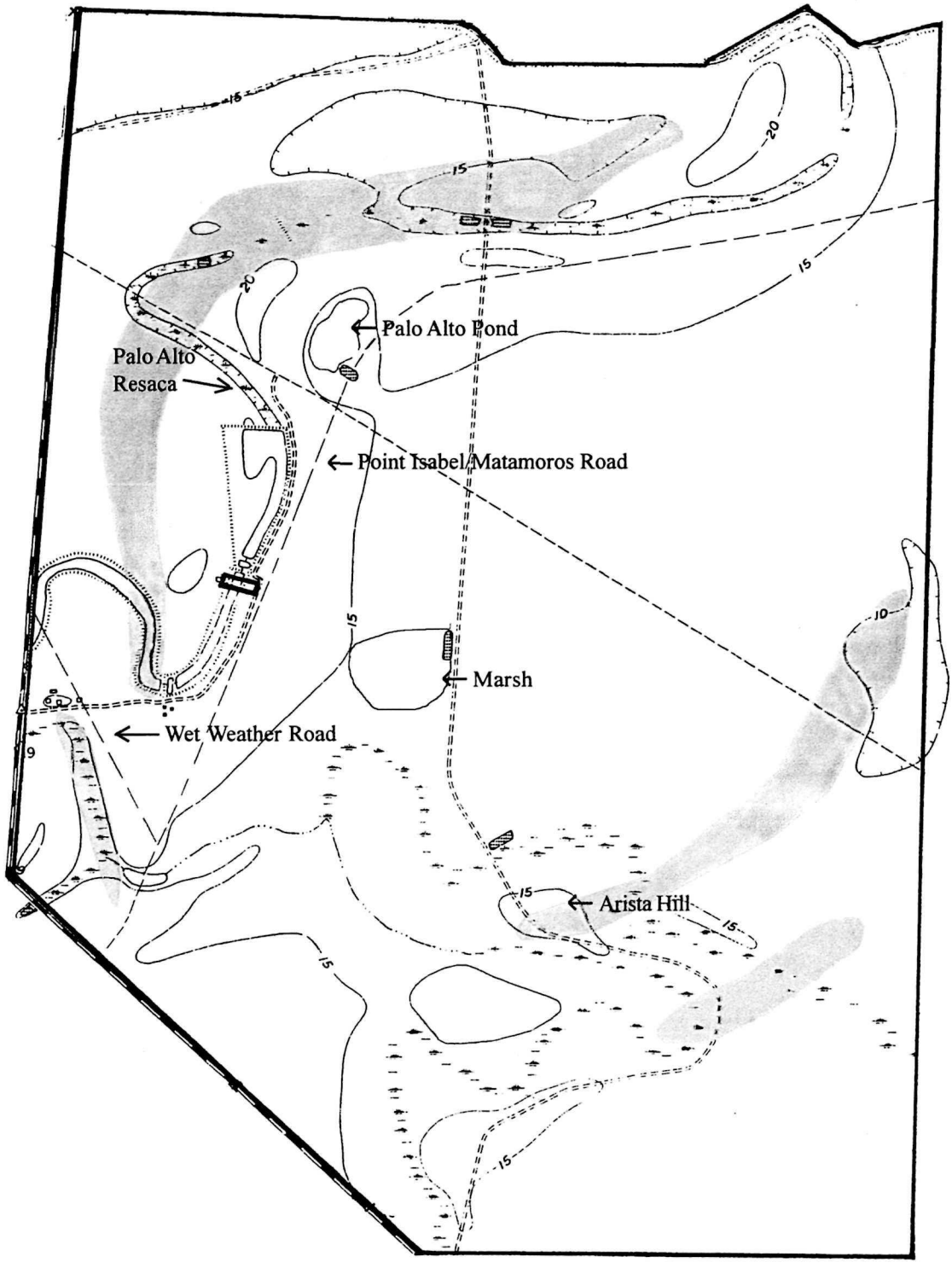


Figure 5. Prominent natural and cultural features noted on historical maps of the Palo Alto battle. Location of woods (shaded areas) varied among maps of the battlefield. Those depicted here were adapted from the map by Henry (see Figure 30).

One of these ranches extended into Texas and contained thousands of stock. As a result of this intensive overgrazing and probably other factors, various woody species and cactus species entered the area or expanded their range at the expense of grassland plants. Many of the plant species found in the region during the early Historic period provided a source of food for local populations. According to Salinas (1990:117), the three plants used most often by Historic Native Americans were prickly pear, for their fruits; mesquite, for the beans; and maguey, for the root crowns.

Fauna - Pronghorn and some deer, and, at least at times, bison were among the larger game animals of the upland grassland (Bailey 1905:62-63, 67-70; see also, Schmidly 2002:Figure 10). Schmidly (2004:277) states that, in southern Texas, the diet of the white-tailed deer consists mainly of browse species, although their food source varies depending on locale, and their home range is relatively small. Consequently, unless their diet changed, deer may not have been numerous as they are today, except near streams where more arboreal species of vegetation would have been found. In his review of documents dating from 1519 to 1886, Salinas (1990:115) indicates that nearly all recorded lists of animals hunted by Native Americans include deer, but bison were rarely seen south of the Rio Grande and east of the State of Coahuila. However, according to Foster (1995:236-237) early Spanish *entradas* through present day northern Mexico and Texas describe large bison herds ranging south of the Rio Grande (in northern Coahuila and Nuevo León) in the late 1500s. By the end of that century, the bison had been decimated by Spanish settlers. Henceforth, most accounts describe bison being found only north of the Rio Grande (see also, Weniger 1997:16-18). Hester (1980:42-44) notes that some Native American groups crossed the river northward into South Texas to hunt bison. In 1897, antelope were reportedly observed as far south as the mouth of the Rio Grande (ibid.:43). Pronghorn were found on the South Texas Plains until about 1903 (Hester 1989a:3). Additions to the regional fauna in recent times, possibly during the Historic period, include the collared peccary. Salinas (1990:115-116) indicates that peccary was widely hunted by Historic Native Americans.

The Modern Environment

Climate - Based on data from a station in Brownsville, 1951 to 1980, Griffiths and Bryan (1987:83-84) show the mean monthly precipitation rate for Cameron County as highest in September (5.2 inches; 13.2 cm) and lowest in December (1.2 inches; 3.0 cm), with a total annual average of 25.4 inches (64.5 cm). The mean monthly precipitation in May (the month the Palo Alto battle took place) is 2.2 inches (5.6 cm). The greatest monthly total from 1871 to 1980 was in September 1886 with 30.57 inches (77.6 cm), and the record annual high was 60.06 inches (152.6 cm) from that same year (ibid.). Using data from 1950-1979, Larkin and Bomar (1983:53-66) report the average monthly gross lake surface evaporation rate as lowest in January (2.5 inches; 6.4 cm) and highest in July and August (8.25 inches; 21.0 cm) with an annual average evaporation rate of 61 inches (155.0 cm), a deficit of 36 inches (91.4 cm) over the annual mean precipitation rate.

Data from 1951 to 1980 give the lowest mean monthly temperature as 60° F (15.7° C) in January and the highest as 84° F (29.1° C) in July and August (Griffiths and Bryan 1987:84).

Average wind direction and speed at Brownsville for the period 1961 to 1980 were compiled as wind roses for the four seasons by Larkin and Bomar (1983:82-85). In winter, the winds blew more frequently from the south and north-northwest, with wind speeds sometimes exceeding 21 miles per hour (34 km per hour). Little wind blew from the west and southwest. In spring and summer, most winds blew from south, south-southeast, and southeast. Higher wind speeds often exceeded 21 miles per hour (34 km per hour) during these months but with a smaller percent of the time from the southeast. In autumn, the wind directions were distributed more evenly from south, east, and north, with little from the west and southwest. Higher wind speeds, greater than 21 miles per hour (34 km per hour), were from the south and south-southeast, but occurred less frequently than in the other seasons.

Geology - The surface deposits in most of the Rio Grande delta plain are mapped as Holocene floodplain deposits (Brewton et al. 1976). Those adjacent to the resacas in the battlefield area are classified as predominantly silt and sand, and the resaca channels as predominantly mud (ibid.). The segment of Palo Alto Resaca where the current fieldwork was conducted is shown under water on the geologic map. Details of the surface and subsurface soils and sediments exposed in backhoe trenches are presented later in this report.

Geomorphology - Although not named on the USGS topographic map (Geological Survey 1983), the 1846 battlefield is identified as the "Plan de Palo Alto" on the first of two sketches prepared by Jean Louis Berlandier (discussed later in this report). The plain or prairie of Palo Alto apparently derived its name from stands of mesquite that, intermingled with patches of open area, extended southward toward the Rio Grande (Haecker 1994:23). The battle took place on this grassy plain about two miles in diameter with scattered hills and irregularly-shaped depressions (ibid.). A series of resacas are a dominant feature of this area. The resacas and depressions are often moist and sometimes contain standing water. Figures 3 and 4 show the part of Palo Alto Resaca and adjacent terrain where the current fieldwork was conducted. The landscape will be discussed in more detail later in this report.

Soils - Three sources of information were considered regarding soils in the project area: the Soil Survey of Cameron County (Williams et al. 1977), data from groundwater monitoring wells in the immediate vicinity (Lantz 2003; see Figure 12 of this report), and the results obtained from examining the profiles of backhoe trenches excavated during the current project. The County soils report presents a general description of soil types throughout the area. This information is intended to support a variety of land uses, but these are not always sufficiently detailed for describing specific locations. Soil descriptions from the current fieldwork will be presented later in this report.

Data from monitoring wells were obtained from the upper 8 feet (2.4 m) within the channel bed except for one which included the upper 18 feet (5.5 m). Those located along the adjacent banks/levees documented soils in the upper 12 feet (3.7 m), with the exception of one which extended to a depth of 15 feet (4.6 m). Throughout the channel bed the soils were described as silty clay at the surface. Below this was a sandy clay, over a silty clay. The deeper well in the channel encountered a clayey sand at 17.5 feet (5.3 m) below surface. Along the banks of the resaca, the upper soils were silty mostly clay above clay, then silty clay, and finally a clayey sand. The reddish brown clayey sand was encountered in both banks between 9.5 feet (2.9 m) and 11.5 feet (3.5 m) below surface. A similar soil was found in the deeper well within the resaca at 17.5 feet (5.3 m). In two of the wells along the east bank of the resaca, sandstone fragments were reported: in one well at a depth of 10 feet (3.0 m) below surface, and in the other at depths of 5.5 feet (1.7 m) and 7.5 feet (2.3 m) below surface. The origin of these is not clear but they may be sandy clay aggregates rather than sandstone rock fragments or cultural remains.

Hydrology - A number of irregular depressions and linear resaca channels throughout PAAL are or were essentially marshes during wet weather; however, there are no regularly through-flowing streams in the area. The section of Palo Alto Resaca where the current fieldwork was conducted was dry and sufficiently firm to allow a backhoe to traverse the channel without difficulty. As discussed later in this report, the present investigation has disclosed evidence regarding the hydrology of the resaca in Historic times, including the time of the battle. Haecker (1994:23) indicates there had been heavy rains just before the battle that left the depressions and resacas with either standing water or in a marshy condition. Historical maps show an alternate "wet weather" road apparently used when the road through the battlefield area was difficult to use. This indicates that wet weather was a well-known occurrence in this area at certain times of the year.

Topography - The 7.5-minute map, Los Fresnos, published by the U.S. Geological Survey with a contour interval of 5 feet (1.5 m), indicates that the topography was obtained by plane table surveys in 1930 and may not reflect land surface modifications that have occurred since that time. Much of the area within PAAL is essentially level, but higher elevations range from 10 to 15 feet (3.0 to 4.6 m) Above Mean Sea Level (AMSL). These elevations increase toward the west and northwest, in places to 20 feet (6.1 m) AMSL or more, with a decrease in the vicinity of the resacas. Overall elevations on the plain range from 8 to 20 feet (2.4 to 6.1 m) AMSL (Haecker and Mauck 1997:105; Weaver 1999:3). Measurements made in the field during the current project show the difference in elevation between the Palo Alto Resaca channel and the adjacent bank on the east side is about 1.6 feet (0.5 m). Scattered throughout PAAL are small hills with higher elevations ranging mostly between 15 and 20 feet (4.6-6.1 m) AMSL, including Arista Hill toward the south which is prominent on some of the historical maps and was significant in conducting the battle. At least two hills toward the north probably exceed 20 feet (6.1 m) AMSL. In addition to the resacas, there are several depressions within the area which exhibit a marsh condition and may contain water during rainy periods. One of these, Palo Alto Pond, is located toward the north and served a prominent role in the battle as a water source for the U.S. forces (see Figure 5).

Flora - Weaver (1999:10) identifies several vegetation communities in or near the battlefield that vary in location according to the landscape features. Most of the battlefield is grassland, consisting of sacatal (or Gulf cordgrass; *Spartina spartinae*) and other species; vegetation within Palo Alto Resaca is mostly Bushy-Sea-Ox-Eye (*Borrichia frutescens*); honey mesquite (*Prosopis glandulosa* var. *glandulosa*) occurs naturally on plains and prairies but also in disturbed areas; and a brushland community exists on elevated areas (ibid.). Brushland community species listed by Richard and Richardson (1993:8-10) include honey mesquite, spiny hackberry (*Celtis pallida*), Texas prickly pear (*Opuntia engelmannii*), and horse crippler (*Echinocactus texensis*). During the current field work, mesquite was observed growing along the banks of Palo Alto Resaca, whereas prickly pear (*Opuntia engelmannii*) and other cactus species were noted on the adjacent prairie to the east. According to Richard and Richardson (ibid.:7), brush species that occupy areas such as the low hills southeast of the battlefield most likely have changed little since 1846. However, as discussed later in this report, various factors, mostly anthropogenic, have altered the vegetation in several areas of PAAL. These factors include planting by ranchers (ibid.:31) of several introduced species among which are Johnson grass (*Sorghum halepense*) and buffelgrass (*Cenchrus ciliaris*). Details regarding the plant species found on PAAL are provided by Weaver (1999) and by Richard and Richardson (1993).

Fauna - Distribution of faunal species varies with the vegetation communities providing cover and food sources. Richard and Richardson (1993:18-29) discuss the ecology. Brushland areas contain various herbivores, such as the Eastern cottontail (*Sylvilagus floridanus*) and the southern plains wood rat (*Neotoma micropus*), which in turn serve as food sources for predators such as the bobcat (*Lynx rufus*) and coyote (*Canis latrans*). Prairie occupants observed during the current field work include the black-tailed jackrabbit (*Lepus californicus*), the Texas horned lizard (*Phrynosoma cornutum*), and a variety of bird species, including the bobwhite (*Colinus virginianus*). Animal species observed in the Resaca were the fiddler crab (*Uca subcylindrica*) and the Rio Grande leopard frog (*Rana berlandieri*). Among introduced species in the area, according to the National Park Service staff, are feral hogs (*Sus scrofa*) and nilgai (*Boselaphus tragocamelus*), a species of antelope native of India and Pakistan (Schmidly 2004:283).

Landscape Modifications - Changes to the battlefield and surrounding area since the battle include construction of three small earthworks the day after the battle to protect the wagon train, later use of the area for cattle ranching and farming, excavation of stock ponds, construction of dams across the resaca, relic collecting and possibly even backhoe trenching for treasure, systematic cultural resources investigations using metal detectors that resulted in removal of battlefield artifacts, and construction of buildings. Backhoe excavations for this investigation also modified the landscape, but these effects are localized and temporary. The stratigraphic sequence within the trenches was, however, permanently altered by excavation and refilling. Details regarding these and other changes in the landscape are presented later in the report.

CULTURAL ENVIRONMENT

In terms of cultural remains, the primary focus of this investigation is the 1846 battle. One of the goals of the National Park Service is to restore the landscape to resemble that which existed during the battle. To achieve this, the objectives include environmental reconstruction and removal of earthen mounds and/or backdirt from excavations that postdate the battle. Associated with this process is the potential for encountering cultural materials from the battle, but also from earlier human activities in that same area. The following discussion provides an overview of both the prehistoric and early historic cultural periods that have been defined for South Texas through previous investigations. A brief review of the 1846 battle is also presented, with emphasis on how various natural features influenced the battle, especially the resaca studied during the current investigation.

The cultural chronology for South Texas is separated into the Paleoindian, Archaic, Late Prehistoric, Protohistoric, Historic, and Modern periods. The earlier periods are summarized in some detail by Black (1989:48-57) and Hester (1995a). Ricklis (1995) provides an overview of the prehistory of the lower Texas Coast. Hester (1980:38-56; 1989b:77-84) and Salinas (1990) provide information on the Historic Native American populations of South Texas, and Fox (1989:85-91) summarizes the Historic Anglo-European exploration and colonization of southern Texas.

Paleoindian period - The Paleoindian period is currently considered to range from about 9200 B.C. to 6000 B.C. (Turner and Hester 1999:51-65) Fluted lanceolate projectile points, including *Clovis* and *Folsom*, are associated with the earlier part, while non-fluted lanceolate points, such as *Angostura*, are found in the later part of the period. Although their presence in the Rio Grande delta-plain region is not yet well documented, the human population in South Texas is thought to have been sparse during this period, operating in small bands over extensive territories (Black 1989:48). These groups in South Texas may have hunted large animal herds as a primary food source, but a strong reliance on a variety of animal resources is likely during later times. Plant resources probably were important, but evidence of their use at this time is not yet demonstrated. Archeological sites along the South Texas Coast dating to this period are likely to reflect an inland rather than a coastal adaptation, considering the location of the coastline at that time and the subsequent rise in sea level. These factors would place the Paleoindian-age coastal sites in offshore sediments.

Archaic period - The Archaic period, from 6000 B.C to A.D. 800, is generally separated into three chronological stages: Early (6000 B.C. to 2500 B.C.), Middle (2500 B.C. to 400 B.C.), and Late (400 B.C. to A.D. 800). A shift in technology with a change from the lanceolate projectile points to stemmed Archaic dart points is evident during the transition from the Paleoindian period to the Archaic. A variety of dart points used for hunting and tools associated with plant processing, including manos and metates, are found at archeological sites from this period. Very few dart point styles are associated specifically with the Early Archaic in South Texas. Black (1989:49) states that sites dating to this period are not known from the delta area of the Rio Grande. Turner and Hester (1999:68), however, indicate that the *Abasolo* dart point has been recovered in this region, and they date that point type to the Early to Middle Archaic. Several later dart point styles and other time-diagnostic tools have been found in the region. The *Tortugas* dart point has been found within the lower Rio Grande area and dates to the Middle Archaic (ibid.:188). The *Ensor* dart point may occur in this part of South Texas and is considered by Turner and Hester (1999:114) to be Transitional (200 B.C. to A.D. 600 or later), but that range of dates overlaps the Late Archaic as herein recounted. The *Catán* (ibid.:89) and *Matamoros* (ibid.:153) dart point styles have been found along the South Texas Coast and are considered representative of the Late Archaic to Late Prehistoric. Low population densities, small band sizes, and large territorial ranges continued to characterize human inhabitants during the Early Archaic. In contrast, population densities apparently increased during

the Middle Archaic, and territorial ranges appear to have been more restricted than before. Intensive plant processing is indicated, but a variety of animal species still served as important resources. In the Late Archaic, population densities reached the highest levels yet attained, and territories became even better defined, as suggested by the development of cemeteries. The inhabitants appear to have exploited a narrower range of animal species than in later times, but use of a wide range of plants seems to have continued. The Late Archaic economy has been characterized as more collector-gatherer than hunter-gatherer in nature (Black 1989:51).

Late Prehistoric period - This period ranges from about A.D. 800 to probably the early 1500s in South Texas, including the Rio Grande Delta, when Spanish expeditions began to make contact with the Native Americans. This period reflects a continuation of the same general lifestyle as that found during the Archaic; however, a number of significant cultural changes occurred. The most notable change was in technology, through introduction of the bow and arrow and the use of pottery. Within the Rio Grande Delta area, this period includes the Brownsville Complex, which is associated in large part with a shell-working industry, including scrapers, projectile points, beads, and pendants (Black 1989:52; see also Ricklis [1995:290-291]). Various stone arrow point styles include *Cameron* and *Starr* (ibid.). Bone artifacts also were made by the Brownsville Complex groups (Hester 1995a:446-447). Ceramics are uncommon in the Rio Grande Delta area (Black 1989:52). However, a number of non-local ceramics, from what is now northern Mexico and Mesoamerica, have been found associated with these groups (Hester 1995a:447-448). Exploitation of a wide variety of plant and animal resources is suggested during this period. Bison and deer were among the larger game species, and, along the shore, fish and shellfish were utilized.

Protohistoric period - A Protohistoric period is suggested here for South Texas, spanning the years between the Late Prehistoric period and the Historic period (Hester 1995a:449; see also discussions of this concept by Hindes [1995] and Hester [1995b]). Although not yet fully defined, a few general statements can be made regarding the nature of this period (early 1500s to the early 1700s). Two fundamental lifestyle changes may have occurred in Late Prehistoric groups inhabiting any particular area. One is the European presence that may have affected inhabitants, but without having direct contact. The other is the direct, but intermittent, contact with these groups by early European travelers and explorers.

As early as 1519 to 1523, Spanish explorations and an attempt to establish a settlement near the mouth of the Rio Grande (Salinas 1990:3) may have resulted in direct contacts between Spanish and native populations in the area of PAAL. Other intermittent contacts followed, including expeditions by Cabeza de Vaca and his group (1528 to 1535), eventually crossing the Rio Grande probably through what is now the Falcon Reservoir area (Campbell and Campbell 1981). Other contacts include the Spanish expedition in 1638 led by Jacinto Garcia de Sepulveda who explored the north bank of the Rio Grande to the present site of Brownsville (Garza and Long 1996:918). Spanish presence in the region may have resulted in the displacement of native populations from previously utilized areas, the introduction of glass or metal materials through trade with native populations, and the introduction of diseases..

Some archeological sites dating to this period have contained a few metal and glass objects, representing an intermittent Spanish presence in the region. In addition, localities formerly occupied by Native American groups began to change, as a result of direct or indirect pressures from Spanish activities. Rather than being related to specific archeological sites, indirect causes of lifestyle changes during the Protohistoric Period would most likely be reflected by studying groups of archeological sites on a regional scale (cf. Hester 1989b:78). Spanish explorations throughout what is now northeastern Mexico and into South Texas in the 1600s and 1700s, followed by colonization along the Rio Grande, eventually led to Spanish domination of the region. Throughout South Texas and elsewhere, continued contact with Europeans resulted in the destruction or displacement of Native Americans through introduction of disease, deliberate extermination,

and other means, marking the end of the Protohistoric period and the beginning of the Historic period (cf. Hindes 1995:29, in which the Protohistoric period, as defined here, is identified as the "Historic Aboriginal Contact Period.").

Historic period - In South Texas, the Historic period begins in the early 1700s, when Spanish presence in the region came to dominate the lifestyles of the Native Americans through further explorations, the establishment of towns and missions, and related activities. Fox (1989:85) identifies the years from about 1716 to 1821 as the Spanish/Mexican period. Several Historic Indian groups were in the Rio Grande Delta of Texas and northeastern Mexico in the early to middle 1700s. For example, Salinas (1990:27) notes that records from 1747 show a large number of named groups living both north and south of the Rio Grande. Among these were the Malaguitas, who moved out of northern Mexico to the Rio Grande, then down to the mouth of the River, and then up the coast at least as far as Copano Bay, near present-day Rockport (ibid.:48).

Settlement in the region of PAAL began in the late 1700s with Spanish land grants and continued in the early 1800s, with additional grants issued by the Mexican government (Garza and Long 1996:918-919). Ranching was the early economic endeavor. Massive cattle herds ranged across the region, and, by 1840, scattered settlements had been established (ibid.:919). The site of the Palo Alto battle was originally deeded to a rancher, José Salvador de la Garza (Weaver 1999:15). Texas achieved independence from Mexico in 1836. After the U.S.-Mexican War and the Treaty of Guadalupe Hidalgo in 1848, Texas officially became a part of the United States, and Cameron County was formed that same year (Garza and Long 1996:919). Farming increased after the Civil War but later declined until a railroad was built in 1904, allowing access to expanded markets for produce. This, in turn, led to additional land clearing and the development of extensive systems for irrigation (ibid.:919-920). The effects of ranching, farming, and settlement on PAAL caused a variety of landscape changes, including establishment of several homesteads, crop planting, maintenance of grassland for livestock, and development of irrigation ditches and ponds.

Modern Period - The Modern era covers the past 50 years, essentially the period beginning at the end of the decade following World War II. Cultural materials associated with this time are generally not considered significant in evaluating cultural deposits for potential listing in the National Register of Historic Places or for designation as a State Archeological Landmark. Among the materials most likely dating to this period are those made of plastic, aluminum, and styrofoam, especially when the form of the material is considered, such as aluminum foil or a styrofoam cup. In addition, there are items that clearly can be associated with this period, such as dated coins.

The Battle of Palo Alto

The plain of Palo Alto on which the battle took place was an open, flat terrain covered with cord grass reportedly several feet high (Haecker and Mauck 1997:29; Appendix E in this report). Thick growths of mesquite and brush (called "thick chaparral") surrounded the battlefield, although more sparse and with occasional breaks toward the east and northeast according to some of the historical maps.

As discussed above, Palo Alto Resaca, along the west side of the main battlefield, and unnamed resacas north and south of the battlefield (see Figure 5), were among the most prominent natural features associated with the battle. There are two prominent marsh or pond areas: one in the center of the battlefield and the other, "Palo Alto Pond", at the northwest corner. According to Haecker (1994:23), there had been recent rains, so these low areas may have contained standing water or were marshy during the battle. Several low hills are located throughout the area, especially to the southeast. Among these is Arista Hill at the southeast corner of the battlefield (see Figure 5 for locations of these features; several Historic-period maps presented later in this report show the locations of wooded areas in the vicinity of the battle field).

The Point Isabel-Matamoros Road which passed north-south through the battlefield was the primary cultural feature in the battle. Two branch roads, one southwest of the battlefield, extending northwest and then north, served as an alternative "wet weather" road to Point Isabel and other areas to the north and east (Berlandier appears to have labeled it as the road to San Antonio). The other branch road was located north of the battlefield and led northwest and then north.

Activities leading up to the first battle of the U.S.-Mexican War of 1846 are presented in Haecker (1994:17-23) and Haecker and Mauck (1997:11-29). The following summary of the battle on May 8th, 1846, has been extracted from these and other sources and from a review of historical maps, with an emphasis on the relationship between the natural features and conduct of the battle. In particular, indications of the Palo Alto Resaca's role in the battle will be noted here and discussed later in this report.

Mexican forces under the command of Major General Mariano Arista proceeded northward to the south edge of the Palo Alto plain and aligned the main body of troops east-west. The west end extended across the Matamoros Road toward Palo Alto Resaca and the east end abutted a mesquite thicket, probably at or near Arista Hill. According to Weems (1974:129), General Arista began forming his forces for battle about mid-morining on May 8th "facing the plain, a short distance in front of a stand of trees. On his right, sheltered atop a wooded elevation of ground, he placed a light artillery regiment." In his Notes to the text (ibid.:471), Weems appears to indicate the source of this information as Alcaraz et al. (1850) entitled *Apuntes para la historia de la guerra entre México y los Estados Unidos* (Notes for the History of the War between Mexico and the United States). Weems' statement is inconsistent with Haecker and Mauck's (1997:map 3) reconstruction of the alignment of Mexican forces. It should be noted that Berlandier's maps appear to show a combatant unit (identified by the Spanish "ligero" and abbreviated "lig." on one of the maps) on Arista Hill. "Ligero" may be translated as "swift" or "light", possibly referring to light artillery. Additional archival and archeological investigation of this may be required.

. U.S. forces, with Brevet Brigadier General Taylor in command, moved the pack train and soldiers south along the Point Isabel-Matamoros Road, stopping near Palo Alto Pond and Resaca (Haecker and Mauck 1997:31), about 0.75 miles (0.47 km) from the Mexican force, to water horses and men. Taylor then aligned his forces from just south of the Pond westward across the road, facing the Mexican forces to the south, with the pack train situated nearest the Pond. A group of Texas Rangers under Captain Samuel Walker had been providing scouting services for the main military units and were initially stationed west of the road, near the west edge of Palo Alto Resaca. They were just beyond the main U.S. force, providing picket duty there and in the thickets further west. Captain Charles May's dragoon squadron was initially held in reserve near the wagon train east of the road (Dobbins map) but later moved south to attack, along with other units, the left flank of the Mexican line. The Stewart map of 1887, prepared by altering one of Berlandier's maps, shows May's unit moving southwest from the original position near the Point Isabel road, undoubtedly crossing the Palo Alto Resaca, and proceeding southward (the Dobbins and Stewart maps are included later in this report).

Apparently, General Taylor had planned for the battle to be focused on the use of infantry and bayonets, and General Arista anticipated such an attack. However, when the U.S. forces began moving across the plain toward the Mexican line, the Mexican artillery began firing heavy cannons but to little effect, partly due to the tall grass. The U.S. forces, on the other hand, included both heavy and, under command of Brevet Major Samuel Ringgold, a very mobile light artillery battery called the "flying artillery". As the battle developed, it became clear that the fight would be largely a duel of artillery, with the lighter, more mobile units dealing a severe blow to the Mexicans without the Americans sustaining much damage. General Arista abandoned plans to charge the U.S. line with infantry and cavalry, possibly inhibited by the large marsh area in the central battlefield and tall grass throughout. Instead, apparently while artillery units from both sides continued exchanging fire, Arista ordered General Torrejón's lancers to cross the Palo Alto Resaca to the west and attack the right flank of the U.S. forces. The lancers proceeded and crossed the Resaca, but the cannons had difficulty crossing because of the wet conditions. The lancers entered the mesquite thicket but

bogged down in another, deeper resaca that was within the thicket. These movements were noted by U.S. Colonel David Twiggs who was responsible for the right flank and who subsequently sent an infantry unit to meet Torrejón's lancers, probably by crossing the Palo Alto Resaca to the west. The lancers reached firmer ground, attacked the infantry unit, and were repulsed. Torrejón sent word to Arista that the Resaca made this effort impractical, but Arista ordered another attempt.. Torrejón tried to move his cavalry further north and then east to circumnavigate the infantry unit in order to attack the wagon train, but was hit again by the infantry. Meanwhile, another infantry unit had moved into the vicinity of the wagon train, so that plan was no longer feasible. Then Torrejón's two 4-pounder cannons finally managed to cross the marshy resaca, protected by the lancers, and prepared to fire on the infantry unit. However, part of the "flying artillery" unit quickly came to support the infantry unit and, together with the Texas Rangers, who were assigned to protect that unit, drove Torrejón's lancers back to the Mexican line.

In the meantime, the artillery duel was progressing, and fire from one of the U.S. cannons set the cord grass ablaze. With increased intensity in the winds from the Gulf, the smoke and flames quickly spread across the battlefield, obscuring both U. S. and Mexican forces and causing a halt in the artillery firing. During the lull in fighting, Taylor realigned his forces by rotating them counterclockwise so that the U. S. battle line became oriented essentially north-south. Arista's forces rotated the same way to remain parallel to the U.S. battle line, opening up the road so that the American heavy artillery pieces were able to approach the Mexican line and set up a devastating fire. The artillery duel continued, since several shallow pools of water, probably within the large marsh area in the battlefield, interfered with frontal assaults by either side except along the flanks.

Later in the battle, a Mexican cavalry unit was seen by U.S. forces emerging from the chaparral, presumably west of Palo Alto Resaca, and heading toward the wagon train. If indeed they were west of the Resaca, it would have meant crossing the Resaca to reach the wagons. However, a part of the "flying artillery" unit observed this cavalry movement and realized the Mexicans could potentially reach the wagon train, still located near Palo Alto Pond, as indicated on the Stewart map. The artillery opened fire and the Mexican cavalry unit retreated into the woods. The artillery unit was then moved so that it and the other artillery units were pouring a devastating fire into the Mexican line. By 7:00 PM, and with the available artillery shells expended, Arista ordered his force to camp for the night in a mesquite area southeast of his right wing. This was presumably on or near Arista Hill, or on one or more of the other low hills in that area, as indicated by one of the historical maps. With darkness approaching, Taylor decided to camp for the night as well, intending to resume the battle in the morning. However, when day broke the next morning, the Mexican forces were gone. They were followed by the U.S. forces and another battle ensued, this time further south at Resaca de la Palma.

PREVIOUS INVESTIGATIONS

A surface survey of sampled areas conducted by Mallouf et al. (1977) included parts of Willacy County not far north of PAAL. Several of the survey samples occurred in a landscape setting similar to that of the battlefield: flat and open, containing occasional low hills and circular depressions, usually within relict interdistributary channels (resacas) possibly containing water in places, especially after heavy rains (ibid.). The results of the survey indicate some possibilities for the existence of prehistoric remains within the PAAL area. In addition to a few Historic-period habitation sites, several probable prehistoric sites were recorded. Cultural materials found in one of the survey areas consisted of lithic debitage and a single ceramic sherd along the edges of a large depression (ibid.:118-123). In another area, lithic debitage, occasional bone, and burned clay lumps were found along the edges of several small depressions, with one site situated on an elevated surface (ibid.:130-133). A resident farmer reported recovering, many years previously, a saber and a cannonball (ibid.:133). Although the lithic and ceramic materials from these sample areas were undated, it seems likely they indicate occupations during the Archaic, Late Prehistoric, and Historic periods.

Beginning in the mid-1970s, several research efforts have been conducted at the site of the Palo Alto battle. Shafer (1974) apparently visited the battlefield area but did not collect artifacts associated with the battle. In 1976, archeologists from Texas A&M conducted a surface reconnaissance and archival research. They tentatively identified the battlefield as an area extending northwest from Loma Alta, a long, narrow, east-west hill situated along the north side of Loma Alta Lake, to a bend in a resaca southeast of what appears to be the actual battlefield (Baxter and Killen 1976:17). According to Haecker and Mauck (1996:56), none of the artifacts recovered during that investigation could be attributed to the 1846 battle. Information provided by A.A. Champion, who had studied the battle history for some time, indicated the probable battlefield was located further toward the northwest, a suggestion supported by two maps prepared by Jean Louis Berlandier (ibid.; the maps are discussed later in this report).

In 1979, at the request of the National Park Service, an archeological team from Texas A&M conducted a reconnaissance survey of the area which Baxter and Killen had identified as the probable battlefield, and then conducted a more intensive survey of a second area toward the northwest as suggested by Champion (Bond 1979:Figure 9). Surface inspection and limited metal detector surveys were conducted in this latter area (ibid.), with a few artifacts recovered that could be attributed to the actual battle (Haecker and Mauck 1996:57). In 1991, Walter Plitt III, Chairman of the Palo Alto Battlefield National Park Committee, documented the locations of artifacts obtained by collectors from the battlefield (ibid.). In later research, the National Park Service staff found the probable location of the Palo Alto House or Inn, including traces of a structure and a trash dump near the Point-Isabel-Matamoros Road (Ivey 1992, cited in Haecker 1994:39). In 1992 and 1993, archival research and intensive surveys of selected areas, using metal detectors, resulted in locating substantial numbers of artifacts clearly indicating the battlefield area (Haecker 1994; Haecker and Mauck 1997).

In 1997, Perttula described cultural remains observed on the surface at several locations within PAAL (Perttula 1997:18-26). Archeological remains found on the surface at the Palo Alto House or Inn were discussed by Perttula and Nelson (1997:27-30).

In December 2001, NPS staff of the Battlefield Site conducted a metal detector survey within Palo Alto Resaca at two locations: one including the area where the current fieldwork was conducted and the other in an adjacent meander to the west (locations are shown later in discussing land modifications). A cannonball (Catalog #1008) was recovered from the first survey area, and a cannonball (Catalog #1043), a musket ball, and a lead fragment were recovered from the second location.

METHODS

Archival Research

On July 28-30, 2004, files at the Texas State Archives and Library and at the Texas General Land Office were reviewed for historical maps of PAAL. On August 9 and 10, files at the National Park Service headquarters in Brownsville, at the library (Hunter Room) of The University of Texas at Brownsville, and files of the Battlefield office were reviewed for maps and aerial photographs of the Battlefield and surrounding area. Copies of several aerial photographs were provided by the staff of PAAL, including a number that were placed on a CD. On September 16th and 23rd, reports of archeological investigations conducted at PAAL were reviewed in the library of the Texas Historical Commission.

Field Research

In response to the scope of work for this project, eight backhoe trenches were excavated across Palo Alto Resaca, generally aligned east-west. UTM coordinates for the southeast corner and the dimensions for each backhoe trench are listed in Table 1 (see the results of fieldwork presented later). At BHT-1, the width was extended about mid-level at the west-northwest end for safety purposes. Part of several trenches was excavated to greater depths than the remainder of the trench to allow maximum exposure of soils with minimum excavation. Not shown in the length measurements of Table 1 is a sloping ramp excavated at each trench for easy access.

Soil samples were collected from BHT-4 between 13 and 235 cm below surface. The samples were submitted for radiocarbon assays and stable-isotope analyses and for analyses of pollen and diatoms.

Laboratory Processing

Soil samples were collected in BHT-4 from the following levels: 13-28 cm bs, 80-100 cm bs, 130-155 cm bs, and 205-235 cm bs. These four soil samples were submitted to the Illinois State Geological Survey, Isotope Geochemistry Laboratory, for radiocarbon assay and stable-isotope analysis. Parts of the samples were sent to B.M. Winsborough for analysis of diatoms and to B. Albert for analysis of pollen. The results will help define the age of the Palo Alto Resaca and the deposits filling it, as well as the nature of the paleoenvironment. Combined with the stratigraphic and geomorphic findings, the laboratory data will provide a basis for reconstructing landscape evolution in this part of the Rio Grande delta plain.

RESULTS

Archival Research

Historic-Period Maps - Several available maps depict the battle as observed by various individuals among either the U.S. or Mexican forces on May 8, 1846, possibly at different times during the day and most certainly from different locations. One map showed defensive earthworks constructed the day after the battle. Other maps were prepared well after the battle, including some that made use of earlier maps or were actually modified earlier maps to show additional or revised details. Parts of two small-scale maps showed the region in which the Battlefield was located. Following is a discussion of each map beginning with the map characteristics, including the source where it was obtained, the individual identified as responsible for the map's preparation, the date represented by the map, and details regarding the map's construction. A brief review of the general content is provided, with an emphasis on the position of the military forces relative to Palo Alto Resaca, followed by an analysis of the utility of the map for this project. The two general area maps are discussed first, but the remaining maps that specifically address the Palo Alto battle will be reviewed in the general order in which they were produced.

Boundary Between the United States & Mexico (Emory)

Characteristics - Prepared under the direction of Brevet Major W. H. Emory, Corps of Topographical Engineers; surveyed in 1853; obtained from the Texas General Land Office; also available in the Texas State Archives and Library. Only a segment of the map was obtained. North is toward the top of the map. The scale is 1:60,000.

Analysis - The map shows the location of the Battlefield just east of the road between Brownsville and Point Isabel with no other details about the battle area. Wooded and marshy areas are indicated to the north, east and south of the battlefield.

Comment - This small-scale map provides information about the region in which the Palo Alto battle took place but no details about the battle or the landscape in that immediate vicinity. It was of limited use for this project.

Map of Country Adjacent to the Left Bank of the Rio Grande below Matamoros (Abert)

Characteristics - Prepared under instructions from Col. J. J. Abert, Corps of Topographical Engineers; published in 1857; obtained from the Texas General Land Office. Only a segment of the map was obtained. North is toward the right as the map is oriented. The scale is one inch to a mile.

Analysis - The map shows the location of Palo Alto battlefield adjacent to the Point Isabel-Matamoros Road and provides information about the region. The area surrounding the battlefield is shown as grassland.

Comment - There are no details regarding the battlefield or about the landscape in that vicinity. It was of limited use for this project.

Sketch of the Battle of Palo Alto (First Berlandier)

Characteristics - This is the first of two maps prepared by Jean Louis Berlandier depicting the battle on May 8, 1846. Copies were obtained from the National Park Service and from the Hunter Room in the Library, The University of Texas at Brownsville. This map is also shown in Haecker (1994:Figure 26) and Haecker and Mauck (1997:Figure 4.3). There is a bar scale but no north arrow; however, the relative positions of the natural and cultural features show north to be at the top of the map (see Figure 6 of this report).

There is no legend, but some features and the military units are annotated. The bar scale appears to be in *varas* (1 *vara* = about 33 inches, or 2.75 feet/0.8 m) and indicates one inch = 400 *varas*.

Analysis - The map shows a road, oriented approximately north-south, identified on other maps as the Point Isabel-Matamoros Road . Branching to the northwest just south of the battlefield is another road, identified on other maps as the alternate "wet weather" road (Figure 6). Resaca de Palo Alto is shown west of and roughly parallel to the main road, beyond which is a wooded area. A large, probable marsh area is shown east of the road between the U.S. forces to the north and the Mexican forces to the south. A semi-rectangular area northwest of the U.S. forces between the resaca and the road is probably the U.S. wagon train (shown on other maps in the vicinity of Palo Alto Pond). Apparently the beginning position of the two groups of forces is indicated, as well as a second position later in the battle, along with the movements of various military units during the battle. What appears to be the main battle line of the U.S. forces is spread east-west at or near the outset of the battle, with the western flank across the Resaca. Late in the battle a number of U.S. units were apparently located along the west edge of the Resaca.

Comment - This first sketch by Berlandier is one of the most useful maps available for this project. The two Berlandier sketches were the only maps available that showed a feature identified as the Palo Alto Resaca (Resaca de Palo Alto). It was a firsthand account of the battle and the surrounding landscape from the perspective of the Mexican side. Consequently, the details regarding the battle may be somewhat less accurate with respect to the U. S. Forces and activities and natural features toward the northern part of the battlefield. An attempt is made later in this report to match the Palo Alto Resaca, as shown on the current USGS map, with this map.

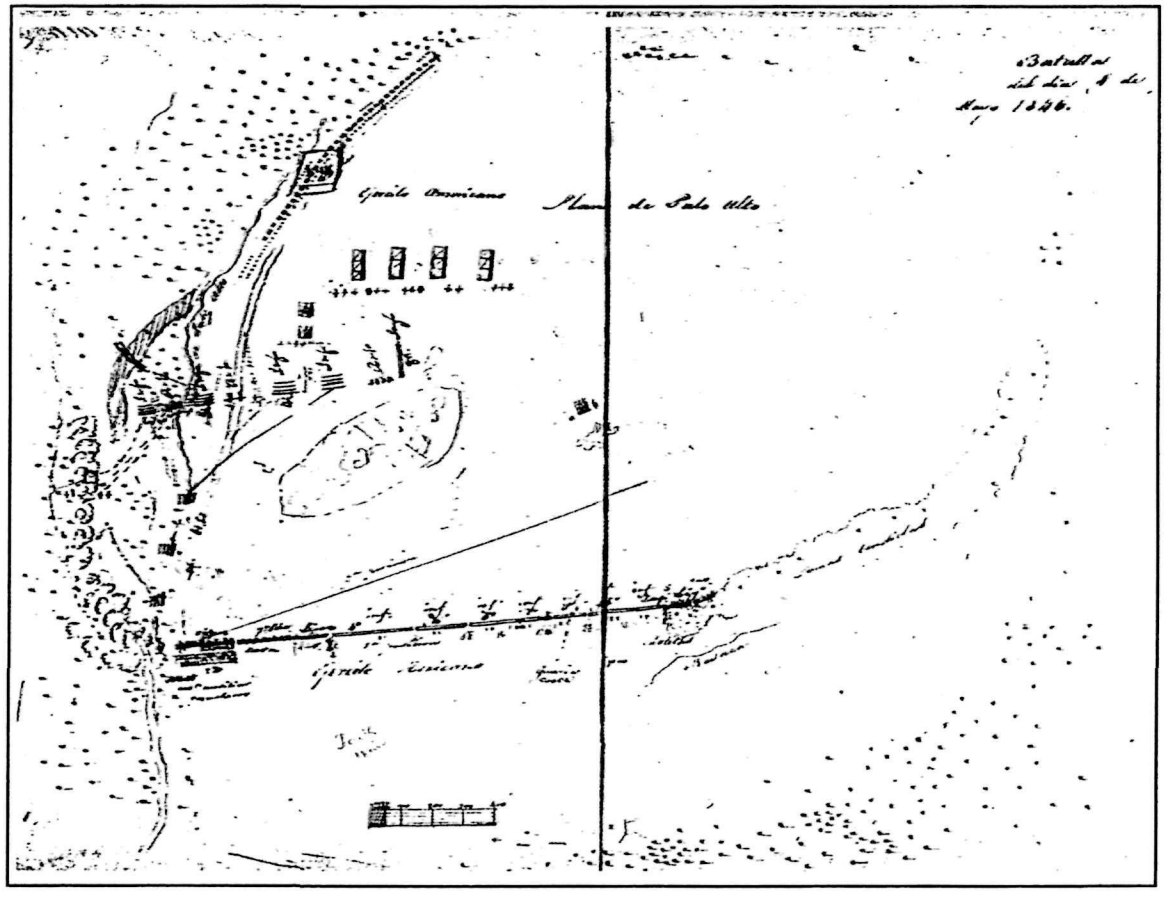


Figure 6. First sketch by Jean Louis Berlandier depicting Battle of Palo Alto . Note marsh area in middle of battleground, hills to southeast, pack train (Park) along Point Isabel-Matamoros Road to the north (roughly rectangular), and Palo Alto Resaca (Resaca de Palo Alto) west of road. Courtesy National Park Service.

Sketch of the Battle of Palo Alto (Second Berlandier)

Characteristics - This is the second of two maps prepared by Jean Louis Berlandier; May 8, 1846. It was obtained from the National Park Service and also appears in Haecker (1994:Figure 27) and Haecker and Mauck (1997:Figure 4.4). There is no north arrow but, based on map features, north is toward the top of the map. There is no legend, but features and units are annotated on the map. The bar scale shows 1 inch = just under 500 *varas*.

Analysis - The road between Point Isabel and Matamoros is indicated as the road to El Fronton (El Frontón de Santa Isabel, a small fishing village established in the 1830s where Port Isabel now is located; Garza 1996:279). Palo Alto Resaca is indicated just west of the road. The wet-weather branch off this road to the northwest also is shown. The initial positions of the U.S. and Mexican forces are shown, including the changing positions as before, and the movement of units during the battle.

Comment - This appears to be a partial revision of the first map, with only a few features indicated. The quality of the available map is poor, but it appears to show the U.S. forces lined up east-west as indicated previously but all of them to the east of the Point Isabel Road.

Sketches of the Palo Alto Battle (Scarritt)

Characteristics - According to Haecker and Mauck (1997:125), three sketches of the battle and one sketch of the defensive earthworks around the wagon train were prepared by Lieutenant J. M. Scarritt a few days after the battle, as illustrations in a letter discussing the battle. The three battle sketches are shown in Haecker (1994:Figures 33-35) and in Haecker and Mauck 1997:Figures 4.10 to 4.12). The sketch of the earthworks is shown in Haecker (1994:Figure 15) and in Haecker and Mauck (1997:Figure 2.15). There is no scale or legend, but some of the units are labeled. There is no north arrow, but the locations of units and natural features as shown on other maps indicate north is to the bottom of these maps. The sketch of the earthworks and cannons, however, seems to have north toward the top.

Analysis - The maps provide information on some of the units and battle activities, and a depiction of the earthworks. The Point Isabel Road is shown, although not identified, and various units are identified. The second and third sketches appear to indicate Palo Alto Resaca west of the Road. The sketch of the pack train, earthen revetments, and cannons appear to be shown at the south edge of Palo Alto Pond. Several small features behind each cannon seem to depict equipment supporting cannon operations.

Comment - The sketches of the battle vary in content, and apparently were not intended to depict the entire battle in any great detail. The sketch of the earthworks shows one of the first changes in the battlefield, having been constructed the day after the battle (see the discussion and map later in this report). This construction was in fact part of the military operations considered necessary before the U.S. forces moved south to pursue the Mexican army (Haecker and Mauck 1997:50-51).

Sketch Map of the Palo Alto Battle (Dobbins)

Characteristics - Drawn by Lt. S. D. Dobbins, 3rd Infantry; May 8, 1846, and obtained from the National Park Service (see Figure 7 of this report). It is shown in Haecker (1994:Figure 32) and Haecker and Mauck (1997:Figure 4.9). According to Haecker and Mauck (ibid.:123), the map was published a few months after the battle. There is no north arrow but, based on features and other maps, north is toward the bottom of this map. Military units are identified throughout the map. There appears to be no scale, although there is a horizontal line within the legend and accompanying note which may be a bar scale that has been lost from repeated duplication of the map over time. The legend indicates this was either part of a larger map or was published in two parts, one showing the Battle of Palo Alto (No. 1, labeled as such on the map)

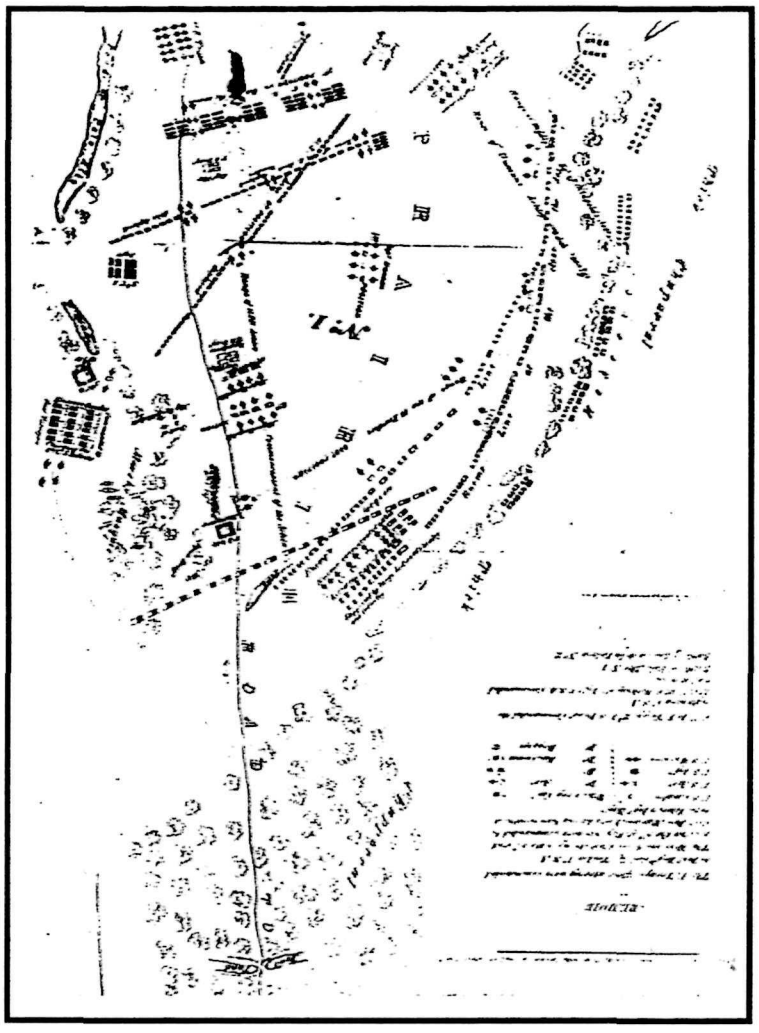


Figure 7. Sketch depicting Battle of Palo Alto drawn by Lt. S. D. Dobbins, with north toward bottom of map (inverted here with north toward top). Note Point Isabel-Matamoros Road, Palo Alto Pond (Pond de Palo Alto) to northwest, hills toward southeast. Courtesy National Park Service.

and the other apparently containing a map of the Battle of Resaca de la Palma (No. 2).

Analysis - The road between Matamoros and Point Isabel is shown as a north-south line west of the main battlefield. The U.S. and Mexican forces are depicted in two positions as the battle proceeded, along with an indication of the ranges of various cannons. The initial battle lines of both U.S. and Mexican forces are oriented east-west, and units of both extend across the road to the west. In the second battle position, the Mexican battle line is pivoted and moved eastward so it is well away from the road. The second position of the U.S. battle line was likewise rotated, but the right flank still extends westward beyond the Point Isabel-Matamoros Road. The open center of the battlefield is identified as "Prairie". An area identified as "Thick Chaparral" is shown south of the battlefield on both sides of the Matamoros Road. A scatter of woods is shown along the east side of the battlefield, again with the notation of "Thick Chaparral". A line of woods on the west side of the battlefield is west of the road. An area of "Marshy Musquit" is located west of the road, southwest of the main battlefield area. To the north of the marsh area is a linear-shaped pond. Still further north is a similar, larger feature. Both are oriented generally north-south, with the northernmost identified as Palo Alto Pond. The marshy area and smaller pond may represent parts of the Palo Alto Resaca.

Comment - The military units and many of the natural features are clearly identified. The large marsh area shown on other maps in the center of the battlefield is not indicated, and the row of low hills along the southwest side of the battlefield is not shown, although a curved row of trees in that vicinity may represent these features. An attempt is made later in this report to match the Palo Alto Resaca, as shown on the current USGS map, with this map.

Mexican Battle Map (De La Batalla Dada En Palo-Alto)

Characteristics - Prepared by Berlandier; and published about 1847, this map was obtained from the National Park Service, the Hunter Room in the Library, The University of Texas at Brownsville; and is shown in Haecker (1994:Figure 28) and Haecker and Mauck (1997:Figure 4.5). According to Haecker and Mauck (1997:118), this map was published about a year after the battle, probably using the earlier Berlandier sketches as sources. The map contains a north arrow and legend but no apparent scale.

However, the notes on the map seem to indicate the length of the Mexican battle line was 1,050 *varas* long, or about 2,888 feet (880.1 m), which provides some basis for scale.

Analysis - The road between Matamoros and el Frontón (Point Isabel) is oriented northeast along the west side of the battlefield, then east at the north end of the battlefield, and then finally north. All of the area west and north of the road is shown as wooded except for two marsh areas, one oriented northwest-southeast across from the middle of the main battlefield, possibly part of the Palo Alto Resaca, and the other to the northeast, oriented northeast-southwest, probably Palo Alto Pond (the U.S. wagon train is depicted nearby on the road). At the southeast edge of the battlefield, there is a series of low, wooded hills oriented northeast-southwest, 18 to 20 feet high (5.5 to 6.1 m), according to the legend. Two of the hills are parallel, with a marsh area between and another marsh area just to the southwest. A road to the Tanques del Ramireño starts at the southwest end of these hills and proceeds southeast. Apparently two positions of both U.S. and Mexican forces are indicated, along with movements of various units during the battle. The initial left flank of the Mexican battle line extends just beyond the Matamoros Road to the west, and the east flank reaches eastward to the low hills. Most of the U.S. forces are shown to be east of the Point Isabel Road except for units on either side of the southern marsh area west of the road.

Comment - In some ways this map is similar to the earlier Berlandier sketches with respect to the Mexican positions but not the U.S. forces. The main road is more curved than is shown on other maps, and all of the area west of the road is wooded unlike the earlier Berlandier maps. It does not show the Palo Alto Resaca identified on the earlier maps by Berlandier. The row of low hills to the southeast is much more prominent than is indicated on many of the other maps. Although details of military unit movements during the battle are shown in some detail, many of the natural features of the area were not identified.

Sketch Map of the Palo Alto Battle (Henry)

Characteristics - This map was shown in Haecker (1994:Figure 31) and Haecker and Mauck (1997:Figure 4.8). According to Haecker and Mauck (ibid.:123), the map was prepared by Captain W. S. Henry, who joined General Taylor's command several months after the battle, and was published in 1847. There is no scale and the north arrow appears to be reversed, with features on the map indicating it is presented with north toward the bottom of the map. There is no legend but some of the features are annotated.

Analysis - The Point Isabel-Matamoros Road is shown curving north to northeast through the battle area, with an unnamed branch road proceeding north just beyond Palo Alto Pond. The large marsh area within the battlefield is indicated, and a probable smaller marsh is seen to the west of the road. A narrow arc of woods is shown along the west side, becoming wider northwest of the battle area. U.S. units are situated along the east edge of this wooded area, and Mexican units are west of these woods. Segments of woods are also shown southeast of the battlefield. Apparently two positions for both U.S. and Mexican forces are depicted. Units of both are shown extending west of Matamoros Road, probably between the woods and Palo Alto Resaca, in the initial battle line. In the second position, the U.S. forces are rotated but still extend west beyond the road, along or across what appears to be part of Palo Alto Resaca. The Mexican forces rotated the same way so that they are further from the road than during the initial battle line.

Comment - The map provides few details. Probable marsh and wooded areas are shown by symbols but not identified, with the only natural feature labeled being Palo Alto Pond. An attempt is made later in this report to match the Palo Alto Resaca, as shown on the current USGS map, with this map.

Sketch Map of the Palo Alto Battle (Ramsey)

Characteristics - This map is shown in Haecker (1994:Figure 29) and Haecker and Mauck (1997:Figure 4.6). According to Haecker and Mauck (1997:120), the map was in a book edited by Albert C. Ramsey in 1850, an American translation of a published Mexican account of the U.S.-Mexican War that included this map. The map was prepared by Berlandier (probably using the information from his earlier sketches; ibid.). There is a scale and an extensive legend but no north arrow. Military units and natural features are identified by notations contained in the legend.

Analysis - The Matamoros-Point Isabel Road (labeled "Road to Fort Isabel) arcs north and northeast along the west side of the battlefield, with two branches. The southern branch, southwest of the battlefield, proceeds northwest and back northeast, is identified as the "Road to Fort Isabel in the Rainy Season". North of the battlefield a second branch road, unidentified, branches north. A series of "Low Bottoms", probably marsh areas, or areas of standing water during rainy periods, are shown oriented northeast-southwest across the battlefield. Other "low bottoms" are scattered to the southeast. Another series of low lands extends north-south between the wet-weather road and the main road. It may represent segments of Palo Alto Resaca. Nearly all the area west of the main road is shown as wooded. Southeast of the battlefield is a long, narrow wooded hill oriented northeast-southwest, identified as the place where the Mexican forces spent the night after the battle. The battlefield is apparently identified by symbol as grassland. The area to the southeast is wooded, crossed by the "Road to Tanques del Ramireño" which begins near the southwest end of the wooded hill at the east flank of the initial Mexican battle line. Two positions of both Mexican and U.S. forces are depicted along with movements of various units during the battle. The initial U.S. battle line extends west across the main road, possibly near Palo Alto Resaca. Two of those units later moved south along the road and then west, possibly crossing the Resaca. Mexican units at some point in the battle crossed the Resaca and moved northward to a point just west of the U.S. units located nearer the Resaca.

Comment - The map provides a large amount of information about the battle as well as some of the natural features.

Sketch Map of the Palo Alto Battle (Stewart)

Characteristics - The map was obtained from the National Park Service and shown in Haecker (1994:Figure 30) and Haecker and Mauck (1997:Figure 4.7). According to Haecker and Mauck (ibid.:120), this map was prepared by J. W. Stewart in 1887 using the Mexican map prepared earlier by Berlandier. There is a detailed legend keyed to features on the map, and a scale but no north arrow.

Analysis - The three roads are similar to those shown on the Ramsey map, the main road to "Fort Isabel", the "Rainy Season" road, and an unidentified road north of the battlefield. As with the other maps, there are two positions for the U.S. and Mexican battle lines. Both positions of the U.S. battle line extend further west from the main road than is shown on most of the other maps, moving the units closer to the Palo Alto Resaca in both cases. Both of the Mexican battle lines are shown east of the main road. The Mexican and U.S. units west of the main road (and probably west of Palo Alto Resaca) are depicted in the same area at one point in the battle where an encounter took place (discussed earlier in this report). Numerous "Low Bottoms" are identified throughout the battlefield and west of the main road, the latter probably representing part of the Palo Alto Resaca. The range of low hills shown on other maps is indicated as a single narrow hill on this map. Wooded areas are shown along the edges of the battlefield except toward the northeast. The battlefield is depicted by symbols as grassland.

Comment - The basic map is essentially identical to that provided by Ramsey, and some of the military unit locations are the same. However, the legend was changed and the locations and movements of some Mexican and U.S. forces have been changed. An attempt is made later in this report to match the Palo Alto Resaca, as shown on the current USGS map, with this map.

Sketch of the Battle Ground at Palo Alto, Texas (Eaton)

Characteristics - This map was prepared by J. H. Eaton, 3rd Infantry; May 8th, 1846; obtained from the National Park Service (reproduced at the National Archives, according to a notation). The map contains a north arrow (magnetic), a legend, and a bar scale indicating 2.3 inches = 1 mile. Military units are identified by key to the legend. The date of preparation is not given.

Analysis - The north-south road, curving eastward north of the battlefield, is identified as the "Road to Point Isabel", with a branch to the north just beyond what is possibly Palo Alto Pond labeled "Wet Weather Road". However, this is not the location of the wet-weather road shown on some of the other maps. Neither the marsh in the central part of the battlefield nor Palo Alto Resaca is shown, although there is a marshy area and a north-south linear strip west of the main road that may be parts of the Resaca. Dense woods called "Thick Chaparral" are shown northwest and south of the battlefield. The Palo Alto plain is identified as "Low Salt Prairies". Two positions of both U.S. and Mexican forces are indicated, with the first position shown at their 3:00 PM locations. The map depicts the original U.S. battle line as extending well past the Point Isabel Road to the west, possibly extending to or beyond the Palo Alto Resaca. The rotated second position of the U.S. battle line extends west across the road, with the right flank adjacent to a marsh, probably Palo Alto Resaca. There are other units located along a north-south line adjacent to a wooded area west of the main road. A marsh shown between two of these units may be part of the Resaca. The left flank of the first Mexican battle line, a unit of cavalry, is situated on the Matamoros Road. After the Mexican battle line rotated later in the day, they are shown well away from the Road.

Comment - The quality of this map is good and the unit locations for both Mexican and U.S. forces are identified to some extent. The wooded areas and the plain are the only natural features identified.

Modern Maps - A 15-minute topographic map published about 1929 by the U. S. Geological Survey, available in the Texas Natural Resources Information System, showed only the general location of Palo Alto Battlefield. Two maps published more recently provided information on the general area of the battlefield and on land modifications that have occurred in recent years. The USGS 7.5-minute topographic map, Los Fresnos, was published in 1955 at a scale of 1:24,000 and a contour interval of 5 feet (1.5 m) and was revised in 1983. The cultural features and drainage were obtained in part from aerial photographs taken in 1953 and the topography was obtained by plane table surveys in 1930, but revised in 1955. The Brownsville topographic map was compiled in 1958 by the U.S. Army Topographic Command at a scale of 1:250,000 and a contour interval of 50 feet (15.2 m) and was revised by the USGS in 1969.

Aerial Photographs - Three sets of 9 inch x 9 inch aerial photographs were obtained from the National Park Service. These photographs provide stereoscopic viewing of PAAL. One set was taken in 1939 and the other two in 1992 (one set is black-and-white and the other color-infrared). These were reviewed briefly at the National Battlefield Site and then were placed on a CD by the NPS staff to support the current investigation. The images were later printed to aid in the stereoscopic analysis. Parts of single aerial photos were made available on a CD and were later printed to support the analysis effort. The photos were taken in the following years: 1934, 1939, 1950, 1962, 1977, 1996, and 2000. The approximate area covered by each of these photos is shown in Figure 2 as the broader project area. In addition to the photos provided in CD format, enlargements of aerial photos from 1962 and 1977 and a mosaic of photos from 1934 were provided, each of which showed most or all of the Historic Battlefield Site. An enlarged portion of a color-infrared aerial photo taken in 2000 also was provided by NPS. This suggests locations of the U. S. and Mexican forces, apparently at the beginning of the battle.

Results from review of these aerial photographs follow in sequence beginning with the oldest. For each photo or set of photos, characteristics including scale are presented, followed by analysis of pertinent features observed, with emphasis on Resaca condition and landscape modifications in the battlefield area.

Finally, comments are provided regarding the utility of each photograph and some of the changes that were observed as compared to previous photos.

1934

Characteristics - The mosaic of black-and-white aerial photos covers most of the National Battlefield Site at a scale of about 1:10,000. Overall they are of poor to fair quality. The single image is an enlarged portion of a black-and-white aerial photo showing the broader study area (see Figure 2). The scale is about 1 inch = 100 meters (see Figure 8).

Analysis - Palo Alto Resaca, Palo Alto Pond, and Arista Hill are prominent on the mosaic, but the marsh area within the battlefield is invisible because of poor image quality. Several buildings were located east of the NPS Visitor Center, and another group along the road to the west, near what is now Paredes Line Road. At least one building appears to be inside the resaca meander to the north, west of Palo Alto Pond. Several roads or trails are evident. A trace of one road, oriented northeast-southwest, extends northward to the lower east edge of Palo Alto Resaca where it can no longer be seen. Another trace of what is possibly the same road appears further north, oriented northeast-southwest. These may be parts of the earlier road between Matamoros and Point Isabel extant during the Palo Alto battle. Among the more distinct roads is a recent one that passes along the east edge of Palo Alto Resaca, then turns northeast, along the west side of Palo Alto Pond.

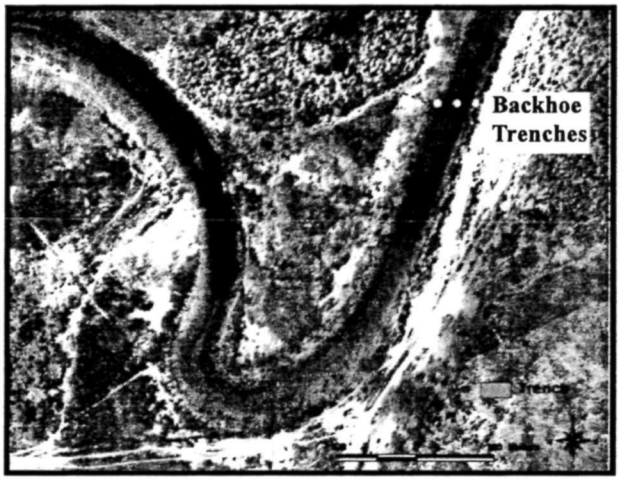


Figure 8. Part of 1934 aerial photograph showing meander of Palo Alto Resaca with backhoe trenching (upper right). Note structures outside meander bend, considerable scarring of ground surface, wooded hill inside meander. Digital copy courtesy National Park Service.

On the single photo enlargement, the area where the backhoe trenches were excavated is dry and contains a cover of grass or forbs and, mostly along the edges, a scatter of shrubs. However, along the western segment of this meander, and toward the north, the resaca contains a relatively dense cover of shrubs. Several roads and trails are seen throughout the image, especially along the outside edges of the resaca. The buildings at the south edge of the meander and those to the west, are seen along the road curving east around the resaca and proceeding north, with substantial scarring of the ground surface visible along the way. Inside the meander toward the top of the image is the low hill located just west of the resaca and near the area where fieldwork was accomplished. At least one structure may be situated on top of this hill, surrounded by a circular arrangement of trees, together with a road oriented north-south crossing the hill at the west edge of this area. Another road seems to branch from this one, proceeding northeast to the west edge of the resaca near where the current fieldwork was conducted. This road leads to a single building (also shown on the USGS topographic map prepared from aerial photos taken in 1953; see Figure 2).

Comment - The combination of a mosaic covering much of the Historic Battlefield and an enlargement of the broader project area at such an early date provided an opportunity to view the landscape in some detail around the immediate project area and at the same time place this smaller area in the context of the overall battlefield. A better quality set of aerial photos from the same date, especially with stereoscopic coverage, would have provided even more information about the land surface in 1934. Such photos also could have been used more effectively for comparison with later photos to determine changes over the last several decades. The enlarged image of the project area is probably from one of the photos used in preparing the mosaic, so the original quality was likely better than that available for this project.

1939

Characteristics - Three overlapping black-and-white photos taken on October 12, 1939, provided stereoscopic coverage. The scale of these photos, about 1:15,000, allowed a relatively broad area to be observed but with somewhat less detail than most of the larger-scale photos. The single image is the negative of an enlarged portion of a black-and-white aerial photo that shows the broader study area (see Figure 2). The scale is about 1 inch = 100 meters.

Analysis - On the set of stereoscopic photos, vegetation is seen as relatively dense along the banks of the resaca where fieldwork was conducted. Darker areas through the center of the resaca and lighter areas along the edges seem to indicate some moisture in the lower-elevation central part. Further south, and in the western part of the meander, the resaca appears dry. A cleared area is visible along the east side of the resaca adjacent to a road. Just to the east of the cleared area is a north-south dirt road that may be the remains of the Point Isabel-Matamoros Road seen in 1934 photos. The large marsh area in the central part of the battlefield is very prominent and is clearly a depression compared to the surrounding land surface. The edges appear so distinctive that the area may be surrounded by a fence, except for an irregularly-shaped portion on the northeast side. Palo Alto Pond also is prominent on these photos, and a trace of north-south road can be seen along the east side of the Pond that may be part of the historic road. A more recent road is seen along the east side of the resaca and west of Palo Alto Pond proceeding north and then curving to the northeast above the Pond. The building noted on the 1934 photo mosaic, inside the meander to the north, and west of Palo Alto Pond, can be seen. Just west of Palo Alto Resaca and north of the current project area appears to be a large, cleared area with a row of trees along the west edge, possibly an earlier location of the resaca. The area between the row of trees and the resaca is more clearly shown than on the 1934 photo mosaic and may be under cultivation. A fence line oriented north-south extends from the edge of the resaca southwest of Palo Alto Pond across the hill west of the current fieldwork and the resaca meander just east of the NPS Visitor Center.

The single 1939 aerial photo negative contains the same features as the stereo photos within the project area and appears to be from the same set as the stereo photos.

Comment - One of the photos in the stereoscopic set used previously to mark various features, possibly soils, has some of the details obscured. Nevertheless, these photos provide a good opportunity to study variations in terrain elevation as well as various landscape features over a broad area. The north-south fence is probably a property line which will influence land modifications later as a result of clearing and plowing observed mostly on the east side.

1950

Characteristics - This image (Figure 9) is an enlarged portion of a black-and-white aerial photo showing the broader study area (see Figure 2). The scale is about 1 inch = 100 meters

Analysis - This single image of the broad study area shows large scarred ground areas throughout, especially beyond the resaca banks. The dam just north of the backhoe trenches is shown for the first time in this series of photos, with standing water on both sides. A narrow strip of moist soil or standing water extends along the central part of the resaca southward for some distance from near the dam. In the vicinity of the current fieldwork, the resaca bed seems to be mostly grass and forbs, but trees and shrubs are scattered along the banks, with greater density on the west side. Much of the hill west of the resaca is obscured by clouds. A rectangular cleared area, situated in the west part of the meander and possibly containing water, appears to have been excavated for nearly the width of the resaca, about 28 m, and along the resaca for about 78 m. Dense trees grow along the east bank opposite the excavated pond. Adjacent to the resaca and this tree line is a concentration of large trees (seen on the earlier photos but not as clearly).

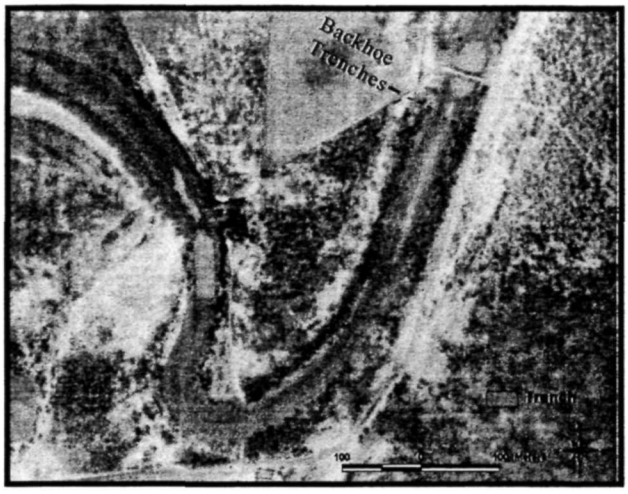


Figure 9. Part of 1950 aerial photograph showing project area. Note the north-south fence line, possible corrals by structures outside south edge of meander, and rectangular area within west segment of the resaca. Digital copy courtesy National Park Service.

A road leads from there south across the resaca to the general vicinity of the buildings east of the NPS Visitor Center. The north-south fence line seen on the previous photo passes just east of this road and crosses the resaca within the meander bend. At the bottom of the image and just east of the fence, there appear to be corrals where the cluster of buildings is located. These are seen more clearly on the earlier photos.

Comment - This image provides a good view of changes made in the resaca, including the first indication of a dam just north of the fieldwork, and a rectangular clearing possibly for retention of water.

1962

Characteristics - An enlargement of a 9" x 9" black-and-white aerial photo at a scale of about 1:13,500 provides a view of the battlefield and adjacent areas. An enlarged portion of a black-and-white aerial photo shows the broader study area (see Figure 2) at a scale of about 1 inch = 100 meters (Figure 10).

Analysis - The full photo enlargement shows all of the National Battlefield Site, with the resacas, Palo Alto Pond, the marsh area in the battlefield, and Arista Hill all clearly indicated. A new road passes north-south through the battlefield from a large ditch at the north edge of the Battlefield Site. The road curves around a bend in the resaca and extends on to the south edge of the photo. Two other roads or fence lines parallel this road toward the east, possibly indicating property boundaries. A pipeline scar oriented north-west-southeast crosses through the center of the battlefield. Large segments of the battlefield and the area north between the resaca and the north ditch and west of the resaca have been plowed, some in circular rows. A stock pond has been excavated at the southeast edge of Palo Alto Pond. The resaca north and west of the battlefield appears to contain water at several locations.

The enlarged segment of apparently the same photo includes the area where fieldwork was conducted and the meander to the south (Figure 10). Water can be seen on the north side of the dam and along a narrow strip down the center of the resaca just south of the dam. The low hill on the west side of the resaca has been cleared of trees and circular- plowed around the hill. The single building, seen on the earlier photos and on the USGS topographic map and located near the west end of the backhoe trenching area is situated at the southeast edge of this plowed field. A road oriented northeast-southwest extends from the dam just north of where fieldwork was conducted, across the south part of the hill to the west part of the meander. Another road appears to join this road from the northwest along the east side of the hill. The north-south road and fence in the 1950 photo, crossing the hill and extending south, appears to cross the bend in the resaca over a new dam, with a distinct change in vegetation on either side of the fence. The resaca, from the dam above the backhoe trenching area southward

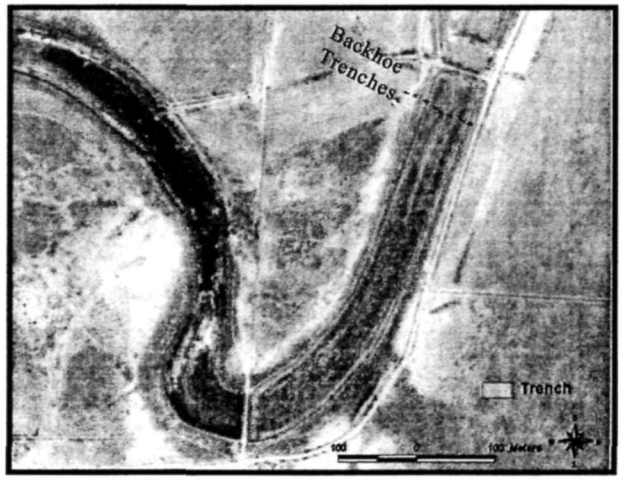


Figure 10. Part of 1962 aerial photograph showing project area. Note dam across resaca at the meander bend and ditch along each side of resaca between the two dams.Digital copy courtesy National Park Service.

to the lower dam, appears to have a fairly dense cover of grass or forbs, darker on the west side of the dam. The banks are lined with a sparse growth of trees and shrubs. Vegetation further north along the west part of the meander changes to a dense growth of shrubs or trees extending northward so that the rectangular area seen on the 1950 photo has been covered over. There appears to be a ditch on either side of the resaca between the two dams, but the scale and quality of the photo are insufficient to provide certainty. There is a connecting road between the road along the east side of Palo Alto Resaca and the north-south road through the battlefield to the east.

Comment - Although the aerial photo showing the larger area provides information regarding land modifications, including large areas under cultivation or cleared to support ranching activities and the addition of fences and roads, the overall quality is relatively poor and does not provide details at specific locations. The enlargement of the broader study area, however, provides evidence of another dam on the resaca, at the bend in the meander, and good detail regarding changes in the vegetation along the resaca. It also provides the best view of the building near the northern dam. The later photos show the ditches along the resaca more clearly, but they are evident on this enlargement of the project area. The ditches apparently were built between 1950 and 1962.

1977

Characteristics - The enlargement of a substantial portion of a black-and-white aerial photo covers most of the Battlefield Site at a scale of about 1:10,000. The enlarged portion of probably the same aerial photo shows the broader study area (see Figure 2) at a scale of about 1 inch = 100 meters.

Analysis - Among the prominent features on the larger image are the resacas, Palo Alto Pond, Arista Hill, the north-south road through the battlefield, the northwest-southeast pipeline, and extensive disturbances from plowing. The most obvious new features are two stock ponds, one in the central part of the battlefield and one just northwest of Arista Hill. The two small dams on the Palo Alto Resaca to the west have ponds backed up behind them. The segment of the Resaca just north of the dam, near the current backhoe trenching area, appears to have been put under cultivation from the east bank westward to a fence line, including part of the hill, and north to a point where the resaca begins to meander toward the northwest. The area west of the fence line contains a moderately dense cover of trees and shrubs in contrast to the cleared area to the east. East of Palo Alto Resaca, large parts of the battlefield have been cleared and possibly plowed. The three concentrations of buildings seen on earlier photos are still evident, inside the meander to the north, at the south edge of the meander east of the current Visitor's Center location, and west of there toward Paredes Line Road (the latter not as distinct as in earlier photos).

On the enlarged segment of the photo, the vegetation in the resaca channel is probably grass and forbs broken very little by shrubs or taller vegetation. The banks of the resaca where fieldwork was conducted contain a fairly dense cover of trees, shrubs, and possibly cordgrass. Inside the west segment of the resaca meander, and extending east to the north-south fence line, is a moderately dense cover of trees and shrubs to the north and a cultivated strip to the south. There are two dirt roads along the east side of Palo Alto Resaca that connect toward the south. The east-west road connecting these dirt roads with the north-south road through the battlefield is now the south edge of a cleared area, with the area south containing a moderately dense cover of trees or shrubs. The cluster of buildings at the south edge of the meander bend is clearly evident. The single structure shown on previous photos and on the USGS topographic map near where the fieldwork was conducted has been removed.

Comment - Although of relatively poor quality, the larger area photo does show some changes in the battlefield and adjacent terrain, including the addition of several stock ponds. The enlargement of the project area provided a good view of the vegetation in the resaca and nearby, as well as the continued cultivation or clearing of lands adjacent to the resaca. The probable ditches along the resaca between the two dams are still evident.

1992 Black-and-White

Characteristics - A pair of black-and-white aerial photos taken on November 2, 1992, at a scale of 1:6,000 provided stereoscopic coverage of much of the broader project area, including the place where fieldwork was conducted. The photos covered more area toward the battlefield to the east but with less coverage to the west of the project area than the color-infrared photos of the same year reviewed below.

Analysis - The Palo Alto Resaca is dry on the south side of the dam located just north of the area where fieldwork was conducted. The pond on the north side of the dam is dry. Dense trees line the pond edges. The dry floor of the pond is smooth with a scatter of shrubs, in contrast to the remainder of the resaca channel bed. A relatively dense growth of trees extends along the west (right) bank of the resaca although the tree cover increases in density on that side toward the south, but fewer trees grow on the east (left) bank. A large cultivated area is located on the east side of the resaca. There is a scarred strip between the cultivated area and the east bank of the resaca. This is the first clear indication of the two ditches encountered during the current project. The ditch on the east side is more evident. The width measured from the photo using only the approximate scale is 4 m (as noted later, the width measured in the field was 4.5 m). The resaca contains scattered shrubs throughout with greater density along the ditches and outer edges of the resaca, but the central part is mostly grass or forbs. West of the resaca, a curved fence marks the south end of the cultivated area seen on earlier photos. A concentration of taller trees is seen adjacent to the fence near the right bank of the resaca. The vegetation cover south of the cultivated field is fairly sparse, with scattered open areas. Numerous vehicle tracks can be seen throughout. East of the resaca, the marsh area shown on historical maps in the central part of the battlefield is clearly evident (seen on the south photo outside the stereoscopic coverage). Other cultivated areas can be seen in the battlefield area, and there are several two-track dirt roads crossing between the resaca and the cultivated areas to the east. Two rectangular stock ponds can be seen on either side of the former marsh area, one to the northeast and the other to the southwest. The backdirt from excavating these ponds appears to have been placed along the two long edges in both cases. Both ponds have mesquite or other trees growing on the long sides. Just north of the northernmost stock pond there seems to be a rectangular feature that may be a corral with trees growing along the perimeter. On the other hand, this may be a result of plowing that left rows of shrubs or grass. There appears to be a small structure at one corner of the pond. There also seems to be a ditch leading from the southwest corner of this stock pond west along the south side of the cultivated area and extending nearly to the Palo Alto Resaca. There may be other ditches along the fields but the photo coverage is not sufficient to determine if this is the case. The stock pond northwest of Arista Hill is also evident in one of these photos.

Comment - These were the best quality photos available for study., providing detail about vegetation, water conditions in the resaca and stock ponds, cultivation activities, and other landscape features.

1992 Color-Infrared

Characteristics - A pair of color-infrared aerial photos taken on November 2, 1992, at a scale of 1:6,000 provided stereoscopic coverage of all of the broader project area. They also cover the area further south and west, but with less area to the east of Palo Alto Resaca than the black-and-white photos taken the same day.

Analysis - In the area where backhoe trenching was conducted, the ditch at the west edge of the resaca is more distinctive than on the black-and-white photos because of dense low vegetation with scattered tall trees or shrubs. Sparse vegetation grows along the edges of the east ditch, although the density increases further south. With the improved relief on this set of air photos, as contrasted with the black-and-white set, both banks of the resaca seem to be for the most part an extension of the adjacent land surface rather than the elevated surface usually identified as a levee. The resaca channel is a linear depression below the land surface existing beyond the banks; however, the land surface on the west side seems to drop slightly

in elevation for a short distance just beyond the resaca bank and then becomes fairly level. The fence line west of the resaca, at the south edge of the cultivated area, is shown to be in a depression extending a short distance to the south containing a small concentration of taller vegetation, possibly mesquite. A group of buildings east of the NPS Visitor Center appears on both the black-and-white and color-infrared photos. These buildings are not indicated on the USGS topographic map until the 1983 revision but were seen on many of the earlier photos.

Comment - The relief on this stereo pair is more exaggerated than on the black-and-white set of the same date. All of the structures located at the south edge of the meander, east of the present Visitor Center, are clearly shown. Differential growth on each side of the north-south fence line is clearly seen, indicating the differences in land use practices on either side.

1996

Characteristics - This color-infrared photo shows the broader project area (see Figure 2). The scale is about 1 inch = 100 meters.

Analysis - Only a few changes in the landscape are noted compared to the 1992 photos. There is water in the pond on the north side of the dam just north of the fieldwork location. The ditch on either side of the resaca is seen as a thin line at the channel edges. The vegetation in the resaca channel seems to be grass or forbs with a consistent pattern throughout. The banks are lined with trees and shrubs, with several open areas on both sides. The rectangular area in the west part of the meander evident on the 1950 photo is again apparent, but as vegetation rather than water. In 1962, this area was covered with dense vegetation which became a sparse grass cover in 1992. Here, it appears as a bright red rectangular area.

Comment - Although the color-infrared properties provide good information about the vegetation, the overall quality is only fair.

2000

Characteristics - An enlarged segment of the original color-infrared photo, with a scale of about 1 inch = 100 meters (Figure 11), shows the broader project area (see Figure 2). In addition, there are two other color-infrared photos. One is an enlargement showing all of the National Battlefield Site at a scale of about 1:10,000. The other is an enlargement of the battlefield area at a scale of about 1:4,800, with locations of the U.S. and Mexican forces superimposed.

Analysis - The landscape on the smaller-scale photo is very similar to the 1996 photo. One difference is that the resaca in the western part of the meander has been cleared of the taller vegetation except along the banks, and standing water is seen where the rectangular feature can be observed on some of the previous photos. On the enlargements, an additional pond of water is shown in the resaca southwest of the battlefield. This probable stock pond just northwest of Arista Hill appears to contain a small amount of water, while the ones toward the central part of the battlefield and in the southeast edge of Palo Alto Pond have been filled in. The large areas of disturbance for farming and ranching are still evident throughout the battlefield and elsewhere, as are many of the other more localized modifications which have occurred over the previous decades (e.g., the pipeline, dams, roads, and buildings).

Comment - This set of photos provides a variety of views that aided in understanding the battlefield features mentioned in the literature, as well as showing what is essentially the current landscape.

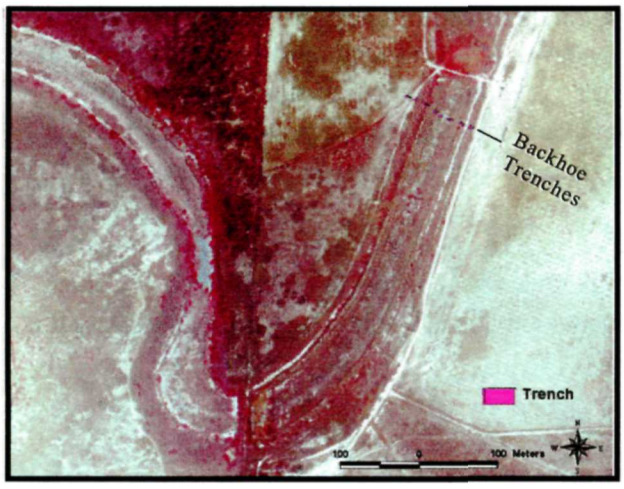


Figure 11. Part of color-infrared aerial photograph taken in 2000 showing meander of Palo Alto Resaca where backhoe trenching occurred (upper right). Note structures outside meander bend and changes since 1934, including ground clearing for ranching/farming, addition of fence line and dams. Digital copy courtesy National Park Service.

Field Research

Introduction

A geoarcheological investigation was conducted at PAAL at the request of the National Park Service. The project area encompasses a key part of the main battlefield. Physical conditions at this site are thought to have had a significant, but ill-defined influence on the conduct and outcome of the military engagements (Haecker and Mauck 1997). Defining the conditions and their role are among the primary goals of this investigation. Although no artifacts or direct evidence of the battle were found, the investigation produced credible indications of local conditions at the time of the engagements, which bear on the means of military prosecution as a whole.

Location and Geomorphic Setting

Palo Alto Battlefield National Historic Site is located 8.5 km north of the City of Brownsville, Cameron County, the southernmost county in Texas (see Figure 1). Although some characteristics of the site have changed over the past 158 years, others have remained relatively constant, providing useful insights into conditions of the past. The Site is on the lower (eastern) river delta of the Rio Grande, 13 km northeast of the modern river channel and 20 km southwest of the Laguna Madre, a restricted, sometimes hypersaline bay on the western Gulf of Mexico (Brown et al. 1980). The Rio Grande discharges directly into the Gulf through its main channel, but also flows into the Laguna Madre through smaller channels. Before reaching the Gulf near Brazos Island, the Rio Grande crosses the Gulf Coastal Plains physiographic province (Fenneman 1946; Ferguson 1986). This region has very low relief, particularly near the Gulf. As a result, the channel gradient of the Rio Grande is extremely low, <0.001% (Geological Survey 1985). Although other factors are also important, low gradient tends to divert the force of the river's flow laterally, causing the channel to broaden, shallow, meander, and sometimes bifurcate (Morisawa 1968). Throughout its lower valley, the main channel of the Rio Grande is highly meandering, but maintains a net southeastward flow direction almost to the river's mouth, where the channel turns generally eastward.

A river's ability to transport sediment also depends, in part, on its channel gradient. Within the zone of low gradient, the capacity of the Rio Grande—that is, the quantity of sediment carried per unit volume of water—is greatly reduced, causing rapid sedimentation. Sedimentation at the mouth of the Rio Grande has created a large delta. Most large river deltas have two components: submarine or subaqueous and subaerial (above-water). The submarine component of the Rio Grande delta lies both within the Laguna Madre and offshore, beneath the Gulf of Mexico. The subaerial portion is a broad, low-relief, low-gradient geomorphic terrain known as a delta plain. Approximately 7000 km^2 in areal extent, the Rio Grande delta plain is 110 km wide, extending from northernmost Cameron County southward into the state of Tamaulipas, Mexico, and 120 km long (straight-line distance), from western Hidalgo County, Texas, downstream to the river's mouth in neighboring Cameron County (see Figure 1). Sea-level fluctuations, changes in channel alignment, and other events in the geological past have caused the location of the Rio Grande delta to shift. The present delta has been relatively stable throughout the Late Pleistocene and Holocene epochs, for at least the past 13,000 years (Winker 1991).

The perennial Rio Grande flows through its delta plain along a continuous, meandering course. In contrast, the surface of the delta plain is characterized by intermittent distributary drainage related to episodic riverine flooding. Distributary streams bifurcate or separate in the downstream direction, whereas tributary streams coalesce or conjoin. At the head (upstream edge) of the flat delta plain, the river banks are so low that, in the past, the Rio Grande overflowed frequently. The unconfined flow of floodwater separated into multiple distributary channels radiating across the delta plain on both the Texas and Mexico sides of the river. When the flood receded and the river returned to its principal channel alignment along the central axis of the delta, many of the small meandering distributary channels were abandoned or cut off from the river, and were partly infilled with sediment from the waning flood waters.

This process partitioned the distributary channels into numerous disconnected narrow depressions with irregularly curving orientations. These channel segments are known by their Spanish name, resacas. When the Rio Grande flooded often, some resacas retained water throughout the year and became shallow oxbow lakes. Others were generally dry, although the water table was high enough to maintain wetland vegetation in many of them. An individual resaca might persist for a few millennia, but all are ephemeral landforms that eventually fill with sediment deposited during successive floods. Sediment is also deposited between the resacas, creating the flat delta plain, beneath which there are many filled resacas. Over the past century, impoundment and withdrawal of river water at many points upstream have greatly reduced the flow of the Rio Grande, essentially preventing riverine flooding in the lower valley (Brown et al. 1980). Without occasional inflows of sediment-laden floodwater, most of the delta plain is now effectively inactive, no longer evolving in the traditional manner. No new resacas are forming and the existing resacas may be more permanent features on the landscape. Although an individual resaca may persist longer, gradual erosion of its banks will ultimately cause it to widen, infill, and disappear.

In general, the nature of the delta plain probably changed little throughout prehistory until the Historic Era. Elevations are low, nowhere greater than 7 m in PAAL (Geological Survey 1983). The flat terrain is disrupted only by depressions indicating relict channel systems. Historically, much of the area was grassland dominated by gulf cordgrass, also called sacatal grass (*Spartina spartinea*), with smaller areas of diverse Tamaulipan brushland and seasonal and permanent wetlands (Weaver 1999). Following the introduction of cattle ranching and tillage agriculture, most notably after the mid-1800s, the flora changed dramatically. Essentially pure stands of the thornshrubs honey mesquite (*Prosopis glandulosa*) and huisache (*Acacia farnesiana*) appeared quickly and continued to increase in area and density. These aggressive plants were part of the regional flora, but were able to spread into disturbed habitats much more rapidly than were other brush species. Land clearing and cultivation reduced the continuity of the grassland and Tamaulipan brushland in particular. In addition, large parts of the delta plain were artificially drained or otherwise modified with respect to surface-water movement. Combined with reduced riverine flooding over the same period, deliberate drainage resulted in a loss of permanent wetland acreage, in part through a general decline in the water table and possible increase in groundwater salinity or other solute concentrations. The present investigation will attempt to define these changes more closely.

Geomorphic Processes

The principal geomorphic processes that might potentially affect archeological sites in the lower Rio Grande valley include: flood-induced erosion, deposition, and channel avulsion; hurricane storm surge and other effects; localized sheet, rill, and gully erosion and slope-wash deposition, particularly in and around resacas; deflation and eolian deposition; and bioturbation and pedoturbation (Brown et al. 1974; Brown et al. 1980). Superimposed on these natural processes are a wide variety and intensity of human activities, which have modified the landscape in ways comparable to those of the most widespread and enduring effects of nature. Potential cultural-resource distribution and site integrity are likewise influenced by these processes, as discussed below.

Riverine Flooding and Channel Realignment

Records of flood frequency and severity compiled by Patterson (1965) include data relevant to the Battlefield project area. Since the mid- to late-1800s, large-scale water diversion and storage in reservoirs upstream have mediated flow through the lower Rio Grande. There are, however, at least partial records of unabated flooding on the Rio Grande in Cameron and nearby counties from as early as 1746 (Patterson 1965:483-491). River waters have risen as much as 10 to 13 m in response to heavy rainfall and runoff upstream from observation points in this area. Flood events of this magnitude can cause extensive channel erosion, even while depositing large amounts of suspended sediment across the delta plain. The sediment caused rapid aggradation of the delta plain. Brown et al. (1980:Fig 10, p. 56) reported that Holocene deposits near the river in eastern Cameron County may be 18 to 20 m thick. This conclusion is consistent with observations by Brewton et al. (1976), Pryor et al. (1976), Williams and et al. (1977), and Neck (1985), who investigated stratigraphic sequences at locations in the Battlefield area. The combined effects of channel erosion and overbank deposition altered the alignment of the river channel, forcing the abandonment of some reaches while new watercourses were cut and established. Comparison of maps and aerial photographs of part of the lower valley from the middle 1800's to the present chronicled numerous major shifts in the alignment of the main channel and repeated avulsion of channel segments (Brown et al. 2002). In addition, distributary channels on the delta plain formed new resacas and modified or even destroyed others. In only 150 years, the lower Rio Grande and its distributary network transformed much of the delta plain. By the late Twentieth Century, however, the flow of the Rio Grande had been so reduced and controlled that conditions became essentially static. Widespread flooding, which was perhaps an annual event in the historical past, could then occur only during a major hurricane.

Hurricane Storm Surge and Related Processes

Large parts of the Rio Grande delta along the river and adjacent to the Laguna Madre lie at elevations below 7 m. These areas are particularly susceptible to the effects of hurricanes and tropical storms. When these severe storms approach the region or make landfall, they can cause high winds, intense rains, and storm surge. Storm surge occurs when strong onshore winds drive seawater toward the shore, producing a temporary, but marked rise in sea level of as much as 7 to 8 m. From either the shallow bay or up the river valley, seawater may penetrate far inland, often accompanied by violent, wind-driven waves. Almost the entire Palo Alto Battlefield Site lies below 7 m elevation and is susceptible to storm-surge inundation along the alignment of discontinuous resacas extending westward from the Laguna Madre to Palo Alto Resaca at the main battle site (see Brown et al. 1974; Brown et al. 1980: Active Processes Map; and Geological Survey 1983). In addition, tropical storms and hurricanes produce heavy rainfall, which cannot drain quickly because of the heightened sea level and low-gradient slopes. In 1967, Hurricane Beulah made landfall in northern Mexico just south of Brownsville, producing a 6-m storm surge, winds of 219 km/hr, and maximum rainfall of 635 mm (Griffiths and Ainsworth 1981:155). The storm surge extended as much as 25 km inland over the Rio Grande delta plain (Brown et al. 1974). With normal runoff impeded, the storm's prolonged intense rainfall caused freshwater flooding extending more than 100 km up river. Tropical storms and hurricanes caused some of the most extreme floods during the period of historical record, submerging thousands of square kilometers for as long as a year or more in the most poorly drained areas of the lower delta plain (Grozier et al. 1968). In these areas, flooding can occur regardless of whether the river or streams rise, because the low slope gradient and large numbers of resacas and other closed depressions reduce the rapidity of runoff and prolong inundation. The Battlefield project area is poorly drained and was almost entirely flooded during Beulah as a result of impoundment of rain water and runoff. Possible local effects of this storm will be addressed later in this report.

Sheet, Rill, and Gully Erosion and Slope-wash Deposition

In contrast to the episodic effects of riverine flooding and hurricanes, many geomorphic processes operate on a nearly continuous basis. Sheet, rill, and gully erosion and slope-wash deposition affect much of the landscape, particularly where ground cover is limited (Strahler 1964). Riverine flooding of the entire delta plain formerly resulted in extensive sheet erosion and deposition of suspended sediment, but even diffuse runoff may strip away a thin sheet of soil. Runoff can also incise shallow isolated microchannels or rills, which may develop into gullies. Gullies are ephemeral channels deeper than rills, but likewise poorly integrated with trunk streams. Gullies form where runoff collects and flows along shallow linear depressions or swales, causing rapid incision. The effect of runoff can be enhanced by loss of ground cover and direct disturbance of soil cohesion. In the past, cultivation and high concentrations of livestock may have affected the Battlefield project area adversely by stripping grasses and other plants, disrupting the soil, and creating pathways to capture and convey runoff, increasing sheet and rill erosion and forming gullies.
Sheet, rill, and gully erosion mobilizes sediment, which is then transported farther downslope and redeposited. Despite the diffuse nature of these erosional processes, their effects are widespread and large quantities of sediment can be redistributed in this manner. Soil type, gradient and continuity of slope, density of ground cover and extent of soil disturbance, and the amount and rate of water flow all affect these processes. With the loss of riverine flooding and restoration of natural ground cover following cessation of grazing and cultivation, erosion within the Battlefield Site has undoubtedly been reduced. The only parts of the local landscape that may be materially affected by these processes are the relatively steep banks of the resacas, which do exhibit some effects of runoff-induced erosion. Narrow aprons of redeposited sediment are found at the base of both banks of the Palo Alto Resaca. During periods when this and other resacas retained water, livestock were attracted to them preferentially, and gained access to the water by climbing down the banks, disturbing the soil. Waves produced by wind during periods when the resacas contained shallow water also may have eroded the banks, but these effects were probably minor and temporary.

Deflation and Eolian Deposition

Another geomorphic process particularly associated with the resacas is deflation or wind erosion. Deflation occurs under conditions similar to those that enhance sheet erosion and rilling: minimal ground cover and direct disturbance of the soil. Cultivation and grazing would have increased the potential for deflation throughout the Battlefield Site in the past, but those influences have been eliminated since the 1990s. Today, and in prehistory, when natural ground cover prevailed, the principal areas of deflation are the floors of the resacas. If a resaca has been dry for an extended period, ground cover may be reduced, causing the soil to be exposed. Winds blowing across a resaca may erode the soil and transport particles that are silt to fine sand-size out of the resaca onto flat areas of the surrounding delta plain. Conversely, sudden inundation of the resaca floor following heavy rains or floods may kill grasses and many other plants, making the soil prone to deflation when the water level drops. Soils within the resacas contain a large amount of gypsum, a saltlike mineral that inhibits growth of many plants and that also causes the soil to become poorly consolidated and more easily eroded. Examination of the soil profiles within and adjacent to the Palo Alto Resaca during the present investigation revealed the presence of redeposited organic-rich, clayey, gypy sediment mantling the ground surface around the resaca and diminishing in thickness with distance from the bank. The predominant wind direction in this area is southeast to south-southeast during most of the year, which would favor deposition of eolian sediment on the west-northwest side of this resaca (Griffiths and Bryan 1987:16-17, 83). As discussed later in this report, data from the stratigraphic study concur with this conclusion. The entire delta plain would also receive small amounts of fine-grained eolian sediment deflated from the nearby wind-tidal flats along the Laguna Madre and from the offshore barrier island (see Brown et al. 1980).

Bioturbation and Pedoturbation

Bioturbation and pedoturbation cause sediment to be redistributed locally, both within a soil profile and at the ground surface, although usually with minimal downslope transport. The term bioturbation refers collectively to a combination of processes whereby organisms (including humans) disturb the soil through root growth, burrowing, compaction, ingestion, devegetation, direct erosion, plowing, and many other activities (see Waters 1992). Impact on soil structure is direct and immediate, but may persist for extended periods. Bioturbation affects all soils, but particularly those of the Rio Grande delta plain where the water table lies at shallow depth. The burrowing Laguna Madre fiddler crab (*Uca subcylindrica*) is especially common in the resacas, where the water table is shallowest (Fig. 13). Burrowing may mix and redistribute the entire soil profile within a few years.

Similar effects can result from pedoturbation, which is a mechanical process involving spontaneous movement of fluids and solids within the soil. These movements modify the soil profile internally as a result of induced volume and density changes related to expansive clays, growth and dissolution of mineral filaments and nodules, differential loading and compaction, vibration, chemical reactions, accumulation or decomposition of organic and other materials, and other effects. Within the Battlefield project area, clayey soils undergo marked volumetric changes, particularly as a result of alternate wetting and drying. During extended dry periods, they also crack to great depth, allowing coarse organic matter to penetrate directly. Growth of secondary minerals such as gypsum is another common effect. Ground water flowing through the saturated portion of wet soils and in the capillary zone above the water table provides a ready source of dissolved minerals. When the local ionic concentration of these waters reaches a threshold, gypsum and other minerals precipitate in the soil. Gypsum forms elongate crystals and rounded nodules, both of which grow displacively, thereby disturbing the soil profile. These processes tend to disrupt stratification and the integrity of buried cultural resources.

Anthropogenic Effects

The intensity of human activity in the lower Rio Grande valley is probably greater now than at any time in the past. Prehistoric hunting, gathering, and small-scale agriculture produced artifactual and other physical records, but probably had no enduring effect on the landscape. Land use intensified in the middle 1700s as a result of widespread grazing, which affected vegetative cover and erosion (Chipman 1992). A few buildings and other structures from the early Historic Period are extant, but the intrinsic character of the regional environment was not permanently changed. By the Nineteenth Century, however, the pace of land clearing and leveling and water-resource exploitation began to accelerate with increased agriculture, particularly grazing and cultivation of cash crops. Yet the resulting changes in landscape remained modest until the modern era, when large-scale agriculture, canal, road, and utility construction, groundwater withdrawal, oil and gas drilling and sand mining, commercial and industrial development, housing encroachment, and recreation began to effect permanent environmental consequences throughout the region. Today, the lower Rio Grande valley is undergoing unprecedented changes, many of which may affect cultural resources. Archeological assessments permit discovery and characterization of these resources.

Stratigraphic Investigations

Genetic Stratigraphy

To meet the objectives of the present investigation, a series of eight backhoe trenches were excavated at closely spaced intervals across the project area (Figures 12 and 13). These trenches were located within and adjacent to the Palo Alto Resaca and reached depths of $\leq$2.5 m (Table 1). The stratigraphic profiles observed in the trenches were described and illustrated in detail and sampled for analyses of radiocarbon age, carbon stable-isotope ratios, and identification of fossil pollen and diatoms (Tables 2-7; Figures 13-20). Results of the stratigraphic assessment are summarized in Table 2 and discussed below. In general, the strata consist of widespread fluvial overbank (delta-plain) deposits, palustrine (fresh- to brackish-marsh) deposits within the resaca, and a variable thickness of eolian sediment blanketing the landscape outside of the resaca. Most of the eolian sediment derived from the palustrine deposits and was deflated from the resaca during dry periods, then redeposited nearby. Results of the analyses of sediment samples are presented in full in Appendices A, B and C. Together with geomorphic, stratigraphic, and historical data collected and compiled during the present investigation, the analyses provide the basis for detailed interpretation of the geomorphic evolution and paleoenvironment of this area. These findings have significant implications regarding the prehistory and history of PAAL, particularly the main battleground and the conditions under which the battle was waged.

Profile Descriptions

Three of the eight backhoe trenches were excavated on the flat delta plain, close to, but outside of the Palo Alto Resaca: numbers 1, 5, and 8 (Figure 12). Trenches 2 and 7 were emplaced along the steep banks, one on each side of the resaca. The other three trenches, 3, 4, and 6, were within the resaca floor, with trench 4 in the center. Low, linear mounds or berms of earth parallel the resaca on both sides, at the top of each bank. Backhoe trench 1 (BHT-1) was excavated just west-northwest of the mound on the western side of the resaca. That side is identified as the "right bank" in Figure 13, a stratigraphic/geomorphic cross section bisecting the project area. The line of section runs south-southeastward through all eight trenches. Topographic evidence demonstrates that the distributary channel that became the Palo Alto Resaca was formerly a generally southward- to southeastward-draining branch of the larger Resaca de los Cuates to the north (Geological Survey 1983). When looking directly downstream, the right-hand side of a channel is, by convention, called the right bank.

Backhoe Trenches (BHTs) 1, 5, and 8

BHT-1 was the deepest of the eight trenches, reaching 250 cm below ground surface (Table 3; Figures 14 and 15). Stratum 1 is a brown to dark brown, 41-cm thick layer of very silty slightly sandy clay (silty clay) capping the profile. The clay is sticky and plastic when moist and the sand is very fine. White filaments of gypsum are common, as are gypsic nodules below 30-cm depth. Stratum 1 has the characteristics of an Ay horizon: it is a surficial to shallow-buried layer of fine-grained mineral sediment lacking primary sedimentary structures (i.e., internal bedding related to deposition); and it contains an abundance of fine grained, evenly dispersed organic matter (humus), imparting a darker color value than that of the subjacent horizon (Soil Survey Division Staff 1993). This particular A horizon contains gypsum, denoted by the lowercase "y" (from yeso, the Latin word for gypsum) in the horizon-classification symbol.

Strata 1 and 2 are separated by a gradual, wavy boundary, indicating ongoing bioturbation. Stratum 2 lies between 41 and 75 cm depth and is composed of very sandy clayey to very clayey silt (silt loam), slightly coarser than the texture of Stratum 1, although the sand is very fine. The predominant colors are reddish brown to yellowish red, resulting from progressive concentration of oxidized iron. Sediment from Stratum 1 has been displaced downward into Stratum 2 along burrows and root conduits, causing discrete mottling.

Table 1. Dimensions and location of backhoe trenches across Palo Alto Resaca.

Trench Number	Length (m)	Width (m)	Maximum Depth (m)	UTM Coordinates Northing	Easting
BHT-1	2.8	1.5	2.5	28 79 285	6 52 775
BHT-2	8.1	1.5	2.1	28 79 279	6 52 790
BHT-3	3.7	1.75	1.2	28 79 270	6 52 800
BHT-4	3.0	1.65	2.4	28 79 265	6 52 807
BHT-5	2.6	1.2	1.7	28 79 253	6 52 846
BHT-6	2.5	1.2	1.8	28 79 262	6 52 818
BHT-7	5.5	1.1	1.5	28 79 257	6 52 837
BHT-8	3.0	1.1	1.4	28 79 289	6 52 766

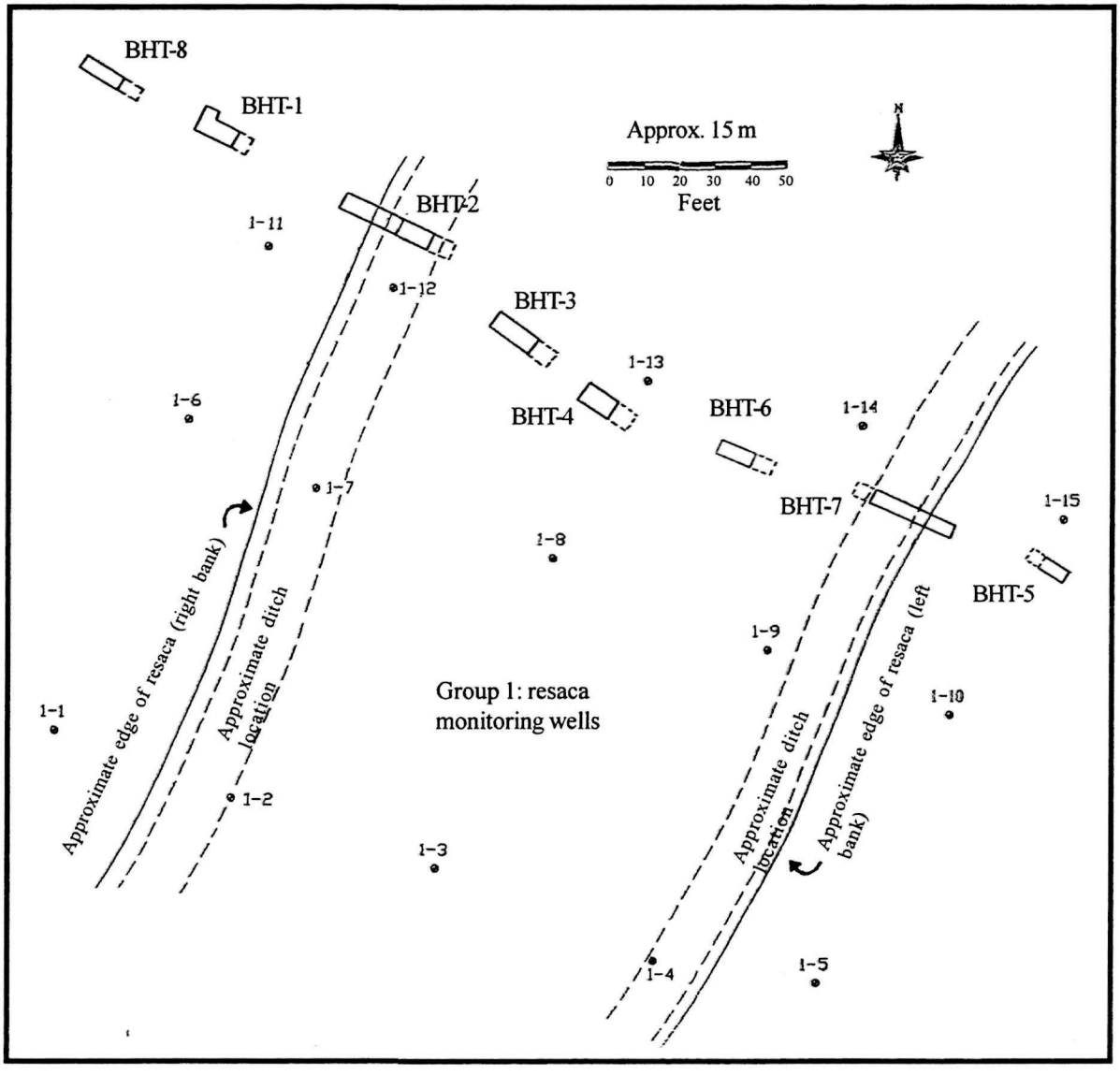


Figure 12. Approximate location and size of backhoe trenches excavated across Palo Alto Resaca and adjacent plain in the vicinity of Group 1 Groundwater Monitoring Wells. Dashed lines on each trench indicate ramp access.

Table 2. Summary of stratigraphic profiles exposed in backhoe trenches at Palo Alto Resaca, Palo Alto Battlefield National Historic Site, Cameron County, Texas. See Tables 3-7 and Figures 13-18.

Backhoe trench	Elevation AMSL	Maximum depth	Stratigraphic description, [interpretation]
BHT-1	4.5 m	250 cm (water table at 245 cm)	Ay-By-Bw profile [late Holocene to modern eolian deposit, overlying late Holocene fluvial overbank (delta-plain) deposit]
BHT-2	4.5+ m	210 cm (~4.9 m)	Spoil-Ay-Bk profile [historical spoil, overlying late Holocene to modern eolian deposit, overlying late Holocene fluvial overbank (delta-plain) deposit]
BHT-3	3.5 m	123 cm	Ay-Agy profile [late Holocene to modern palustrine (resaca) deposit]
BHT-4	3.5 m	244 cm (water table at 205 cm)	A-Agy-Bgyc-By profile [late Holocene palustrine (resaca) deposit, overlying late Holocene fluvial overbank (delta-plain deposit]
BHT-5	4.5 m	173 cm	Ay-ABy-By profile [late Holocene to modern eolian deposit, overlying late Holocene fluvial overbank (delta-plain) deposit]
BHT-6	3.5 m	176 cm (water table at 172 cm)	A-Ay profile [late Holocene to modern palustrine (resaca) deposit]
BHT-7	4.5+ m	150 cm (~4.7 m)	Spoil-Ay-By profile [historical spoil, overlying late Holocene to modern eolian deposit, overlying late Holocene fluvial overbank (delta-plain) deposit]
BHT-8	4.5 m	140 cm	Ay-By-Bw profile [late Holocene to modern eolian deposit, overlying late Holocene fluvial overbank (delta-plain) deposit]

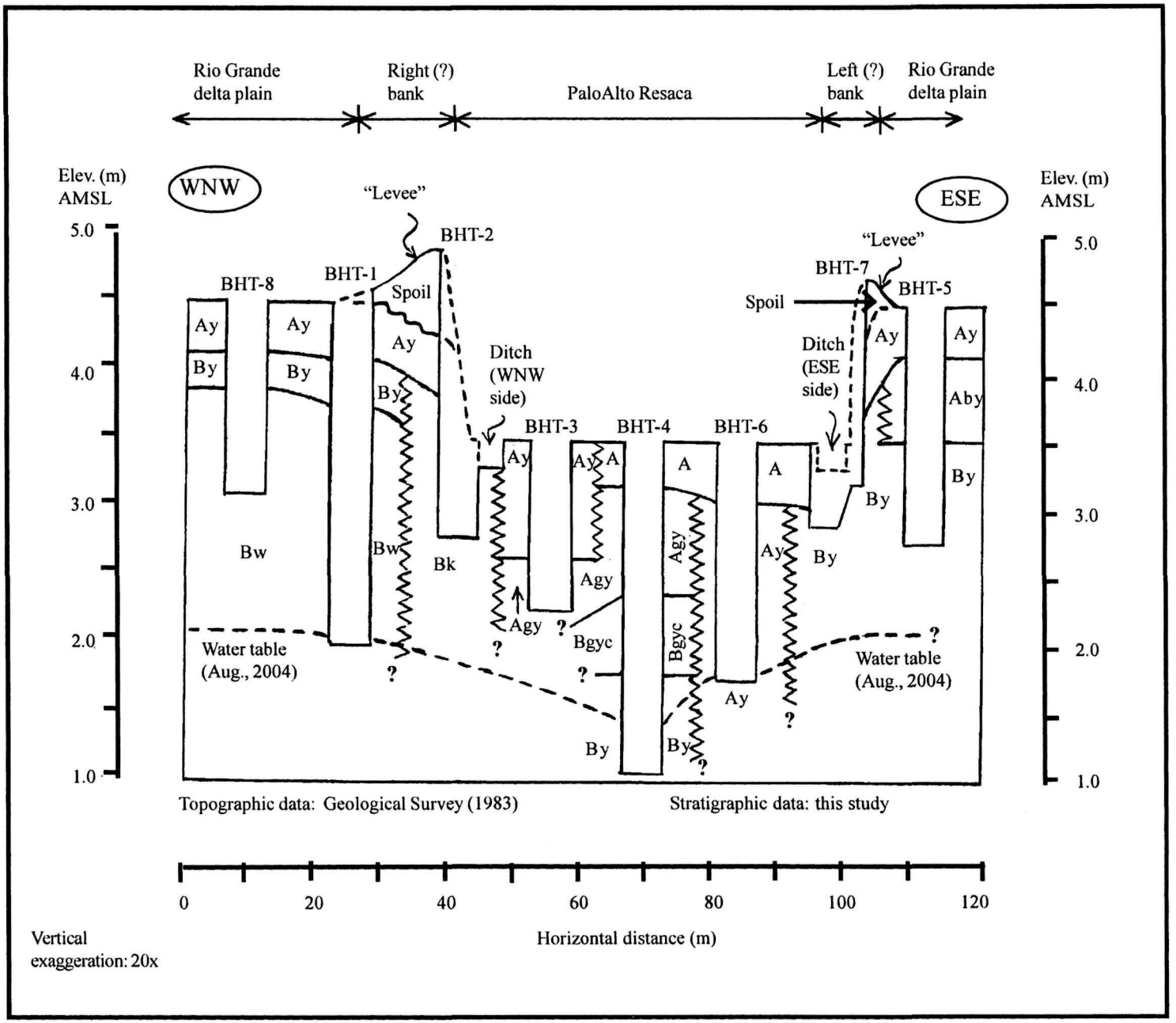


Figure 13. Stratigraphic and geomorphic cross section through Palo Alto Resaca, west-northwest to south-southeast, correlating exposures in eight backhoe trenches.

Most of the burrows were made by fiddler crabs (*Uca subcylindrica*), which move large amounts of organic matter underground from the surface and pack their burrow walls with dark-colored fecal pellets. Gypsum filaments and nodules are present throughout, but are less abundant than in Stratum 1. These properties identify Stratum 2 as a By horizon: it is a mineral sediment, formed beneath an A horizon (in this case, an Ay horizon); and it lacks primary sedimentary structures, has accumulated gypsum through illuviation, and its color is distinctly higher in chroma and redder in hue than that of the superjacent Ay horizon.
A gradual, smooth to wavy, bioturbated boundary separates Stratum 2 from Stratum 3, which is a Bw horizon consisting of mottled brown very silty sand (sandy loam) lacking visible gypsum. The sand is very fine. The lowercase "w" in the horizon symbol indicates that the properties that make this a B horizon are weakly developed, primarily because its coloration is less reddened than that of the By horizon and there has been no or little accumulation of oxidized iron, gypsum, or other translocated materials. Depth range of Stratum 3 is 75 to 250 cm, the limit of exposure. The water table was reached at 245 cm depth. Burrows of fiddler crabs extend downward to the water table from the ground surface.

Stratum 1 is finer-grained and more organic-rich and gypsic than Strata 2 and 3. Strata 2 and 3 are similar to one another except that Stratum 2 is slightly finer grained, rubified (reddened with oxidized iron), and moderately gypsic. Texture is upward fining through the profile, which may indicate that the intensity of floods responsible for depositional events was waning. Flood frequency may have waned because of reduced river discharge or redirection of the flow axis to a different part of the delta. The textures of Strata 2 and 3 are characteristic of delta-plain deposits. Sandy to silty sediment was deposited in laterally extensive beds as flood waters spread across the broad, low-relief, deltaic landform. Water flow was discontinuous, allowing oxygen to penetrate into the sediment to shallow depth during dry intervals. Oxidation converted the available iron to its ferric species, which is stable under most near-surface conditions and produces red and yellow coloration. Iron is present in a variety of mineral grains and adsorbed on organic matter and clays. Relative to Stratum 1, Stratum 2 is less gypsic, but its gypsum nodules are evenly distributed; whereas in Stratum 1, nodules are confined to the lowermost part of the Ay horizon. Evidently, gypsum moved downward from the upper part of the Ay horizon concurrent with sedimentation and vertical accretion. The clay in Stratum 2 also appears to have been translocated from Stratum 1.

Clayey sediment is deposited preferentially in those parts of the landscape where water flow is slowed, as in a resaca. The combination of clay, gypsum, and perhaps organic matter in Stratum 1 would appear to imply these materials had a common source. If that source was the resaca, the amount of Ay-type sediment should decrease with distance from the resaca. The thickness of the Ay horizon in BHT-8 (Table 4) was indeed less than in BHT-1, which is consistent with the hypothesis that the resaca was the probable source (Table 2; Figure 13). The thickness of the Ay horizon in BHT-1 is similar to that in BHT-5, on the east-southeastern side of the resaca close to the bank. There, downward movement of clay, organic matter, and gypsum from the Ay horizon has overprinted the upper part of the underlying By horizon, creating a transitional ABy horizon (Figure 13). In addition, the By horizon is much thicker in BHT-5 and adjacent BHT-7, on the left bank, than in BHT-1 or BHT-8. The greater quantity of gypsum in the profiles east-southeast of the resaca provides evidence of a mechanism of preferential distribution, as discussed below.

Table 3. Stratigraphic profile exposed at the west-northwestern end of Backhoe Trench 1 (BHT-1). See Table 2 and Figures 12-15 and 19).

Location, geomorphic setting, and notes concerning profile description

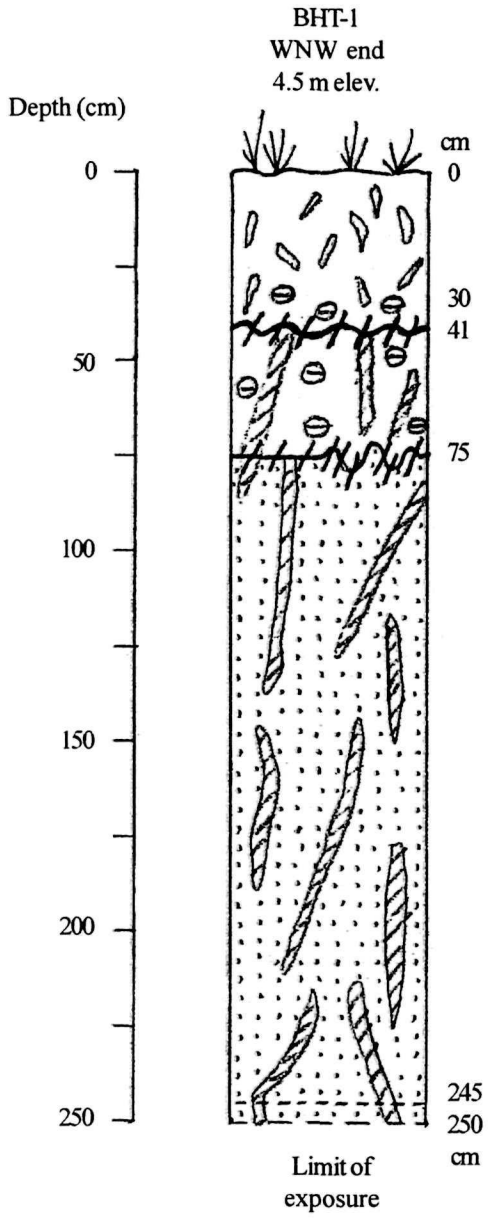
- Palo Alto Battlefield National Historic Site, southern Cameron County, Texas; 4.5 km south-southeast of the community of Los Fresnos; 0.7 km east of Farm-to-Market Road 1847; elevation is approximately 4.5 m AMSL (Geological Survey 1983); Rio Grande delta plain; right(?) (west-northwestern) bank of Palo Alto Resaca immediately west-northwest of the earthen berm ("levee") at its distal margin.
- Proximal vegetation: camphorweed (*Heterotheca subaxillaris*), sea ox-eye daisy (*Borrichia frutescens*), and shoregrass (*Monanthochloe littoralis*) (Jones and Wipff 2003).
- Nominal soil: Laredo silty clay loam, saline (Fluventic Haplustoll) (Williams et al. 1977:15-17, 86, Sheet Number 67). The soil exposed in BHT-1 is somewhat similar to the nominal Laredo series, but is gypsiferous throughout its upper solum and rubified throughout its lower solum. At best, the local soil would represent a taxadjunct to the Laredo series.
- Profile described on 11 August 2004. Vertical sequence, from ground to maximum depth of exposure, with interpretations enclosed in brackets: 1) gypsiferous organic-rich very silty slightly sandy clay [eolian sediment derived from proximal palustrine deposit (hydric soil in resaca)]; and 2) very sandy silt to very silty sand [fluvial overbank (delta-plain) deposits].
- Sediment is permanently water saturated below 245 cm depth, but was probably saturated throughout much of the profile on a seasonal to annual basis prior to artificial drainage during the early Twentieth Century. At present, the ground water is gypsiferous.
- Texture characterized in both geological and pedological terms, aided by 10x magnification and use of grain-size comparator in the field. Pedological terms are shown in parentheses.
- Soil colors were determined in the field under ambient lighting and moisture conditions, using Munsell Soil Color Charts.
- Depths were measured relative to the present ground level at the west-northwestern end of the trench, just beyond the distal toe slope of the earthen berm ("levee").

Profile description

Ay — Stratum 1: 0 to 41 cm; dry and pulverulent from 0 to 5 cm; color variable, brown (7.5YR 5/3) from 0 to 5 cm, brown (7.5YR 4/2) from 5 to 25 cm, and dark brown (7.5YR 3/2) from 25 to 41 cm, with few fine distinct yellowish red (5YR 4/6) mottles from 36 to 41 cm; very silty slightly sandy clay (silty clay); sand is very fine; moderate to strong medium angular blocky structure breaking to fine angular blocky; friable, slightly moist; moderately plastic; moderately sticky; common white gypsum filaments throughout, with few fine rounded soft gypsum masses below 30 cm; few fine rounded soft ferric oxide masses in walls of pores; common fine roots; few fine pores, most partly filled with gypsum or linked gypsum masses; gradual (bioturbated), wavy boundary. Late Holocene to modern eolian deposit derived from palustrine deposit in contiguous resaca during dry periods.

By — Stratum 2: 41 to 75 cm; predominantly reddish brown to yellowish red (5YR 4/4-4/6), with very dark gray (7.5YR 3/1) burrow fills and brown (7.5YR 4/3-4/4) mixed zones around old burrows, and with few fine faint yellowish red (5YR 4/6) mottles; very sandy clayey to very clayey silt (silt loam); sand is very fine; weak to moderate fine angular blocky structure; friable, slightly moist; moderately plastic; moderately sticky; few white gypsum filaments and few medium rounded gypsum masses and nodules, soft with firm exteriors, white when dry, translucent and colorless when moist; few fine roots; few fine pores, mostly open; common nearly vertical medium open and filled burrows of fiddler crabs (*Uca subcylindrica*); 1- to 2-cm thick zones packed with dark-colored fecal pellets around each burrow; few whole terrestrial and aquatic snail shells (*Rabdotus* sp. and cf. *Gyraulus* sp., respectively); gradual, smooth to wavy boundary. Late Holocene fluvial overbank (delta-plain) deposit.

Bw — Stratum 3: 75 to 250 cm (limit of exposure; originally excavated to greater depth, but lower walls quickly collapsed; ground-water level rose to 245 cm while trench was open); predominantly brown (7.5YR 4/4), with very dark gray (7.5YR 3/1) zones around burrows and with few fine distinct yellowish red (5YR 4/6) mottles; very silty sand (sandy loam), with zones of very silty slightly clayey sand (loam) around burrows: sand is very fine; weak to moderate fine angular blocky structure; very friable, wet; few fine roots; common very fine and fine pores; common vertical and steep-angled medium open and filled burrows of fiddler crabs (*Uca subcylindrica*); 1- to 2-cm thick zones packed with dark-colored fecal pellets around each burrow. Late Holocene fluvial overbank (delta-plain) deposit



Stratum 1: O to 41 cm; Ay horizon; color variable, brown to dark brown (7.5 YR 5/3 - 3/2) very silty slightly sandy clay; late Holocene to modern eolian deposit derived from contiguous resaca.

Stratum 2: 41 to 75 cm; By horizon; reddish brown to yellowish red (5YR 4/4 - 4/6) very sandy clayey to very clayey silt; gypy; late Holocene fluvial overbank (delta-plain) deposit.

Stratum 3: 75 to 250 cm; Bw horizon; brown (7.5YR 4/2) very silty sand; bioturbated; water table at 245 cm; late Holocene fluvial overbank (delta-plain) deposit.

Figure 14. Stratigraphic profile exposed in Backhoe Trench 1 (BHT-1). See also Figures 12, 13, and 15.

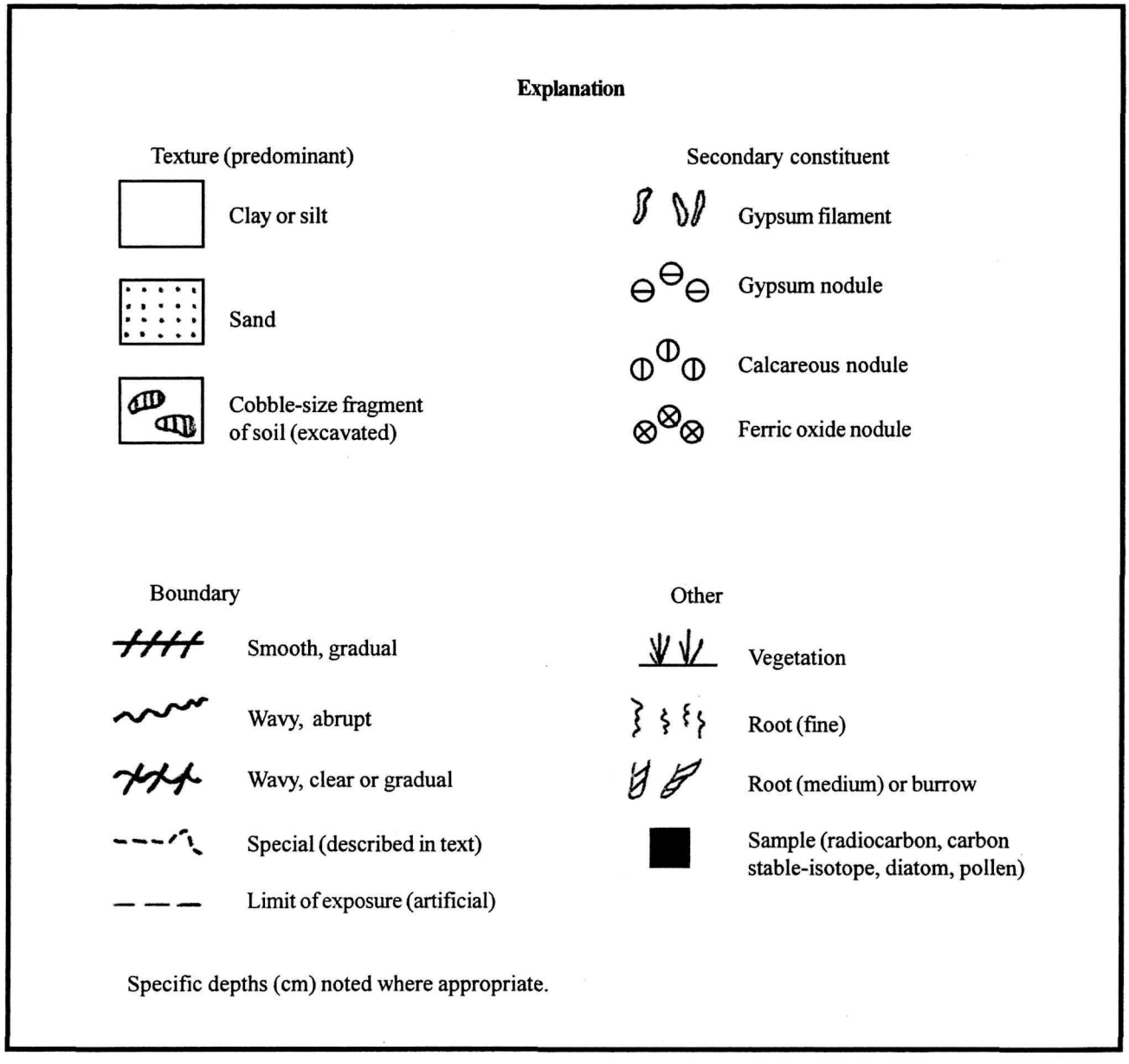


Figure 15. Explanation of symbols used in stratigraphic profiles.

Table 4. Stratigraphic profile exposed at the east-southeastern end of Backhoe Trench 8 (BHT-8). This profile is very similar to that exposed in BHT-1. See Table 2 and Figures 12-15.

Location, geomorphic setting, and notes concerning profile description

- Palo Alto Battlefield National Historic Site, southern Cameron County, Texas; 4.5 km south-southeast of the community of Los Fresnos; 0.7 km east of Farm-to-Market Road 1847; elevation is approximately 4.5 m AMSL (Geological Survey 1983); Rio Grande delta plain; right(?) (west-northwestern) bank of Palo Alto Resaca approximately 10 m west-northwest of the earthen berm ("levee").
- Proximal vegetation: small honey mesquite (*Prosopis glandulosa*), camphorweed (*Heterotheca subaxillaris*), sea ox-eye daisy (*Borrichia frutescens*), and gulf cord-grass (*Spartina spartinae*) (Jones and Wipff 2003).
- Nominal soil: Laredo silty clay loam, saline (Fluventic Haplustoll) (Williams et al. 1977:15-17, 86, Sheet Number 67). The soil exposed in BHT-8 is somewhat similar to the nominal Laredo series, but is gypsiferous throughout its upper solum. At best, the local soil would represent a taxadjunct of the Laredo series.
- Profile described on 12 August 2004. Vertical sequence, from ground to maximum depth of exposure, with interpretations enclosed in brackets: 1) gypsiferous organic-rich very clayey sandy silt [eolian sediment derived from proximal palustrine deposit (hydric soil in resaca)]; and 2) clayey silt to silty sand [fluvial overbank (delta-plain) deposits].
- Water table was not reached.
- Texture characterized in both geological and pedological terms, aided by 10x magnification and use of grain-size comparator in the field. Pedological terms are shown below in parentheses.
- Soil colors were determined in the field under ambient lighting and moisture conditions, using Munsell Soil Color Charts.
- Depths were measured relative to the present ground level at the east-southeastern end of the trench.

Profile description

Ay — Stratum 1: 0 to 37 cm; dry and pulverulent from 0 to 11 cm; dark brown (7.5YR 3/3) with many white filaments; very clayey sandy silt (silty clay loam); sand is very fine; moderate fine angular blocky structure; firm to very firm, slightly moist; moderately plastic; moderately sticky; many gypsum filaments throughout; few fine roots; many fine open pores, some with incipient clay linings; gradual (bioturbated), wavy boundary. Late Holocene to modern eolian deposit derived from palustrine deposit in contiguous resaca during dry periods.

By — Stratum 2: 37 to 62 cm; brown (7.5YR 5/4) with few to common medium faint brown (7.5YR 4/2) mottles; very clayey sandy silt (silty clay loam); sand is very fine; moderate fine angular blocky structure; firm, slightly moist; moderately plastic; moderately sticky; common gypsum filaments; few fine roots; many fine open pores; common nearly vertical medium open and filled burrows of fiddler crabs (*Uca subcylindrica*); 1- to 2-cm thick zones packed with dark-colored fecal pellets around each burrow; clear, smooth to wavy boundary. Late Holocene fluvial overbank (delta-plain) deposit, partly overprinted with downward translocated (bioturbated) sediment from Stratum 1.

Bw — Stratum 3: 62 to 140 cm (limit of exposure); brown (7.5YR 5/4) with few to common medium faint brown (7.5YR 4/2) mottles to 108 cm; very silty clayey sand (sandy loam): sand is very fine; weak fine angular blocky structure; very friable, moist; moderately plastic; moderately sticky; few fine roots to 104 cm; many fine open pores, some with incipient clay linings; common vertical and steep-angled medium open and filled burrows of fiddler crabs (*Uca subcylindrica*) to 108 cm; 1- to 2-cm thick zones packed with dark-colored fecal pellets around each burrow. Late Holocene fluvial overbank (delta-plain) deposit.

Backhoe Trenches (BHTs) 2 and 7

BHTs 2 and 7 were deliberately excavated directly on the right and left banks, respectively. A main purpose for this placement was to expose the deposits composing the linear earthen mounds on both sides of the resaca. The mound on the right bank lies at the top of the slope. The mound on the opposite side is comparably located, but is lower and narrower than the right-bank mound. Each mound is approximately 600 m long, but is linked to other mounds both up- and downstream (Geological Survey 1983). At BHT-2,

sediment draping the upper slope of the right bank and the proximal edge of the delta plain (Tables 2 and 5; Figures 12 and 16).

Combined thickness of the layers varied from 59 to 63 cm, increasing toward the resaca. The sediment composing the fragments was similar to the strata observed in BHT-1. The Los Fresnos topographic map (Geological Survey 1983) covering this area depicts the mounds and identifies them as levees. An artificial levee is, by definition, a water-containment structure, usually for flood control. The levees are linked to others to the north and south and are associated with a complex of small earthen dams, stock tanks, and ditches along a 2.5-km reach of the resaca. Because they completely surround this reach, although not at a constant elevation, the levees would not have kept water flowing through the resaca from breaching and spreading outward. Instead, they appear to have been intended to exclude unconfined flood waters flowing across the delta plain, which might damage the water-supply complex. Flood waters from the Rio Grande formerly did cover the delta plain and an extreme hurricane storm surge could reach this location, even today.

Those segments of the levees within the current project area were evidently constructed from loose sediment produced when digging ditches on the resaca floor. Two ditches were excavated, one along and partly into the right bank and the other at the toe of the left bank. The ditches would have conveyed water downstream from a small artificial reservoir immediately north of the current project area to a stock tank to the south, in order to maintain water for livestock when the rest of the resaca was dry (see discussion of historical site modification later in this report). Additional evidence of the relationship between the levees and ditches was revealed at BHT-7. BHT-7 exposed deposits within the left bank and levee and revealed a cross-sectional view of the contiguous ditch, which was partly filled with recently deposited sediment (Table 6; Figure 17). That ditch was approximately 0.5 m wide and 0.5 m deep. The levee on the right bank is larger (higher and greater in cross-sectional area and volume) than the left-bank levee, perhaps because the ditch on the right side cut part way into that bank, generating a larger quantity of spoil. The ditch on the left cut only into the toe of the bank, producing a relatively small amount of spoil.

The stratigraphy of deposits seen in trenches 2 and 7 was somewhat similar, but in place of the By horizon in BHT-7, BHT-2 exposed a Bk horizon (Figure 13). This difference will be discussed below. Properties of the Ay horizon in trenches 2 and 7 were closely comparable, but in BHT-2, Ay was overlain by a discrete, <1-cm thick layer of silt, directly beneath the spoil. The loose silt was light colored and did not appear to be part of the dark, clayey, cohesive Ay horizon, or to be intrinsically related to the heterogeneous spoil. Whether the silty layer was deposited before or during disposal of the spoil is unclear. Certainly, the silt layer is no younger than the date of spoil placement, which was contemporary with excavation of the ditches. It is, however, entirely possible that the silt layer represents an historical ground surface. Given the probable low rate of sedimentation within the resaca following reduction of flood frequency in the Nineteenth and Twentieth centuries, this thin silty layer may well have been part of the surface over which combatants trod during the Battle of Palo Alto. Although radiocarbon assay and other types of geochronometry probably are not suitable for addressing this hypothesis directly, future archeological studies in the area should be conducted in full awareness of this possibility. Only the discovery of temporally diagnostic historical artifacts in close association with the silt layer would likely resolve this question.

Table 5. Stratigraphic profile exposed at the west-northwestern end of Backhoe Trench 2 (BHT-2).
See Table 2 and Figures 12-13, 15-16, and 19).

Location, geomorphic setting, and notes concerning profile description

- Palo Alto Battlefield National Historic Site, southern Cameron County, Texas; 4.5 km south-southeast of the community of Los Fresnos; 0.7 km east of Farm-to-Market Road 1847; elevation is approximately 4.9 m AMSL (Geological Survey 1983); Rio Grande delta plain; right(?) (west-northwestern) bank of Palo Alto Resaca at the earthen berm ("levee"). The 33- to 30-cm high berm was created by placement of soil excavated from a ditch on the west-northwestern side of the resaca. Maximum thickness of the soil placed on the bank was 70 cm. Prior to placement of the excavated soil, the bank was a convex natural slope with no levee.
- Proximal vegetation: small honey mesquite (*Prosopis glandulosa*), camphorweed (*Heterotheca subaxillaris*), and sea ox-eye daisy (*Borrichia frutescens*) (Jones and Wipff 2003).
- Nominal soil: Laredo silty clay loam, saline (Fluventic Haplustoll) (Williams et al. 1977:15-17, 86, Sheet Number 67). The soil exposed in BHT-2 is similar to the nominal Laredo series, but is gypsiferous throughout its upper solum. The local soil may represent a taxadjunct of the Laredo series.
- Profile described on 11 August 2004. Vertical sequence, from ground to maximum depth of exposure, with interpretations enclosed in brackets: 1) mixed fragments of two soil types [historical spoil excavated from proximal ditch at the west-northwestern edge of the resaca and placed on the resaca bank]; 2) gypsiferous organic-rich very silty clay [eolian sediment derived from proximal palustrine deposit (hydric soil in resaca)]; and 3) very sandy silt [fluvial overbank (delta-plain) deposit].
- Water table was not reached.
- Texture characterized in both geological and pedological terms, aided by 10x magnification and use of a grain-size comparator in the field. Pedological terms are shown below in parentheses.
- Soil colors were determined in the field under ambient lighting and moisture conditions, using Munsell Soil Color Charts.
- Depths were measured relative to the present ground level at the west-northwestern end of the trench.

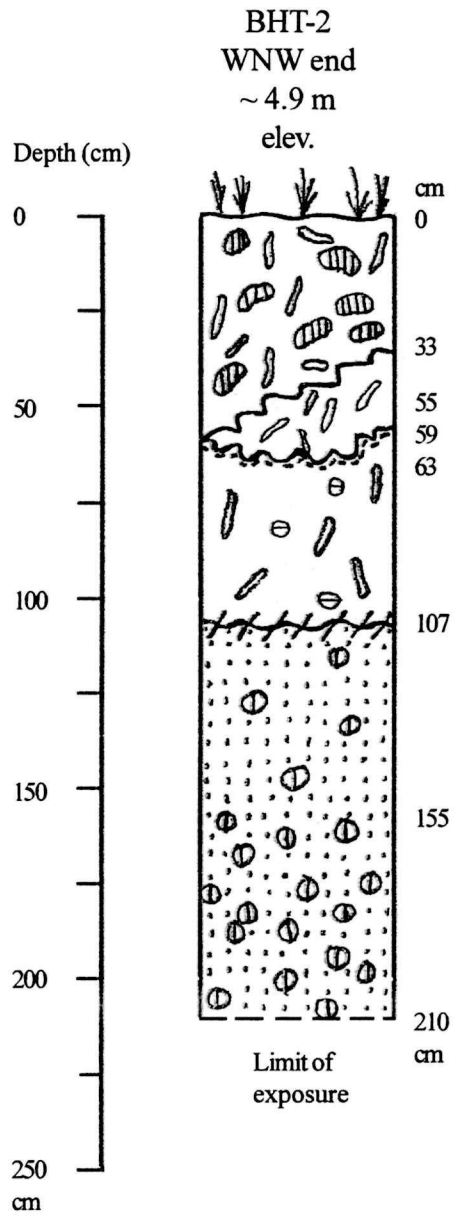
Profile description

Spoil — Stratum 1: 0 to 33-59 cm; partly compacted fragments of black (7.5YR 2.5/1) silty clay (silty clay), with a few reddish brown to yellowish red (5YR 4/4-4/6) cobble-size fragments of very sandy clayey to very clayey silt (silt loam); many gypsum filaments throughout; abrupt, wavy to irregular boundary. Historical spoil excavated from the proximal ditch at the west-northwestern edge of the resaca.

Spoil — Stratum 2: 33-59 to 59-63 cm; partly compacted fragments of strong brown (7.5YR 5/4) very sandy clayey silt (silt loam) with few gray (7.5YR 5/1) and reddish brown (5YR 4/4) mottles; many gypsum filaments throughout; abrupt, wavy to irregular boundary, inclined downward to the east-southeast and locally penetrative into the subjacent natural soil (Stratum 3, Ay horizon) as a result of loading and differential compaction.

Ay — Stratum 3: 59-63 to 107 cm; brown (7.5YR 5/3); overlain by <1-cm thick layer of pulverulent silt locally (ground surface prior to ditch excavation?); very silty slightly sandy clay (silty clay); sand is very fine; moderate to strong medium angular blocky structure breaking to fine angular blocky; friable, slightly moist; moderately plastic; moderately sticky; common white gypsum filaments throughout with few fine rounded soft gypsum masses; few fine roots; few fine pores, most partly filled with gypsum; few to common whole terrestrial snail shells (*Rabdotus* sp.), common only along lower boundary; gradual (bioturbated), wavy boundary, inclined downward to the east-southeast. Late Holocene to modern eolian deposit derived from palustrine deposit in contiguous resaca during dry periods.

Bk — Stratum 4: 107 to 210 cm (limit of exposure); brown (7.5YR 4/4) with very dark gray (7.5YR 3/1) zones around burrows; very silty sand (sandy loam), with zones of very silty slightly clayey sand (loam) around burrows: sand is very fine; weak to moderate fine angular blocky structure; very friable, wet; moderately plastic; moderately sticky; few to common medium to coarse rounded hard calcareous nodules, increasing below 155 cm; few fine roots; common fine pores; common vertical and steep-angled medium open and filled burrows of fiddler crabs (*Uca subcylindrica*); 1- to 2-cm thick zones packed with dark-colored fecal pellets around each burrow. Late Holocene fluvial overbank (delta-plain) deposit.



Stratum 1: 0 to 33-59 cm; spoil (mix of sediment from excavation of ditch on WNW side of resaca); historical.

Stratum 2: 33-59 to 55-63 cm; spoil (sediment from excavation); historical.

Stratum 3: 55-63 to 107 cm; Ay horizon; brown (7.5 YR 5/3) very silty slightly sandy clay; thin layer of silt along upper boundary; gypy; late Holocene to modern eolian deposit derived from contiguous resaca.

Stratum 4: 107 to 210 cm (limit of exposure); Bk horizon; brown (7.5 YR 4/4) very silty sand; calcareous; late Holocene fluvial overbank (delta-plain) deposit.

Figure 16. Stratigraphic profile exposed in Backhoe Trench 2 (BHT-2) See also Figures 12, 13, and 15.

Table 6. Stratigraphic profile exposed in the northern wall and east-southeastern end of Backhoe Trench 7 (BHT-7). See Table 2 and Figures 12-13, 15, 17. and 20).

Location, geomorphic setting, and notes concerning profile description

- Palo Alto Battlefield National Historic Site, southern Cameron County, Texas; 4.5 km south-southeast of the community of Los Fresnos; 0.8 km east of Farm-to-Market Road 1847; elevation is approximately 4.7 m AMSL (Geological Survey 1983); Rio Grande delta plain; left(?) (east-southeastern) bank of Palo Alto Resaca at the earthen berm ("levee").
- Proximal vegetation: small, even-aged honey mesquite (*Prosopis glandulosa*), elbow bush (*Forestiera angustifolia*), and bluewood condalia (*Condalia hookeri*); few large yucca (*Yucca treculeana*); camphorweed (*Heterotheca subaxillaris*), sea ox-eye daisy (*Borrichia frutescens*), and gulf cord-grass (*Spartina spartinae*) (Jones and Wipff 2003).
- Nominal soil: Chargo silty clay (Vertic Ustochrept) (Williams et al. 1977:10-11, 86, Sheet Number 67). The soil exposed in BHT-8 is very different from the nominal Chargo series: it is gypsiferous throughout and not visibly calcareous and has a more rubified lower solum (note, however, that as a nominal Ustochrept, the Chargo series would be expected to exhibit reddening beyond the 10YR to 7.5YR hues described by Williams et al. 1977). The local soil more closely resembles the taxadjuncts of the Laredo series exposed in trenches west of the resaca.
- Profile described on 12 August 2004. Vertical sequence, from ground to maximum depth of exposure, with interpretations enclosed in brackets: 1) mixed fragments of two soil types [historical spoil excavated from proximal ditch at the east-southeastern edge of the resaca and placed on the resaca bank]; 2) gypsiferous organic-rich very silty clay [eolian sediment derived from proximal palustrine deposit (hydric soil in resaca)]; and 3) very sandy clayey silt [fluvial overbank (delta-plain) deposit].
- Water table was not reached.
- Texture characterized in both geological and pedological terms, aided by 10x magnification and use of grain-size comparator in the field. Pedological terms are shown below in parentheses.
- Soil colors were determined in the field under ambient lighting and moisture conditions, using Munsell Soil Color Charts.
- Depths were measured relative to the present ground level at the east-southeastern end of the trench.

Profile description

Spoil Stratum 1: 0 to 22-31 cm; partly compacted fragments of very dark gray (7.5YR 3/1) silty clay (silty clay), with a few reddish brown to yellowish red (5YR 4/4-4/6) pebble- to cobble-size fragments of very sandy clayey silt (silt loam); many gypsum filaments throughout; abrupt, wavy to irregular boundary. Historical spoil excavated from the proximal ditch at the east-southeastern edge of the resaca.

Ay Stratum 1: 22-31 to 100 cm; dark gray (7.5YR 4/1) with few white filaments; very silty clay (silty clay); moderate fine angular blocky structure; firm, slightly moist; moderately plastic; moderately sticky; few gypsum filaments throughout; few fine roots; many fine open pores; gradual (bioturbated), wavy boundary. Late Holocene to modern eolian deposit derived from palustrine deposit in contiguous resaca during dry periods.

By Stratum 2: 100 to 150 cm (limit of exposure); reddish brown (5YR 4/4) with very dark gray (7.5YR 3/1) burrow fills and zones around burrows; very sandy clayey silt (silt loam); sand is very fine; moderate fine angular blocky structure; firm, slightly moist; moderately plastic; moderately sticky; common gypsum filaments; few fine roots; many fine open pores; common nearly vertical medium open and filled burrows of fiddler crabs (*Uca subcylindrica*); 1- to 2-cm thick zones packed with dark-colored fecal pellets around each burrow. Late Holocene fluvial overbank (delta-plain) deposit.

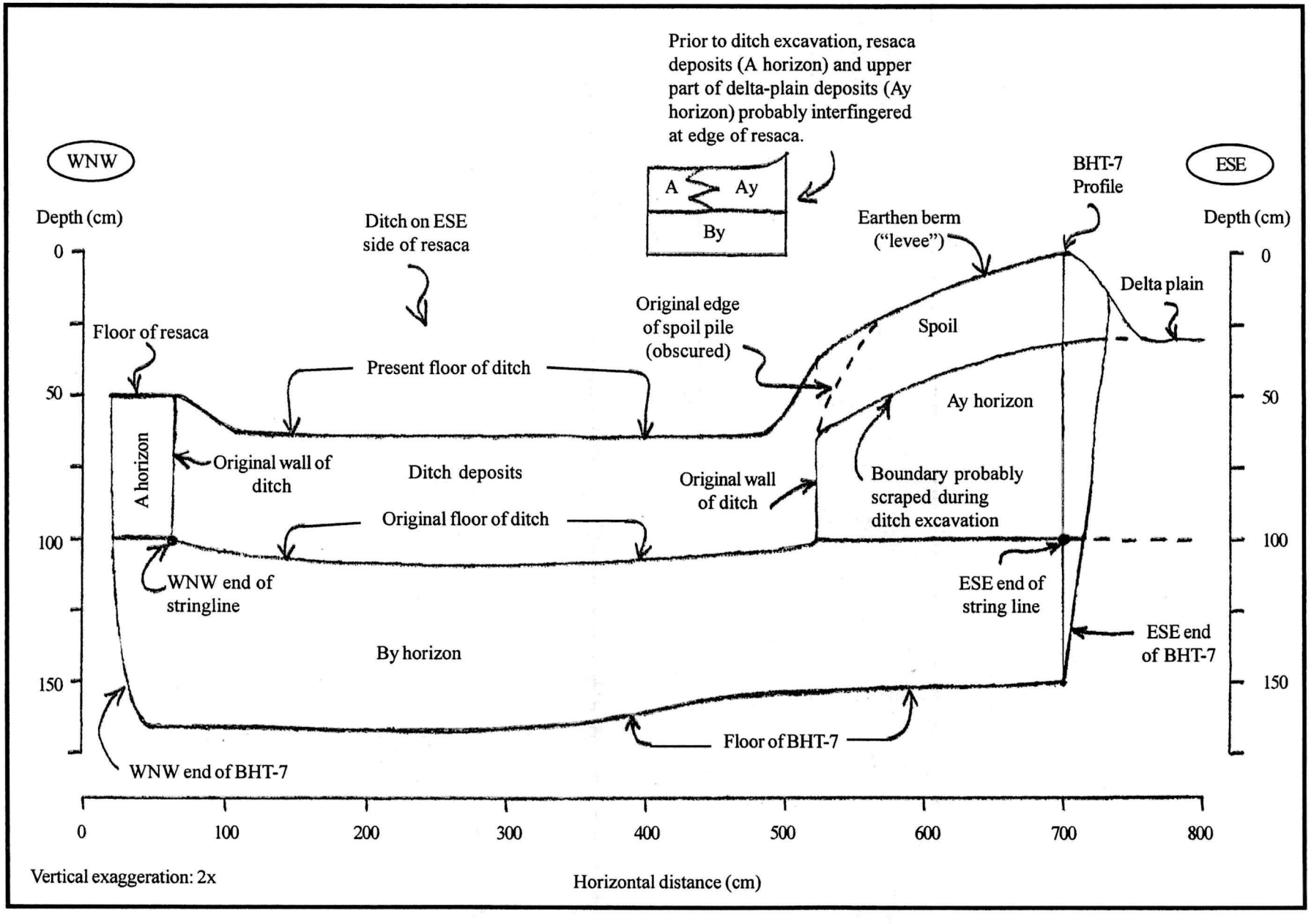


Figure 17. Stratigraphic cross section through ditch, levee, and left bank (east-southeastern side) of Palo Alto Resaca, as exposed in Backhoe Trench7 (BHT-7).

Backhoe Trenches (BHTs) 3, 4, and 6

The three trenches excavated on the resaca floor provided a wealth of data regarding Holocene conditions at the PAAL. Table 2 and Figure 13 summarize the stratigraphy at these trenches. Only the profile in BHT-4 will be described in detail, but it is representative of all three. BHT-4 was excavated along the center line of the Palo Alto Resaca to a depth of 244 cm. Gypy ground water seeped into the trench slowly and eventually rose to 205 cm below ground surface. The profile was described and sampled before the water reached that level. Whether the water might have risen yet higher is uncertain.

Stratum 1 is a 31-cm thick layer of black, organic-rich, silty clay (silty clay) containing a few, isolated grains of very fine sand. It is an A horizon, lacking gypsum (Table 7; Fig. 18). The surficial stratum in BHT-6 to the east-southeast is also an A horizon, but that in BHT-3 to the west-northwest is an Ay. The unequal distribution of gypsum in the resaca deposits will be discussed below. In BHT-4, Strata 1 and 2 are separated by a clear, wavy boundary.

Stratum 2, from 31 to 111 cm depth, is an Agy horizon, consisting of dark gray to very dark gray, organic-rich, silty clay (silty clay) with rare very fine sand and common gypsic filaments and nodules. The lowercase "g" indicates that this horizon is strongly "gleyed," which means that the sediment has remained water-saturated since the time it was deposited, preventing atmospheric oxygen from permeating to this depth. As a result, much of the iron remains ferrous or chemically reduced. Reduced iron produces colors with low chromas, imparting distinctive shades of black, green, gray, blue, and intermediate colors. The high clay content and organic-rich nature of these deposits have probably helped maintain gleying conditions. Gleyed sediment often retains unaltered organic matter, which yields particularly useful radiocarbon and carbon stable-isotope data. The lower boundary of Stratum 2 is clear and irregular.

Subjacent Stratum 3, 111 to 170 cm depth, is likewise gleyed and gypsic and has the same texture as Strata 1 and 2, but also contains nodules of ferric oxide. The small, isolated masses of ferric iron may have resulted from localized intrusion of oxygen along root conduits or temporary soil fractures that remained open to the former ground surface long enough to oxidize the iron. Reduced iron concentrates around particles of organic matter, but this iron generally will not precipitate except under oxidizing conditions. The presence of nodules or concretions of iron and some other materials is a factor in soil classification, denoted by the lowercase "c." Stratum 3 is, therefore, classified as a Bgyc horizon. Color of this horizon is dark greenish gray with mottles. The lower boundary is gradual and irregular, but appears to represent a mobile zone of overprinting, whereby the properties of this horizon are being progressively superimposed onto the underlying stratum. In fact, bioturbation may have obscured the original boundary, of which there is a possible ghost at approximately 156 cm depth. Sediment from Stratum 3 has penetrated to 192-cm and even deeper locally, within the burrows of fiddler crabs.

Evidently, the Bgyc horizon has expanded downward at the expense of Stratum 4, a Byb horizon, which is exposed between 170 and 244 cm depth. Stratum 4 is brown and mottled, but not gleyed, and did not develop under conditions of water saturation. It is texturally identical to the overlying strata. Gypsic filaments and nodules are abundant. Because of the aggressive relationship between the Bgyc and Byb horizons, Stratum 4 is clearly relictual and is classified as a buried-soil horizon, indicated by the lowercase "b" in the symbol. The A and perhaps a B horizon under which the Byb originally developed were either stripped away by erosion prior to deposition of Stratum 3 or were completely overwhelmed by overprinting. Early erosional truncation of the buried soil appears most likely, followed by bioturbation. The Bygc and Byb horizons are, therefore, separated by a stratigraphic unconformity, which was subsequently modified to a pedologic boundary. Eventually, the Byb horizon may be destroyed entirely. In terms of its original properties, Byb is genetically unrelated to the horizons now overlying it. This is the basis for identifying it as a buried-soil horizon. The Byb horizon is, however, generally similar to Strata 1 through 3 of this profile. It is unlikely that there is a significant age difference between Strata 3 and 4, although some time gap would be understandable.

The profile exposed in BHT-4 was sampled for analysis of radiocarbon and carbon stable isotopes and identification of fossil pollen and diatoms. Results of these analyses are discussed in detail later in this report. In general, the deposits range in age from the middle Holocene to the present and have an isotopic composition that varies through time. Pollen from a number of plant taxa was recovered and most of these plants are found at the site today (Appendix A; see additional discussion below). Diatoms were not recovered, almost certainly because their remains were destroyed by unfavorable geochemical conditions (Appendix B).

See photographs of soil profiles in BHT-1, BHT-2, BHT-4, and BHT-7 in Figures 19 and 20.

Table 7. Stratigraphic profile exposed at the west-northwestern end of Backhoe Trench 4 (BHT-4). See Table 2 and Figures 12-13, 15, 18 and 20).

Location, geomorphic setting, and notes concerning profile description

- Palo Alto Battlefield National Historic Site, southern Cameron County, Texas; 4.5 km south-southeast of the community of Los Fresnos; 0.75 km east of Farm-to-Market Road 1847; elevation is approximately 3.5 m AMSL (Geological Survey 1983); transverse mid-point of the Palo Alto Resaca.
- Proximal vegetation: erect burhead (*Echinodorus berteroi)*; big-foot water- clover (*Marsilea macropoda*) (Jones and Wipff 2003).
- Nominal soil: Lomalta clay (Udorthentic Pellustert) (Williams et al. 1977:19, 86, Sheet Number 67). The soil exposed in BHT-4 is somewhat similar to the nominal Lomalta series, but has a much thicker black to dark gray A horizon and is gypsiferous throughout its lower solum. Prior to artificial drainage of this part of the Rio Grande delta plain in the early Twentieth Century, soil-forming conditions in the Palo Alto Resaca were probably wetter than those under which the Lomalta soil typically develops. At best, the local soil would represent a taxadjunct of the Lomalta series.
- Profile described on 12 August 2004. Vertical sequence, from ground to maximum depth of exposure, with interpretations enclosed in brackets: 1) silty clay [palustrine deposit (hydric soil in resaca)]; and 2) gypsiferous silty clay [fluvial overbank (delta-plain) deposit].
- Following excavation, ground-water level rose slowly to the present water table, at 205 cm depth.
- Texture characterized in both geological and pedological terms, aided by 10x magnification and use of a grain-size comparator in the field. Pedological terms are shown below in parentheses.
- Soil colors were determined in the field under ambient lighting and moisture conditions, using Munsell Soil Color Charts.
- Depths were measured relative to the present ground level at the west-northwestern end of the trench.

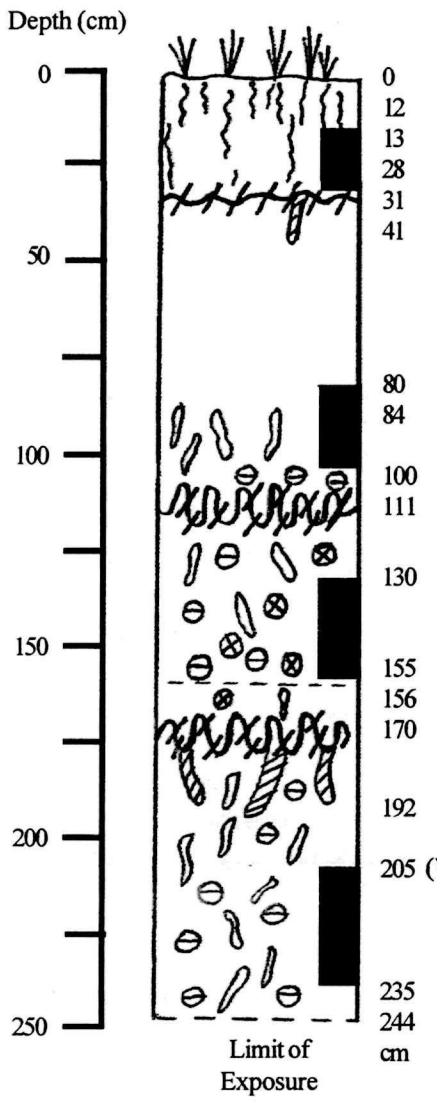
Profile description

A — Stratum 1: 0 to 31 cm; black (7.5YR 2.5/1); silty clay with rare sand (silty clay); sand is very fine; from 0 to 12 cm, weak fine angular blocky structure breaking to granular, and from 12 to 31 cm, weak medium angular blocky structure breaking to strong fine angular blocky; firm, moist; moderately plastic; moderately sticky; abundant fine pressure faces; many to few fine roots, decreasing below 12 cm; common to few fine pores, decreasing below 12 cm, some filled with partly decomposed roots; few fine fragments of terrestrial snail shells; clear, wavy boundary. Late Holocene to modern palustrine deposit. Sampled for radiocarbon, carbon stable-isotope, pollen, and diatom analyses: 13 to 28 cm.

Agy — Stratum 2: 31 to 111 cm; dark gray (N 4/) varying downward to dark gray to very dark gray (N 3.5/); silty clay with rare sand (silty clay); sand is very fine; weak fine angular blocky structure breaking to granular; friable, moist; moderately plastic; moderately sticky; few to common gypsum filaments, increasing below 84 cm, and common fine irregular soft gypsum nodules below 100 cm; few fine roots; few fine pores with one medium pore filled with decomposed root matter from 31 to 41 cm; few fine fragments of terrestrial snail shells; clear, irregular boundary. Late Holocene palustrine deposit. Sampled for radiocarbon, carbon stable-isotope, pollen, and diatom analyses: 80 to 100 cm.

Bgyc — Stratum 3: 111 to 170 cm; dark greenish gray (10Y 4/1) with many fine distinct very dark gray (N 3/) mottles; silty clay with rare sand (silty clay); sand is very fine; weak fine angular blocky structure; very friable to friable, moist; moderately plastic; moderately sticky; many gypsum filaments and many fine irregular soft gypsum nodules; few fine rounded soft black ferric oxide nodules; few fine roots; many fine pores filled with gypsum; gradual, irregular boundary, perhaps originally at 156 cm, but obscured and lowered as a result of continuing bioturbation. Late Holocene palustrine deposit. Sampled for radiocarbon, carbon stable-isotope, pollen, and diatom analyses: 130 to 155 cm.

Byb — Stratum 4: 170 to 244 cm (limit of exposure); brown (7.5YR 4/3) with many to few fine to medium distinct dark greenish gray (10GY 4/1) mottles, decreasing below 192 cm; mottles produced by bioturbation of filled burrows of fiddler crabs (*Uca subcylindrica*); silty clay with rare sand (silty clay); sand is very fine; moderate fine angular blocky structure; firm, moist; moderately plastic; moderately sticky; many gypsum filaments and many fine to medium irregular soft gypsum nodules; few fine roots; many fine pores filled with gypsum. Late Holocene fluvial overbank (delta-plain) deposit. Sampled for radiocarbon, carbon stable-isotope, pollen, and diatom analyses: 205 to 235 cm.



Stratum 1: 0 to 31 cm; A horizon; black (7.5 YR 2.5/1) silty clay; late Holocene to modern palustrine deposit.

Stratum 2: 31 to 111 cm; Agy horizon; dark gray-very dark gray (N4/-N3.5/) silty clay; locally gypy below 84 cm; late Holocene palustrine deposit.

Stratum 3: 111 to 170 cm; Bgyc horizon; dark greenish gray (10Y 4/1) silty clay; gypy; late Holocene palustrine deposit.

Stratum 4: 170 to 244 cm (limit of exposure); Byb horizon; brown (7.5YR 4/3) silty clay; bioturbated; late Holocene fluvial overbank (delta-plain) deposit.

Figure 18. Stratigraphic profile exposed in Backhoe Trench 4 (BHT-4). See also Figures 12, 13, and 15.

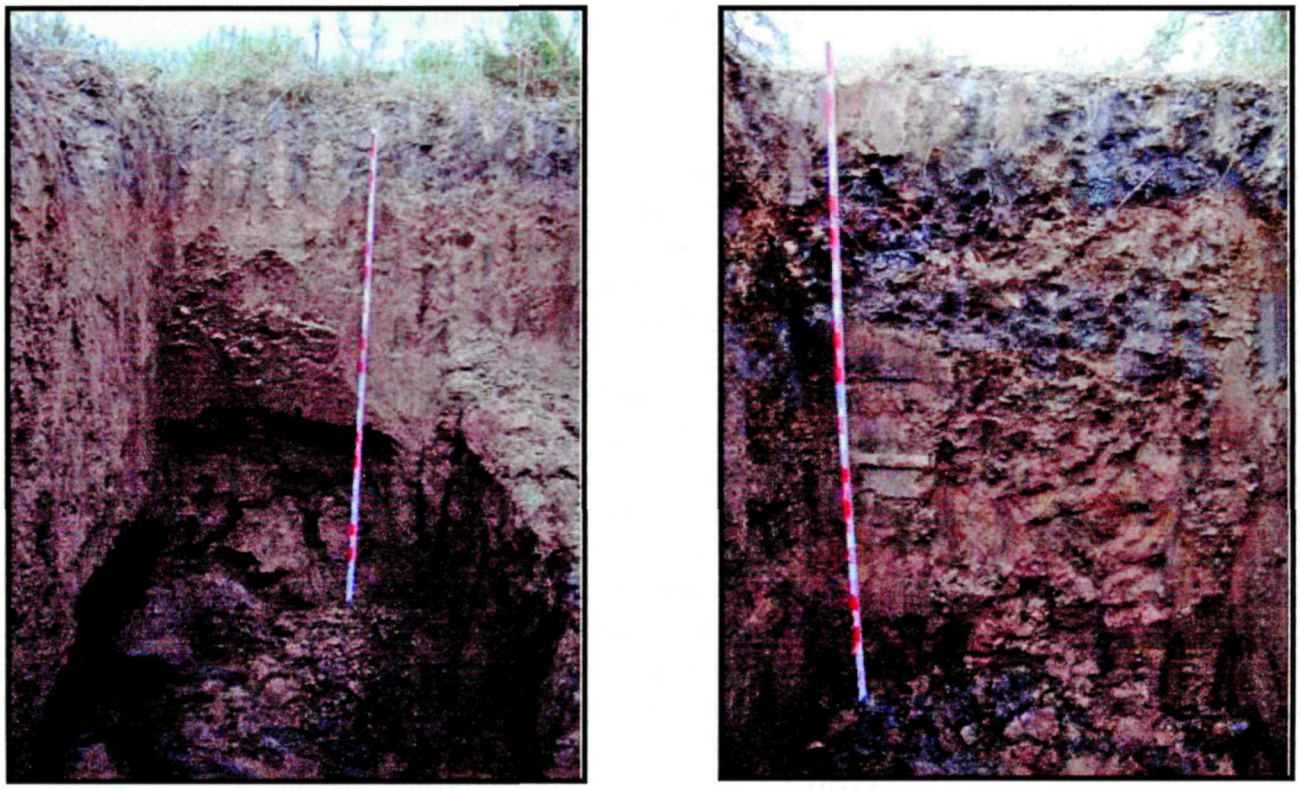


Figure 19. Soil profiles. Left: west-northwest end of BHT-1. Note slumping along side and end of trench. Right: west-northwest end of BHT-2. See Figures 14 and 16.



Figure 20. Soil Profiles. Left: at west-northwest end of BHT-4. Right: east-southeast end of BHT-7. See Figures 17 and 18.

Geomorphic Interpretation of Palo Alto Resaca

Observations at eight backhoe trenches within and near Palo Alto Resaca are depicted in a stratigraphic/geomorphic cross section (Figure 13). The original width and depth of the resaca were approximately 60 m and 4 m, respectively. Important features include: the lateral continuity of most strata and soil horizons within their local geomorphic contexts; stratigraphic variations across the resaca and at its margins; the relationship between the levees and ditches along both banks; and the depth and configuration of the present water table relative to the depths of the gleyed horizons. The west-northwestern side of the resaca floor and the proximal delta plain on both sides of the resaca are capped by an Ay horizon. On both banks, the Ay horizon is overlain only by spoil and is truncated laterally (toward the resaca) by the ditches. Thick Ay or Agy horizons are present in the central and east-southeastern parts of the resaca beneath an A horizon. The Ay is much thinner on the delta plain and banks than are the Ay and/or Agy horizons in the resaca. By, ABy, and/or Bgyc horizons underlie the Ay except at the right bank, where the Ay is underlain by a Bk horizon. A thick Bw horizon underlies the By on the resaca's west-northwestern side and a Byb horizon underlies the Bgyc in the center of the resaca. At the time of the present field investigation (August, 2004), the water table was lower than the depth of the gleyed horizons (Figure 13). This outcome is remarkable, because water had been standing in the resaca just a few weeks earlier and the summer of 2004 was one of the wettest on record in Cameron County (R. L. Garza, personal communication; National Weather Service, unpublished data). Rapid lowering of the water table must be a consequence of artificial drainage, well withdrawals, or other manipulation. If the water table declined so far and so quickly under natural conditions, the gleyed deposits would have been thoroughly oxidized. Dense, organic-rich clays may forestall oxidation, but cannot prevent it indefinitely.

The Ay horizon probably did not develop as a single, laterally continuous body except within the resaca, where it is thickest. Given the distribution and uneven thickness of these deposits and the composition and characteristics of the Ay sediment itself—dark-colored, organic-rich, gypy, silty clay—the resaca is the most likely primary source. Once the resaca was isolated from the river, regular through-flow was prevented and coarse-grained sediment was no longer transported or deposited. Instead, floodwaters occasionally spread across the delta plain carrying fine-grained suspended sediment. Clay was preferentially deposited in the resaca, where lentic or still-water conditions prevailed. Small amounts of silt and very fine sand also accumulated whenever winds carried this sediment from the nearby wind-tidal flats along the Laguna Madre and other areas. Extreme storm-surge events might have pushed marine water upstream as far as the PABNHS on rare occasions. In 1967, Hurricane Beulah caused a storm surge that came within 7 km (Brown et al. 1980). Given the flatness of the terrain, a slightly higher surge might have forced saltwater upstream through the discontinuous lower Palo Alto Resaca in PABNHS. Neck (1985) reported that storm surges can transport marine organisms far inland, but no evidence of this was found during the current investigation.

Historically, the Palo Alto Resaca was a freshwater palustrine environment and is known to have been used as a source of drinking water during the Battle of Palo Alto (Haecker and Mauck 1997; Weaver 1999). Flood-water inflows were common and the delta plain was characterized by a high water table (Baker 1965; see Appendix D of this report for a summary of major storms in the region). As aquatic plants thrived in the resaca, organic matter was deposited along with clay. During the Twentieth Century, however, dam construction and water diversions decreased the flow of the Rio Grande dramatically, while measures were taken to drain Tule Lake, a large closed depression immediately north of the PAAL, and to deepen stock tanks along and near the resaca (Patterson 1965; Weaver 1999). With the disruption of both surface-water and ground-water inputs, the water table declined locally, as did ground-water quality (Baker 1965). Surface water was seen less often in the resaca, perhaps only in particularly wet years. Reduced recharge of the delta-plain aquifer caused the shallow ground water to become increasingly brackish, as it is today.

Stratigraphic evidence indicates, even in the historic and prehistoric past, that ground water within the resaca deposits was never entirely fresh; but today, with less recharge, the ground water remains comparatively undiluted for long periods. Although these conditions are now essentially permanent, they may approximate those of natural episodic droughts, which affected the region from time to time (Riggio et al. 1987).

The pattern of occurrence of gypsic and calcitic horizons in the soil profiles examined at Palo Alto Resaca is complex. A Bk horizon was exposed in the lower part of the profile in BHT-2. Diagnostic properties of a Bk horizon include significant secondary accumulation of carbonate minerals, denoted by the lowercase "k" and usually in the form of nodules or concretions of calcite (calcium carbonate, $CaCO_3$). The predominance of B-horizon calcite along the west-northwestern edge of the resaca and of gypsum (hydrated calcium sulfate, $CaSO_4 \cdot 2H_2O$) in the central and eastern parts is revealing. Notably, the amount of gypsum throughout the profiles in all three trenches on the western side (BHTs 1, 2, and 8) is far less than in those opposite (BHTs 5 and 7) and beneath the resaca floor (BHTs 3, 4, and 6). Gypsum is confined to the surface and near-surface horizons on the western side, but extends to the depth of exposure from BHT-3 eastward. Within the interior of the resaca, the left bank, and the eastern side, gypsum is an intrinsic component of almost every horizon. Only the lower part of the right-bank profile and the uppermost stratum on the east-side floor are not gypsic.

Minerals precipitate under very specific geochemical conditions. The details of these processes are beyond the scope of the present investigation, but a possible explanation for the observed differences in mineralization is that there are two sources of gypsum and that calcite precipitation is affected by two different variables. On the right bank and western side, gypsum is present only in the shallow parts of the profiles and becomes less common with depth. This indicates that gypsum is moving downward through the profile continually as a result of ongoing additions from the surface. The only mechanism for conveying gypsum to the ground surface outside of the resaca is eolian transport and deposition. The floor of the resaca is a ready source of all of the components of the Ay horizon in BHTs 1, 2, and 8: dark-colored, organic-rich, silty clay and gypsum. Silt and very fine sand grains are easily transported by wind, and silt-size masses of clay and gypsum are common components of eolian deposits in this area (Brown et al. 2002). When this sediment is deposited, it accretes vertically and only slowly translocates downward. In contrast, gypsum readily dissolves in rain water and infiltrates the clayey sediment in solution. Gypsum precipitates throughout the horizon as filaments, which are mineral accumulations on the walls of fine open root conduits or filling those conduits. The concentration of dissolved gypsum reaches chemical saturation very quickly in these tiny pores. As infiltration continues, the amount of dissolved gypsum in the lower part of the Ay horizon increases and eventually reaches saturation, precipitating as gypsum nodules. Both nodules and filaments are present throughout the By horizon, but are less common than in Ay. There is no observable gypsum below the By horizon. Gypsum penetration is limited, perhaps because the history of local eolian accumulation is comparatively brief.

Other processes are occurring at BHT-2. The profile in BHT-2 includes an Ay horizon, but no By. Instead, a Bk horizon underlies the Ay directly. The Ay horizon diminishes in thickness from BHT-2 to BHT-1, and from BHT-1 to BHT-8, which is farthest from the resaca. Ay also drapes the upper slope of the right bank, thickening toward the resaca. Formation of the Bk horizon was confined to the edge of the resaca. One possible explanation for this is that the sulfate was removed before it could combine with dissolved calcium to form gypsum, instead allowing the calcium to precipitate as calcite. Sulfate reduction to sulfide is mediated by certain obligate anaerobic bacteria (Postgate 1972). These bacteria (Archeae) require three conditions: an abundance of organic matter; low free oxygen levels; and high concentrations of sulfate in aqueous solution. All three conditions are satisfied within the water-saturated palustrine sediment of the resaca. Because very little atmospheric oxygen permeates into this sediment, the organic matter quickly reacts with the limited available oxygen to produce carbon dioxide (CO_2). The CO_2, in turn, dissolves in the water within the pore spaces, creating bicarbonate (HCO_3). Bicarbonate is a reactant which combines with calcium to produce calcite. As the oxidation of organic carbon continues, the concentration of free oxygen decreases rapidly with depth. Anoxic conditions often exist just a few millimeters beneath the benthic surface.

Sulfate-reducing bacteria thrive in anoxic sediment where organic matter and dissolved sulfate are abundant. The bacteria utilize organic carbon as an oxygen acceptor, reducing the sulfate (SO_4) to sulfide (S). Significant amounts of sulfate can be reduced in this manner.

The anoxic microenvironment is also ideal for bacteria that produce ammonia (NH_3) and ammonium (NH_4). This process creates moderately to strongly basic conditions with hydrogen-ion activity (pH) greater than 9.2 (Hem 1992). During the present investigation, sediment samples were collected at BHT-4 for analysis of diatoms (Table 7; Figure 18). B. M. Winsborough processed the samples, but no diatoms were recovered, despite the fact that the resaca undoubtedly provided excellent habitat for both planktonic and benthic diatoms (Appendix B). The mineral "skeleton" of a diatom is known as a frustule, and it is this species-diagnostic structure that is often preserved. Frustules are composed of opaline silica, which dissolves at elevated pH. The absence of diatom frustules is indirect evidence that high pH conditions were generated on a microenvironmental scale. This outcome was unfortunate, but it corroborates the hypothesis that sulfate reduction and ammonia formation are important processes within the resaca sediment. The production of bicarbonate is also consistent with these observations, because it would increase chemical saturation with respect to precipitation of calcite.

Yet why is calcification so localized? The answer may be related to local movement of ground water. In this part of the PAAL, the ground slopes gently southeastward (Geological Survey 1983). The preferred direction of shallow ground-water flow is likewise southeastward, although topographic irregularities may affect localized water movement. Currently, the water table lies well below the resaca floor and has a slight downward slope toward the center from both banks (Figure 13; note that vertical exaggeration is 20X). This depressed configuration is typical of a water table where ground water is discharging into a channel from the surrounding shallow aquifer (Heath 1983). The water table is depressed because water loss due to evapotranspiration from the channel deposits is greater than from the surrounding delta plain. In the past, however, when surface water flowed through this former distributary channel, the water table was probably highest beneath the channel floor and sloped downward beneath the banks, indicating recharge of the shallow aquifer from the channel. Nonetheless, the net flow direction, both in the past and now, is southeastward. This may help to account for the absence of gypsic horizons at depth on the west-northwestern side of the resaca. The gypy ground water flowed primarily southeastward, causing the strata on that side to be gypsiferous through all horizons. Because flow to the northwestward was limited (slower and at lower pressure), the ground water closest to the right bank was quickly depleted of sulfate through bacterial reduction and calcite precipitated preferentially.

Net southeastward ground-water flow may explain the presence of a non-gypy A horizon in the eastern half of the resaca (Figure 13). The flow of gypy ground water would have created higher pressure in that area, allowing lower-density fresh water from rains to remain buoyed at the surface, rather than infiltrating to depth and mixing with the gypy water, as it apparently did elsewhere. Where it remained isolated, the fresh water either dissolved gypsum from the surficial horizon or allowed non-gypsic sediment to accumulate. The water-management system may have played a role as well by increasing the amount of fresh water in this reach, but this is unclear.

Outside the resaca, the Ay horizon appears to be an eolian deposit. Sediment was deflated (wind-eroded) from the resaca during dry periods, perhaps seasonally, then re-deposited on the sloping banks and the delta plain as a wedge thinning away from the resaca. When the resaca was an integrated distributary channel, dry conditions were less common. At that time, the Ay horizon may not have existed outside of the resaca, or was more restricted and perhaps less gypsic. The character of the underlying By horizon is closely tied to that of the Ay, and may have differed in the past, as well. Regardless of the effect of historical changes in flow frequency, neither the Ay nor the By existed as such before the ancestral distributary channel was cut off, thereby creating the resaca. To fully understand the local history of geomorphic evolution and the nature of the paleoenvironment, samples were collected for radiocarbon assay and other analyses.

Laboratory Processing

Radiocarbon Assays and Carbon Stable-Isotope Analyses

Radiocarbon (^{14}C) and carbon stable-isotope (^{12}C and ^{13}C) analyses were performed on the organic-carbon component of each of four sediment samples from the stratigraphic profile exposed in BHT-4 (Table 7; Figures 15 and 18). The samples were collected between 13 and 235 cm below ground surface, then curated and shipped for preparation and analysis at the Isotope Geochemistry Laboratory of the Illinois State Geological Survey. In the laboratory, each sample was treated with mild acid solutions to dissolve selected minerals, particularly calcite, which is composed of the chemical calcium carbonate. The purpose of this treatment was to remove inorganic carbon, of which calcium carbonate ($CaCO_3$) was the primary source. When analyzing organic carbon, inorganic carbon is generally a contaminant and is eliminated during sample preparation. The treatment reduced each sample to an acid-insoluble residue of non-carbonate minerals (predominantly quartz) and solution-resistant organic matter. Organic matter can be split into various compositional fractions for specialized analyses, but these samples were not treated in this manner. The resulting organic material is, therefore, referred to as undifferentiated or "bulk" organic matter (bulk humate). Organic carbon was then separated from the residue by combustion, producing carbon dioxide gas. The gas was collected, purified, subjected to additional treatments (which vary, depending on the condition of the sample and the specific objectives of the analyst), and analyzed. Radiocarbon ages were determined by liquid-scintillation assay and the stable isotopes of carbon were analyzed by mass spectrometry (Boutton 1991a; Goh 1991).

Radiocarbon Assays

Radiocarbon Ages

Radiocarbon age of these samples ranges from 390 ± 70 to 4730 ± 70 radiocarbon years before present (RCYBP) (Table 8; Appendix C). The reported ages are corrected for $\delta^{13}C$, and the $\delta^{13}C$ values are shown. Dendrocalibrated ages are listed separately, along with their collective range at 1-σ confidence. The following discussion provides a careful assessment of the $\delta^{13}C$-corrected ages and possible error factors, along with background information regarding the radiocarbon dating method. The $\delta^{13}C$ values are discussed separately.

Assessment of Radiocarbon Ages

The sequence of ages is stratigraphically coherent; that is, age increases with increasing depth throughout the profile. The rate of change in age versus depth appears to be relatively uniform. Figure 21 presents this relationship graphically. In this depiction, both radiocarbon age and stable-isotope ratio ($\delta^{13}C$) are plotted along the graph's X-axis, but on different scales, and may be regarded as independent variables (referred to here as X_1 and X_2, respectively). The Y-axis represents depth below ground surface, which is a dependent variable separately coordinated with each of the X-axis variables (X_1, Y; X_2, Y). Points directly on the Y-axis have either a radiocarbon age of 0.0 years (i.e., they represent present time) or a $\delta^{13}C$ value of -19.5 ‰. Because the radiocarbon ages and $\delta^{13}C$ values of the samples are plotted with respect to different scales, the data points representing one of these X-axis variables do not denote the values of the other. Each of the X-axis variables is, however, plotted relative to the same depth scale on the Y-axis.

Linear regression of the four data points in the age-depth coordinate system (X_1, Y) yields a "best-fit" trend line with the formula $Y = 0.0431X_1 + 19.649$ and a coefficient of determination (R^2 value) of 0.9714. This formula is stated in the characteristic form $Y = mX + b$, where: Y is the dependent variable (depth of a given sample); m is the calculated slope of the trend line; X is the independent variable (radiocarbon age of the given sample); and b is the calculated Y-intercept of the trend line. An R^2 value close to the ideal, 1.0, denotes little scatter in the data, such that age increases with depth at a relatively consistent rate.

Table 8. Radiocarbon ages and carbon stable-isotope values of organic carbon in sediment samples from Backhoe Trench 4 (BHT-4), Palo Alto Battlefield National Historic Site, Cameron County, Texas (see text).

ISGS lab number[1]	Sample number	Stratum (horizon)	Depth (cm)	^{14}C age (RCYBP)[2]	$\delta^{13}C_{PDB}$ (‰[3])	Calibrated age (range)[4]
5679	1A	1 (A)	13-28 (mean = 21)	390±70	-19.5	AD 1476 (AD 1411-1652) [BP 539-298]
5682	2A	2 (Agy)	80-100 (mean = 90)	1190±70	-18.0	AD 784, 787, 833, 836, 877 (AD 671-998) [BP 1279-952]
5670	3A	3 (Bgyc)	130-165 (mean = 148)	2990±70	-17.3	BC 1258, 1235, 1215 (BC 1410-1002) [BP 3359-2951]
5669	4A, 4B	4 (Byb)	205-235 (mean = 220)	4730±70	-19.2	BC 3618, 3608, 3521 (BC 3651-3360) [BP 5600-5309]

[1] All sample preparation, radiocarbon assays, and carbon stable-isotope analyses were performed at the Isotope Geochemistry Laboratory of the Illinois State Geological Survey, Champaign, Illinois (Appendix C).

[2] Radiocarbon age in radiocarbon years before present (RCYBP), corrected for $\delta^{13}C$, but not dendrocalibrated.

[3] Carbon stable-isotope ratio in parts per thousand, relative to the PDB standard.

[4] Dendrocalibrated radiocarbon date(s) and two-sigma date range AD or BC, and two-sigma age range in years before present (BP) (Stuiver et al. 1998).

The mean rate is given by the arithmetic inverse of the slope of the best-fit line. Because the Y-axis was chosen to represent depth, the line's slope is 0.0431, which indicates that burial depth increases by 0.0431 cm per year. This figure corresponds to 0.431 mm/yr, a reasonable estimate of long-term net sedimentation within the resaca (Ferring 1986; Brown et al. 2002). Inverse of the slope is 23.2019 yr/cm, which is the mean rate of increase in age with depth.

The regression line provides additional information. The Y-intercept of the formula is 19.649. This is the point at which the trend line would reach the graph's Y-axis, where the radiocarbon age is 0.0 yr. A sample whose radiocarbon age is 0.0 yr would, therefore, be expected to lie at 19.649-cm depth in the profile. If the intercept were instead 0.0 cm, deposits of 0.0-yr age would be found at ground level, which would appear to be the norm. The depth of the 0.0-yr age point varies from its theoretical position because of mixing processes at the site, as well as small discrepancies inherent in radiocarbon age determination. In the present instance, the Y-intercept is a low, positive number, which means that the results are good, but would appear to underestimate the true ages of the sampled deposits. One measure of the magnitude of this discrepancy is given by multiplying the Y-intercept of the regression line by the inverse of the slope: (19.649 cm)(23.2019 yr/cm) = 455.9 yr. If this were the only factor affecting the precision of the radiocarbon assays, the true age of each sampled deposit would, on average, be 455.9 yr older than its reported age.

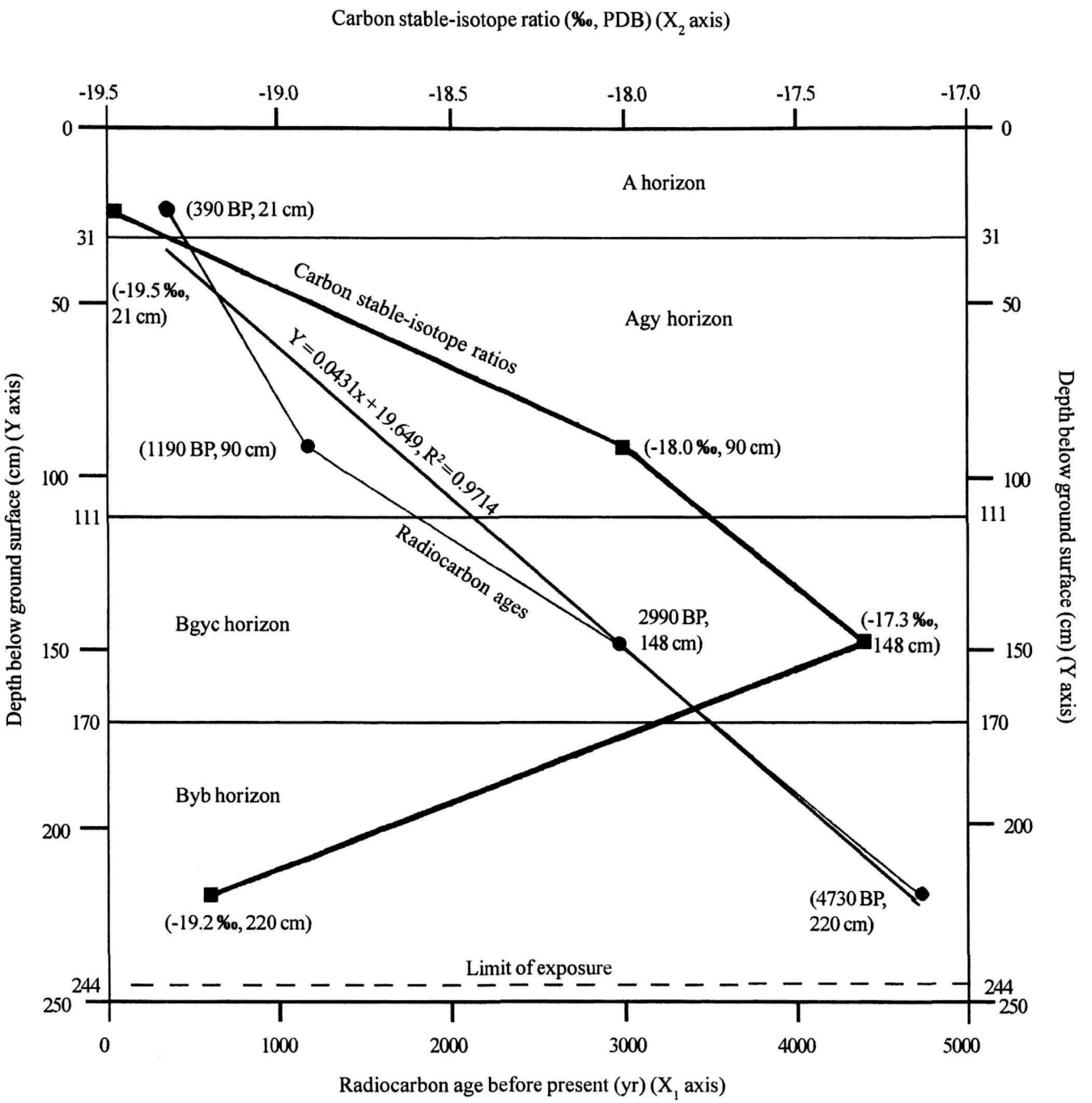


Figure 21. Radiocarbon age and carbon stable-isotope ratio with depth, Backhoe Trench 4 (BHT-4).

An error of this kind could be promulgated by bioturbation, particularly where organic matter is moved downward through the soil profile by organisms. In the Palo Alto Resaca, the organisms responsible for most of the bioturbation are rapidly growing marsh plants, which produce dense, downward-penetrating root clusters, and fiddler crabs, which transport large amounts of plant and animal debris below ground through their burrows, which frequently reach the water table. If a 4.5 g sample of 10,000-yr old organic matter were contaminated with 0.5 g of "modern" organic carbon (^{14}C age: 0.0 yr), the net radiocarbon age of the composite sample would be 8225 yr, which is 1775 yr (~18%) less than the true age of the ancient material (Caran and Julien, in review). Mixing of organic matter is an ongoing process that, in effect, moves the 0.0-yr marker a finite distance downward through the profile. In general, however, the addition of young organic material diminishes as the depth of burial increases. Under stable environmental conditions, bioturbation and sediment deposition are continual, often at nearly constant, but opposing, rates. These competing processes may equilibrate, thereby defining what is known as the "local mean-residency effect". The mean residency is the average period during which a body of sediment at a given location remains within the depth range of significant addition of organic matter, in this case, through bioturbation. By the end of the mean-residency period, deposition will have raised the ground level enough to impede further intrusion of young organic matter below the depth of burial. A discrepancy of 400 to 500 radiocarbon years may be a reasonable estimate of the mean-residency effect of bioturbation in a resaca at PAAL.

There are, however, other processes influencing the precision and accuracy of radiocarbon ages. Some of these additional effects may have an even greater numerical impact, amplifying or offsetting the consequences of bioturbation. Moreover, the effects can be manifest in essentially random combinations, producing a net error that is difficult to predict in a particular instance; however, the nature and approximate magnitude of individual discrepancies usually can be determined and/or compensated. The results of extensive testing and monitoring elsewhere have shown that some of the error factors are systematic, operating on a global or regional scale, whereas others are non-systematic and generally localized. Important systematic error factors include the inconstant assimilation of cosmogenic radiocarbon into the atmosphere and other perturbations of the carbon isotopic composition of the environment by natural and anthropogenic processes (Bowman 1990; Goh 1991).

Systematic error factors are linked to the primary mechanism by which radiocarbon is created. Small amounts of natural radiocarbon are produced continuously in the lower stratosphere and upper troposphere (Faure 1986; Bowman 1990). This process begins when "cosmic rays" (primarily protons radiated from distant stars and other celestial objects) collide with the atomic nuclei of gas molecules at nearly the speed of light. The collisions dislodge neutrons that, in turn, initiate secondary collisions with other nuclei, causing more neutrons to break away ("spall off"). Spallation continues, eventually producing neutrons moving at comparatively slow speeds. If a neutron with a specific, relatively low level of energy then collides with an atom of nitrogen gas, it may be captured in the nitrogen's nucleus. Stable nitrogen has 7 protons, 7 neutrons, and 7 electrons. In contrast, the enlarged nucleus retains the extra neutron, but concurrently emits one of its protons. That proton combines with an electron from the outer shell surrounding the nucleus, thus forming a hydrogen atom that disperses into the atmosphere.

The residual nucleus has the same mass number as nitrogen, 14, yet contains only 6 protons. A nucleus with 6 protons surrounded by 6 electrons is an atom of carbon; however, this particular atom also has 8 neutrons, two more than in the most common form of carbon, ^{12}C, and is thus the ^{14}C isotope. Because the number of protons and neutrons is substantially unbalanced, the ^{14}C isotope is radioactive. Radioactive carbon or radiocarbon that is produced in this manner is said to be cosmogenic. The lack of balance in the nucleus of the radiocarbon atom will ultimately destroy one of its neutrons by the process known as radioactive decay. Decay of the ^{14}C isotope converts one of its neutrons to a proton, an electron, and an uncharged particle known as an antineutrino. An electron emitted from the nucleus of an atom is known as a negative beta (B^-) particle. The ^{14}C isotope undergoes B^- decay at a constant rate, which is the basis for radiocarbon dating. The half-life (time required to reduce the number of ^{14}C atoms by half), is 5730 ± 40 yr, although an older, less accurate measurement, 5568 ± 30 yr, is used for some purposes. After losing a neutron and gaining a proton through radioactive decay, the remaining nucleus contains 7 neutrons and 7 protons. Radiocarbon thus reverts to stable nitrogen, ^{14}N, following decay.

These processes can be represented as follows:
where ^{14}N is an atom of non-radioactive nitrogen (which has a mass number of 14 and consists of 7 protons, 7 neutrons, and 7 electrons); [ ] denotes the composition of an atom or intermediate decay product; p is a proton; n is a neutron; e is an electron; B^- is a negative beta particle; $\bar{\nu}$ is an antineutrino; and ^{14}C is an atom of radioactive carbon (which has a mass number of 14 and consists of 6 protons, 8 neutrons, and 6 electrons),

Cosmogenesis of radiocarbon

^{14}N [7 p, 7 n, 7 e] + low-energy n = ^{14}C [6 p, 8 n, 6 e] + ^{1}H [1 p, 1 e]

Radioactive decay of radiocarbon

^{14}C [6 p, 8 n, 6 e] - 1 n (radioactive decay) =

[6 p, 7 n, 6 e + 1 p, 1 e] = ^{14}N [7 p, 7 n, 6 e] + $B^- + \bar{\nu}$

(In reality, the nitrogen atom would immediately scavenge an electron from the surrounding environment to fill its complement of 7.)

When an atom of ^{14}C is created cosmogenically, it reacts with two atoms of normal atmospheric oxygen to form a molecule of carbon dioxide. Traces of radioactive carbon dioxide rapidly diffuse through the atmosphere, dissolve in the oceans, and are incorporated into organic matter, soils, and many other materials. The quantity of radiocarbon is so infinitesimal that it represents no health hazard and may remain with an organism until it dies. In general then, there are no further additions of radiocarbon. Measurements of radiocarbon age are actually calculations of the date of the moment when radiocarbon assimilation ends.

Systematic Error Factors and Corrections

Sources of systematic variation in radiocarbon age include natural and human-effected processes. Among the natural processes are those influencing the formation of radiocarbon and its dispersion through the environment. In the past, cosmogenic radiocarbon was thought to have been produced, oxidized to carbon dioxide, and diffused through the atmosphere and biosphere at rates that were constant, or which co-varied in a way that permitted accurate age determination (Libby 1955; Taylor 1987). Radiocarbon assay of ancient organic materials of known ages seemed to support this assumption. Any age discrepancies were attributed to minor imprecision in the analytical methods and to non-systematic variations in the isotopic composition of the sample materials. As the number and variety of radiocarbon assays increased, however, and as analytical techniques and instruments were improved, investigators realized that the errors were inherent and were attributable to a number of causal factors. Even worse, the magnitude of the errors was inconstant, preventing the development of a simple numerical correction.

Some of the principal error factors are: secular variations in the production of cosmogenic radiocarbon related to shifts in the Earth's magnetic field (direction and intensity), sunspot activity, and stellar processes affecting the flux of cosmic rays; glacial-interglacial temperature differences that altered the solubility of atmospheric CO_2 in water; changes in oceanic circulation, affecting CO_2 assimilation and mixing rates; inconsistencies in the composition of the atmosphere over the northern and southern hemispheres; unstable rates of out-gassing of non-cosmogenic carbon in CO_2 from volcanoes; changing effects of sedimentation and biomass productivity on the uptake and burial of organic carbon; and many more (Taylor 1987; Bowman 1990). To accurately account for each of these effects throughout the potential period of measurable radiocarbon age would be a nightmare.

Fortunately, tree-ring chronology provides an independent check on radiocarbon age, and the rings themselves record the net effect of the numerous error factors. For many kinds of trees, age can be determined by counting the annual growth rings. In addition, ring width and other characteristics are comparable among trees of a given region and from region to region. Using wood from long-lived trees, ancient structures

of known age, and other appropriate contexts, tree-ring patterns can be matched to produce a composite record extending several thousand years into the past. By assaying wood of known age, errors in measured radiocarbon age can be quantified. The error is not constant, however, so correction requires establishment of a detailed dendrocalibration curve to which radiocarbon ages can be compared (Stuiver and Reimer 1993). In this way, radiocarbon ages of all types of materials from anywhere on the planet can be adjusted as needed. It should be noted that, despite the large number of systematic error factors, adjustments needed to correct radiocarbon ages are generally small and typically within the range of errors attributable to non-systematic factors. The records from some periods are more uncertain than from others, however, resulting in larger statistical corrections.

Since the advent of the Industrial Revolution, human activities have also affected the isotopic composition of the atmosphere. The burning of fossil fuels has added abnormally large quantities of ancient carbon to the atmosphere worldwide, contaminating some of the carbon dioxide. When this CO_2 is respired by a plant during photosynthesis, the carbon enters the plant's biomass, altering its isotopic composition. Thus, present-day organic matter could have a measured radiocarbon age that is hundreds of years too old. This occurs because the amount of the ^{14}C isotope in ancient carbon has been greatly reduced by radioactive decay. Calculation of radiocarbon age is based on the measured amount of ^{14}C relative to that of the most common non-radioactive (stable) isotope of carbon, ^{12}C, in the sample. Although ^{14}C undergoes radioactive decay at a known rate, the calculated age would be too great if the initial concentration of ^{14}C versus ^{12}C were too low. This process, known as the "Suess Effect," is partly compensated by dendrocalibration (Stuiver et al. 1998). In contrast, above-ground use and testing of atomic weapons since World War II produced higher than normal amounts of atmospheric ^{14}C. The "Bomb Effect" generally prevents radiocarbon assay of very young organic material.

Finally, measurement of radiocarbon age requires comparisons among the isotopic compositions of various materials. The original standard was wood (and now other materials) with a stable-isotope ratio of -25.0 ‰. Not all measured radiocarbon samples have this composition, however, which introduces a small error related to the relative amounts of initial ^{14}C versus ^{12}C. This error is routinely corrected by determining the stable-isotope ratio of the sample material and using it to make a formulaic adjustment in the calculated age. This and other detailed procedures for correcting systematic errors are discussed in most standard references on radiocarbon chronometry (e.g., Mook 1980; Taylor 1987; Bowman 1990).

Nonsystematic Error Factors

The effects of nonsystematic errors are complex and usually not subject to systematic numerical correction. Examples of these kinds of errors include: bioturbation, pedogenic overprinting, and related processes that mix materials of differing radiocarbon age; chronologic displacement (e.g., re-deposition of older sediment or reuse of archeological materials); improper sampling, labeling, curation, and laboratory preparation; measurement and calculation errors; and improper correction of systematic errors. Proper field technique and judicious attention to laboratory procedures and data reporting are the best defenses against these problems, which are all too common and may have a fatal effect on data interpretation.

Carbon Stable-Isotope Ratios

Carbon stable-isotope analyses ($\delta^{13}C$ ratios) provide the basis for a generally small, but essential formulaic correction of the measured radiocarbon ages of all sample materials. They also help to identify the source of carbon in the radiocarbon sample and may provide paleoenvironmental data. Understanding the source enables an investigator to assess possible nonsystematic errors and make insightful interpretation.

Four sediment samples were collected from the profile at BHT-4 for radiocarbon and carbon stable-isotope analyses (Table 7; Figure 18). The $\delta^{13}C$ values of the organic carbon in these samples vary from -19.5 to -17.3 ‰ (Table 8; Fig 21). These values were determined relative to the "PDB isotopic

standard," which designates the Cretaceous Pee Dee Formation belemnite, a marine fossil composed of calcite with a very stable isotopic ratio (see Boutton 1991a). The samples exhibited consistent isotopic enrichment (less negative $\delta^{13}C$ values) with increasing depth until reaching the horizon boundary at 170 cm. The sample below that boundary yielded a $\delta^{13}C$ value nearly 2 ‰ more depleted than that of the sample just above. Stratigraphic evidence indicates that the intervening boundary is an unconformity separating an older, truncated, buried soil from younger deposits composing a separate soil sequum (sequence of genetically related horizons). Although bioturbation blurred the unconformity, the pattern of changing $\delta^{13}C$ values corroborates the interpretation that the geomorphic and other environmental conditions under which the buried and younger soils developed were quite different.

Variations in the carbon stable-isotope ratios of organic materials primarily result from biological fractionation. Organisms exercise active and passive selection processes that give preference to one or the other of the stable isotopes ^{12}C and ^{13}C, thereby affecting their ratio. Carbon with distinctive isotopic ratios is respired from the air, consumed in nutrients, and ingested or absorbed from water. The organism modifies the ratio as the carbon is incorporated in its biomass. Photosynthetic pathways, metabolic processes, and diet vary from species to species, influencing fractionation in ways that are characteristic of a species or group of related species. Once an isotopic ratio is fixed in an organic molecule, it remains stable even after the organism's death unless it is degraded or contaminated.

Soils also develop distinctive isotopic signatures. Most of the organic matter in a soil derives from the organisms living on and in it, particularly plants, or is inherited from the source areas where its sedimentary parent materials originated. Although the isotopes themselves are chemically stable, their ratio may be affected by mixing and other influences. A deposit of fluvial sediment may include a substantial amount of organic matter that had been carried downstream. The $\delta^{13}C$ value for this carbon would likely represent a mixture of organic materials from throughout the drainage basin, and may be different from that of the principal organisms at the site of deposition, at least initially (i.e., prior to addition of local organic matter through soil development, etc.). In contrast, the organic matter in a palustrine deposit is largely autochthonous (from sources on site), because the rapidly growing marsh plants add such a large amount of organic material that all other sources are significantly diluted. Unless the deposit was subsequently modified, the $\delta^{13}C$ value for a sample of palustrine sediment should closely correspond to that of the plants inhabiting the marsh and its immediate surroundings.

The type of photosynthesis performed by a plant varies from group to group. In general, each group employs only one of the three photosynthetic processes, which are designated C_3, C_4, and CAM. Moreover, these processes impart distinctive carbon isotopic ratios, which are characteristic for the group of plants utilizing a given process. The C_3 process yields $\delta^{13}C$ ratios averaging -27 ‰, but ranging from -32 to -20 ‰ (Boutton 1991b). The C_3 plants include most trees, shrubs, wetland species, and some others. Warm-season grasses and some dryland herbaceous plants employ the C_4 process, with an average $\delta^{13}C$ ratio of -13 ‰ and a range of -17 to -9 ‰. Most of the CAM-utilizing species belong to the cactus (Family CACTACEAE) and spurge (Family EUPHORBIACEAE) families, and have $\delta^{13}C$ ratios ranging from approximately -28 to -10 ‰, although values from -20 to -10 ‰ are most common. A mixture of organic matter from plants applying different photosynthetic processes would have intermediate $\delta^{13}C$ values reflecting the relative contribution from each source. The comparatively enriched (less negative) isotopic values associated with C_4 plants are most often observed in prairies and other non-arboreal dryland habitats. Mid-range, partly overlapping ratios that are characteristic of CAM plants are largely restricted to desertic areas, although some other habitats also support CAM species. Woodlands and aquatic environments, where C_3 plants predominate, typically produce $\delta^{13}C$ ratios that are isotopically depleted (more negative).

The $\delta^{13}C$ ratios for the four bulk-humate samples from BHT-4 exhibit significant variation through time. Sample 4A/4B, from Stratum 4, the Byb horizon (deepest), had a $\delta^{13}C$ value of -19.2 ‰.

Numerically, this ratio falls within the range of the CAM species, but these plants generally do not produce large amounts of organic matter and are unlikely to impart a "pure" CAM signature in an environment in which multiple organic sources are likely. Instead, the value for Sample 4 probably represents a mixture, lying just outside the range for C_3 plants. Given the depositional context of this sample, most of its organic carbon probably derived from the tree canopy in a riparian woodland. Sample 4 is, however, from a rapidly accreted delta-plain fluvial deposit of sediment transported by flood waters. Therefore, the organic matter must also be regarded as allochthonous (conveyed from remote source areas). Partial overprinting with carbon from C_4 and possibly CAM plants at the site of deposition would account for the slight enrichment of the isotopic value relative to the typical range for C_3 plants. This interpretation is consistent with the palynological data (see below).

Sample 3A, from Stratum 3, the Bgyc horizon, had a $\delta^{13}C$ ratio of -17.3 ‰. This value is close to the range for C_4 plants. Stratum 3, at the base of the palustrine deposits, represents an early stage of depo-sition within the resaca, following its general isolation from the river. Much of the sediment accumulating within the resaca may have washed in from the surrounding landscape, which was probably a coastal prairie comparable to that existing historically. The isotopic signature is diagnostic of a mix of carbon dominated by C_4 plant sources (probably Gulf cord-grass), but with some C_3 plant material added. The C_3 organic matter may have derived from aquatic plants that were just becoming established in the newly created lentic habitat.

This pattern persisted during deposition of Stratum 2, the Agy horizon, from which Sample 2A was collected. Sample 2 yielded a $\delta^{13}C$ ratio of -18.0 ‰, which is intermediate between the ranges for C_3 and C_4 plants. The resaca continued to receive contributions of C_4 organic matter and mineral sediment from the adjacent coastal prairie or other source areas. Although no longer linked to the main channel of the Rio Grande, the resaca would have been inundated during occasional high-volume floods, along with the rest of the delta plain. These flood waters may have deposited at least a modest quantity of suspended C_3-type organic matter and fine-grained mineral sediment. Wetland plants probably contributed, as well, but floods capable of encroaching onto the delta plain may have temporarily disrupted the marsh flora, while adding only small amounts of allochthonous organic matter. The coastal prairie appears to have remained the principal source of organic carbon.

By the time that Stratum 1, the A horizon, was deposited, the environment had changed. The $\delta^{13}C$ ratio for Sample 1 is -19.5 ‰, which is the most depleted of the four values reported and very close to the nominal range for C_3 plants. Riverine flooding may have become so infrequent that undiluted brackish ground water caused gypsum to precipitate within the resaca deposits, which were sometimes eroded by winds and redeposited on the banks and beyond. The dominant source of isotopically depleted organic matter was then the resaca's C_3 wetland flora, which flourished, undisturbed by floods. As a percentage of the total organic content of Stratum 1, the quantity of C_4 plant debris reaching the resaca appears small, but only in comparison to that from the marsh vegetation, a prolific source.

The Pollen Record

Recovered Pollen Types

The identified pollen types are listed in Table 9, as are their respective frequencies within the pollen spectrum for each sample. Figure 22 depicts the changes in frequency with depth. Small amounts of pine (*Pinus* spp.?) and joint-fir (*Ephedra* sp.) pollen were recovered. Both are readily transported over long distances by wind. The pine pollen is clearly allochthonous. A species of *Ephedra* inhabits Hidalgo County, just west of Cameron County, and other species occur not far up river in Texas and Mexico, but *Ephedra* probably was not part of the local paleoflora. The tree pollen is dominated by oak (*Quercus* sp., cf. Texas live oak, *Q. virginiana*), with lesser amounts of elm (*Ulmus* sp., cf. cedar elm, *U. crassifolia*), hackberry (*Celtis* sp., cf. sugar hackberry, *C. laevigata*, and/or spiny hackberry, *C. pallida*), pecan (*Carya illinoinensis*), and ash (*Fraxinus* sp., cf. Berlandier's ash, *F. berlandieriana*). Both *Celtis laevigata* and *C. pallida* are

Table 9. Relative pollen percentages in samples from BHT-4.

Group and taxon [1,2]	Sample number (in italics) and depth below ground surface (cm) *1:* 13-28	*2:* 80-100	*3:* 130-155	*4:* 205-235
Long-distance transported pollen				
Pinus	5.5	10.4	5.8	7.6
Ephedra	0.0	0.0	0.6	0.0
Subtotal	5.5	10.4	6.4	7.6
Tree and shrub pollen				
Quercus	3.0	9.8	16.4	14.7
Ulmus	0.5	0.5	3.5	0.0
Celtis	0.0	0.0	0.0	0.6
Carya	0.0	0.0	0.6	1.8
Fraxinus	0.0	0.5	0.0	0.0
Subtotal	3.5	10.8	20.5	17.1
Wetland pollen				
Typha domingensis	1.5	1.6	2.3	1.2
CYPERACEAE	8.0	1.0	6.4	12.9
LYTHRACEAE	0.0	0.5	0.0	0.0
APIACEAE	2.0	0.5	0.0	0.0
Subtotal	11.5	3.6	8.7	14.1
Grassland pollen				
POACEAE	12.9	31.6	33.3	31.8
Senecio-type	7.5	15.0	4.1	6.5
Centaurea	0.0	0.0	0.6	0.0
Ambrosia	1.5	2.6	3.5	0.0
ASTERACEAE (genus undet.)	13.9	10.9	10.5	8.8
Subtotal	35.8	60.1	2.0	47.1
Mixed wetland and grassland pollen				
CHENOPODIACEAE	43.8	15.0	12.3	14.1
Total	**100.1***	**99.9***	**99.9***	**100.0**

* Actually 100%; numerical discrepancy is caused by rounding incremental values.

[1] See main text for illustrations and descriptions of the sampling locality and stratigraphic profile.
[2] Botanical nomenclature follows Jones and Wipff (2003). Species ranges and local species follow Richard and Richardson (1993), Weaver (1999), and Turner et al. (2003).

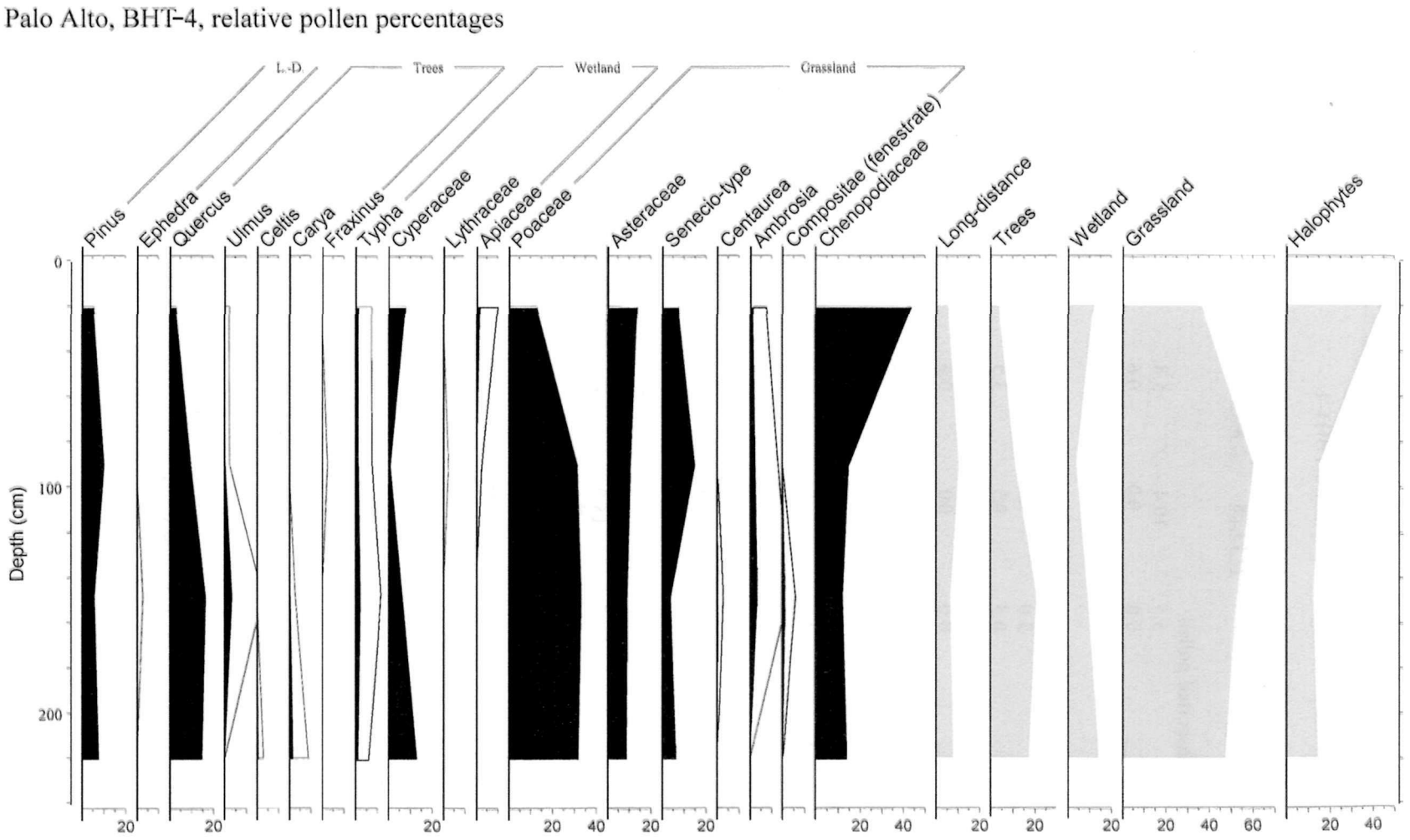


Figure 22. Pollen diagram for four sediment samples collected from Backhoe Trench 4 (BHT-4).

common components of the brushland flora and are known to occupy PAAL today. None of the other tree species occur at PAAL, but all inhabit Cameron County. They are found along the Rio Grande, the larger resacas, and/or locally elsewhere. The pollen of *Quercus virginiana* in particular is wind transported, but the relatively high percentage of oak pollen indicates it may have been carried by flood waters. The same is probably true of the other tree pollen, although *Fraxinus berlandieriana* is found very near the PAAL today and may have been present historically and earlier.

The represented wetland taxa are typical of lentic (standing or very slow-moving water) habitats. These plants include cattail (*Typha domingensis*) and one or more taxa in each of the following families: sedge (Family CYPERACEAE, cf. flat-sedge, *Cyperus* spp., and/or spikerush, *Eleocharis* spp.); loosestrife (Family LYTHRACEAE, cf. California loosestrife or hierba del cancer, *Lythrum californicum*); carrot, Family APIACEAE (cf. marsh parsley, *Cyclospermum leptophyllum*, and/or water-pennywort, *Hydrocotyle* spp.); and chenopod or goosefoot (Family CHENOPODIACEAE, cf. pigweed, *Chenopodium* spp., glasswort, *Salicornia* spp., and/or seepweed, *Suaeda* spp.). All of the wetland plants are found at PAAL today. The Family CHENOPODIACEAE includes some species that occupy prairies, but the relative contributions of the prairie versus wetland chenopods in these samples cannot be determined accurately and both are probably represented. In addition, some of the pollen from two other families, the grasses (Family POACEAE) and sunflowers (Family ASTERACEAE), may have been produced by wetland species. Prairie-dwelling taxa in these families produce pollen in massive quantities, which may have overwhelmed the other local sources.

Pollen representing dryland herbaceous taxa were the most common pollen types recovered. These plants occupied local prairie habitat, which was dominated by species in the grass (Family POACEAE), sunflower (Family ASTERACEAE), and goosefoot (Family CHENOPODIACEAE) families. Grass pollen is especially difficult to identify at the genus or species level, but Gulf cord-grass (*Spartina spartinae*) was the dominant plant throughout this area historically and is almost certainly represented in the pollen record. Other grasses and numerous forbs were also common, particularly forbs of the sunflower family (Family ASTERACEAE). In addition to the ASTERACEAE of undetermined genus, three genera or genera complexes in this family have been identified individually: basketflower (*Centaurea* sp., cf. basketflower, *C. americana*); ragweed (*Ambrosia* spp., probably including western ragweed, *A. psilostachya*, and perhaps others); and *Senecio*-type, which may include butterweed (*Packera* spp.) and other similar genera, as well as groundsel (*Senecio* spp.) proper. Richard and Richardson (1993) did not list *Centaurea americana* or any other species in this genus among the modern flora of the PAAL, but it is common in Cameron County and probably present at the site, at least historically. The taxonomy of the *Senecio*-type complex is poorly understood and both the genera and species are often synonymized. No attempt was made to subdivide the *Senecio*-type complex palynologically, but at least one species, Tampico butterweed (*Packera tampicana*), is common at PAAL and throughout Cameron County today. Several species of saltbush, in the generally non-wetland chenopod genus *Atriplex*, are common at PAAL and/or throughout this area. The species of this genus produce an abundance of pollen and in all likelihood contributed some of the pollen representing this family. As will be discussed below, chenopod pollen was much more common in the single near-surface sample than in the three deeper samples from BHT-4, in which the percentages of chenopod pollen were relatively constant.

INTERPRETATION OF THE NATURAL AND CULTURAL LANDSCAPE

Paleoenvironmental Interpretation

Paleoenvironmental conditions at PAAL can be inferred from geomorphic, stratigraphic, isotopic, palynological/botanical, and historical evidence. Except for the palynological record (presented with only brief discussion in Appendix A), each of these subjects has been discussed previously. The most important findings in each subject area will be summarized here, whereas the palynological data will be treated at greater length. These observations form the basis for a general synthesis of available information regarding the middle to late Holocene paleoenvironment of PAAL.

Geomorphic Evidence

Chief among the geomorphic findings was the conclusion that the Palo Alto Resaca had been a component of the Resaca de los Cuates, one of the radiating distributary channels of the Rio Grande that fanned across the delta plain. The present study area included the floor and both banks of a short segment of the Palo Alto Resaca and adjacent portions of the delta plain. When the Palo Alto channel was part of the distributary network, this reach drained southward and may have been perennial or nearly so (Figure 23). Avulsion or other processes along the main channel of the Rio Grande and/or the Resaca de los Cuates disrupted the continuity of the distributaries, preventing flow through the Palo Alto channel under most conditions. Isolated, this channel became a resaca, which is an abandoned channel containing standing water and a shallow water table. Rains and major floods brought freshwater to the Palo Alto Resaca, which was otherwise sustained by brackish ground water.

Stratigraphic Evidence

Eight backhoe trenches were excavated along a line crossing the resaca from west-northwest to east-southeast. The stratigraphic profiles exposed in these trenches revealed laterally continuous delta-plain deposits incised locally by a distributary channel. This channel was approximately 60 m wide and 4 m deep. Radiocarbon assays indicate that the age of the distributary channel (at least the local reach) is between 4730 and 2990 RCYBP. The older age was from the B horizon of a buried soil, the upper part of which was truncated, presumably during incision of the distributary channel. At least 0.5 m of this soil was lost; therefore, the older radiocarbon age predates the incision by an undetermined period. The younger age was from a sample near the base of the channel deposits and may provide a closer estimate of the time of incision: about 3100 to 3500 BP. If this estimate is correct, the distributary channel was short-lived, because there are no coarse channel sediments at its base and standing-water conditions had already become predominant by 2990 BP. Thereafter, the resaca was a palustrine environment. Surface water and a high water table kept the fine-grained, organic-rich resaca deposits water-saturated. Net groundwater flow was southeastward, producing a complex pattern of mineralization within the deposits. During dry intervals, deflation produced eolian sediment, which was deposited near the resaca. These conditions persisted until the historic period, when the resaca was modified, as was the hydrology of the entire Rio Grande watershed. The resaca was relegated to the ephemeral wetland it is today.

Isotopic Evidence

The carbon stable-isotope record ($\delta^{13}C$ ratios) corroborates the paleoenvironmental reconstruction based on geomorphic and stratigraphic evidence, and is consistent with palynological data. At the base of the stratigraphic section are delta-plain deposits. These deposits contain organic matter transported from the main channel of the Rio Grande, which was bordered by riparian woodlands. The trees produced large amounts of organic matter with a distinctive, isotopically depleted signature. After the distributary channel was incised, the isotopic composition of newly deposited sediment changed abruptly.

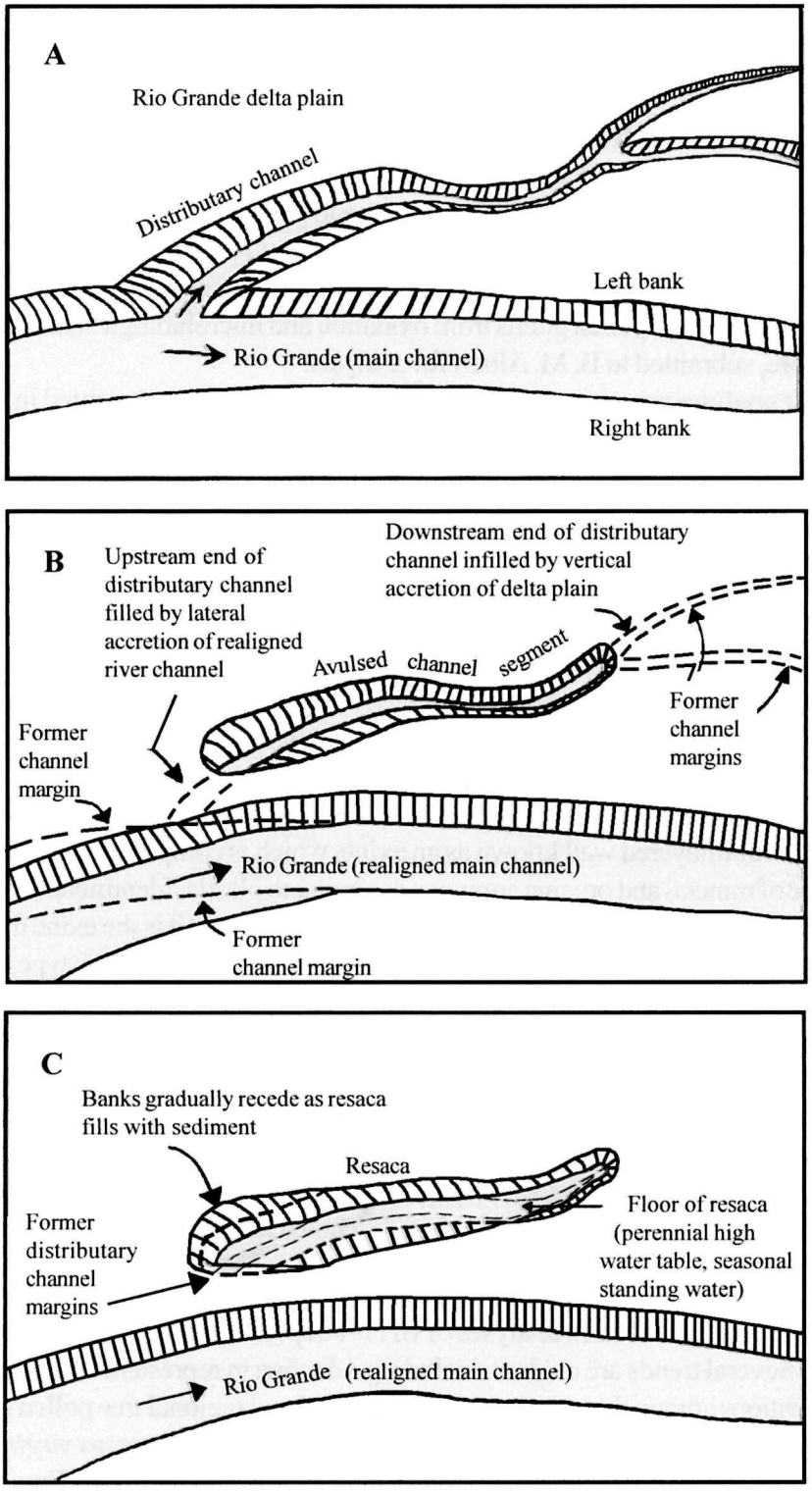


Figure 23. Diagrammatic reconstruction of the avulsion of a distributary channel of the RioGrande and consequent formation of a resaca (oblique view).

Most of the sediment accumulating within the resaca was washed in from the surrounding coastal prairie, which produced organic matter with an enriched isotopic signature. Later, the $\delta^{13}C$ ratios shifted gradually, exhibiting evidence of the increasing significance of wetland plants. Deposits at the top of the stratigraphic profile contain organic carbon predominantly derived from wetland species, although the surrounding coastal prairie continued to contribute.

Palynological and Botanical Evidence

Four sediment samples were collected from BHT-4 for pollen analysis (Table 7; Figure 18). Fossil pollen has only rarely been recovered in South Texas, owing to generally poor preservation (Bryant and Holloway 1985; Albert 2004). Conditions at the Palo Alto Resaca appeared much more favorable, however, particularly the permanent water saturation and organic-rich clayey sample matrix. These properties of the sediment might have protected the pollen grains from oxidation and microbiological decomposition. The samples were, therefore, submitted to B. M. Albert for analysis.

Results of these analyses are summarized and discussed here and are presented in full in Appendix A. The recovered pollen was well preserved, but represented a relatively small number of plant taxa. Most of these plants are found at PAAL today and would have occupied habitats comparable to those now extant. The historical and modern floras of this area include coastal prairie, brushland, and wetland species (Correll and Johnston 1970; Richard and Richardson 1993; Weaver 1999; Turner et al. 2003). All plant names conform to the nomenclature of Jones and Wipff (2003).

Pollen grains are the minute male reproductive bodies or microgametophytes of seed-producing plants, originating in the anthers of Angiosperms (flowering plants such as sunflowers, oaks, and grasses) and the microsporangia of Gymnosperms (conifers such as pines) (Faegri et al. 1989). To ensure successful reproduction, most plants produce an abundance of pollen, which is then widely dispersed by wind, insects, and other agents. Because they are highly durable, pollen grains maintain their viability despite exposure to harsh environmental conditions. This resistance to degradation likewise enhances the preservation of pollen in sediment. Pollen is protected by a multilayered wall known as an exine, which is composed of sporopollenin, an extremely stable mixture of mineral and organic compounds similar to plastic. Identification of pollen grains is based primarily on visual recognition under microscopic examination, and it is the exine that exhibits the distinguishing features. These features include: grain size and shape; exine structure; type, number, and configuration of apertures (fissures or thin areas in the exine); and ornamentation on the exine's outer surface. Although some species produce pollen grains with diagnostic features, many pollen types are so similar that identification is necessarily incomplete. Pollen that cannot be reliably attributed to a particular species may be recognizable at the genus or family level. The pollen recovered during the present investigation was identified as completely as possible based on known grain morphologies. In addition, some problematic pollen types have been tentatively referred to likely species among the known flora of PAAL, which has been studied in some detail. These hypothetical identifications are clearly denoted as such.

Paleoenvironmental Significance of the Pollen Record

Pollen spectra reconstructed from analyses of BHT-4 deposits provide a record of middle to late Holocene paleoflora. Several trends are evident, including a decline in representation of trees, a late increase in chenopods, and fluctuations among the grassland taxa. The local and regional tree pollen (excluding pine, resulting from long-distance transport) primarily comprise oak (probably *Quercus virginiana*) and a secondary representation of elm (probably *Ulmus crassifolia*) and other genera. In South Texas, Texas live oak and especially cedar elm, are common, but largely confined to the riparian woodlands along the Rio Grande and major resacas, although several other species of *Quercus* occupy the inland sand dunes immediately north of the delta plain. Pecan (*Carya illinoinensis*) and ash (*Fraxinus berlandieriana*) were also common along the Rio Grande historically. During the Nineteenth and Twentieth Centuries, however, intensive agriculture, channel modification, artificial drainage, diversion of river water for irrigation, and other impacts destroyed much of the riparian woodland habitat.

These activities were not, however, the primary cause of the reduced representation of tree species in the pollen spectra through time. That decrease began much earlier. For example, the per-sample subtotals of the percentages of tree pollen as a group declined by nearly half between Samples 3 and 2, then more than half again between Samples 2 and 1 (Table 9). This trend probably reflects the progressive loss of through-flowing water in the distributary channel, before and after it was generally isolated from the river and became a resaca. The river would have transported tree pollen from riparian woodlands upstream. Once the resaca was cut off from this input, local pollen sources and eolian transport soon predominated.

Geological data indicate that the water table remained high following avulsion of the distributary channel and declined only during the historic period as a result of deliberate drainage and restriction of river flow. In support of this conclusion, herbaceous wetland pollen types are represented throughout the profile. Sedges (Family CYPERACEAE), which can thrive even in seasonally dry soils, are particularly well represented. Cattail (*Typha domingensis*) pollen spans the period of record, attesting to the persistence of a lentic habitat on an essentially perennial basis. An isolated occurrence of LYTHRACEAE (loosetrife family, probably *Lythrum californicum*) pollen provides additional evidence of lentic conditions despite a concurrent decline in representation of sedges in Sample 2. Although of ambiguous interpretive value, significant quantities of the chenopod pollen type almost certainly represent wetland taxa, particularly gypsum- and salt-tolerant species.

The marked increase in chenopod pollen from Sample 2 to Sample 1 may be an indication of more brackish conditions late in the period of record. Gypsum-tolerant chenopods would have become more common within the resaca. Gypy ground water saturated the resaca deposits, although artificial drainage may now be causing the water table to remain artificially low. At the time of the Battle of Palo Alto, however, the surface water in the resaca was fresh (see Weaver 1999). Available evidence indicates that a layer of freshwater may have been buoyed by denser brackish ground water. Subsequent retardation of flooding and artificial drainage of pooled rainwater probably prevented dilution of the brackish ground water, which lay just beneath the ground surface, well within the depth of root penetration of chenopods. Surface water within the resaca may have been seasonally brackish even in early historic times, however, because the resaca was flushed with flood waters only episodically.

Historical Evidence

Weaver (1999) previously provided a compelling reconstruction of the flora and general environmental conditions at PAAL historically. Many first-person historical accounts from before, during, and after the time of the Battle of Palo Alto have survived, painting a picture of a broad coastal prairie with isolated brushlands and a resaca containing areas of standing freshwater and dense stands of emergent wetland plants (Appendix E). The palustrine environment along the resaca was virtually impassible in places, and served a strategic role during the battle by inhibiting movement of the Mexican Army, particularly its artillery (Haecker and Mauk 1997). Data from three reviews of vintage maps and aerial photographs provide a detailed summary of landscape modification and water-resource exploitation during the Nineteenth and Twentieth Centuries (Richard and Richardson 1993; Weaver 1999; this study). Geomorphic and stratigraphic observations confirm historical records regarding the nature of ditches and levees constructed at Palo Alto Resaca.

General Synthesis of Paleoenvironmental Evidence

A conceptual model of geomorphic processes affecting the PAAL provides a basis for interpreting the results of detailed stratigraphic and specialized analytical studies. These results, when coupled with a review of local history and landscape modifications, particularly since 1846, address each of the questions for which this investigation was conducted. In this area, the Rio Grande delta plain was a featureless expanse frequently inundated by unconfined flood waters. A water-tolerant prairie flora, probably dominated by Gulf cord-grass, was virtually uninterrupted, although isolated brushlands were found nearby.

The flood waters transported and deposited massive amounts of sediment, including allochthonous organic materials from riparian woodlands along the Rio Grande main channel upstream. Between flood events, soils developed within the delta-plain deposits, characterized by rubified (iron-oxide reddened) silty sands to which prairie flora slowly added organic matter. These conditions persisted from early to late Holocene time.

Approximately 3100 to 3500 BP, a major flood or channel realignment caused a distributary channel to become incised. Distributaries developed earlier in other parts of the delta plain, between 5000 and 7000 BP (Pryor et al. 1975). The local channel, ancestral Palo Alto drainage, remained integrated with the Rio Grande and/or the Resaca de los Cuates only briefly before further repositioning of the trunk channel cut off the Palo Alto branch, creating a resaca. The resaca began to fill with sediment from the coastal prairie or transported down-river by occasional floods. After about 1200 BP, flood frequency declined, and the resaca became a stable habitat for marsh vegetation, which had perhaps been less dominant previously. The resaca wetland was virtually unchanged from at least 390 BP (and probably somewhat earlier) to the time of the Battle of Palo Alto in 1846. The battleground was the coastal prairie, with brushlands at widely separated intervals and the Palo Alto Resaca at its flank. During the late Nineteenth Century, however, local and regional development of surface- and groundwater resources and large-scale agriculture altered the environment dramatically, by preventing flooding, draining the wetlands, clearing the brushlands, and tilling and grazing the prairies. Establishment of the Palo Alto Battlefield National Historic Site in 1993 provided an opportunity to restore the intrinsic character of the land as it appeared when momentous events were set in motion here that would ultimately affect the entire world.

The Palo Alto Battlefield Landscape

As noted previously, the historic maps were sometimes unscaled and do not always include north arrows, but reference to the Point Isabel-Matamoros Road and various natural features permit orientation (see Figure 5). The Road splits at the south edge of the battlefield, with the main road proceeding northward, and a secondary road toward the north-northwest (the "wet weather" road to Point Isabel). A second split occurs just north of the battlefield, with the road again proceeding toward the northwest, shown on one map as the "wet weather" road, although this would not have allowed the west part of the Palo Alto plain to have been bypassed during wet weather.

Jean Luis Berlandier, who was traveling with the Mexican army, prepared two sketch maps. According to Haecker and Mauck (1997:118) these maps were prepared soon after the battle. The first (Figure 6) shows a large marsh area and possibly one or two smaller such areas in the central battlefield, but only one in the second version. On the first sketch, he shows U.S. infantry and artillery units on the west side of Palo Alto Resaca in a line with simillar units spread eastward across the main battlefield.

Apparently with these maps as a source, additional maps were published in 1850 by Albert C. Ramsey, and in 1887 by J. W. Stewart (Haecker and Mauck 1997:120). These later maps show a series of marshes along a northeast-southwest line instead of just the one or two Berlandier originally depicted. Apparently, Berlandier presents Resaca de Palo Alto as a continuous, irregular, north-south line just west of the Matamoros Road; however, the Ramsey and Stewart maps show the Resaca as a series of separate ponds along the west side of the battlefield. At the southeast corner of the battlefield appears a line of low, wooded hills, oriented northeast-southwest, with the east end of the initial Mexican battle line adjacent to or near the southwestern end. A resaca is shown parallel to and just southeast of the hills at the southwest end. Dense woods are depicted on the west and south sides of the battlefield while most of the battlefield is depicted on the Ramsey and Stewart maps as a grassy area.

According to Haecker and Mauck (1997.:120), Berlandier published a Mexican map of the Palo Alto battle a year later, probably based on his earlier sketches (ibid.:Fig. 4.5). On this map, all the area west of the Point Isabel (Frontón) Road is depicted as wooded. Two long narrow marsh or resaca segments lie within the wooded area, one oriented essentially east-west and the other northeast-southwest.

The latter may be Palo Alto Pond. Southeast of the battlefield is a long narrow series of wooded hills and probably resaca segments, all oriented northeast-southwest.

Capt. W. S. Henry prepared a map in 1847, containing no scale or legend, with north toward the bottom and many features and military units labeled. The map shows little terrain but includes information relating to the current investigation. An arc of dense woods is located along the west, northwest, and north sides of the battlefield. Other woods are shown to the southeast. The woods along the west side appear as a narrow band close to the south end of the Point Isabel-Matamoros Road, further away proceeding northward, then closer again at the upper edge of the map near Palo Alto Pond. Two features that may be parts of the Resaca are depicted along the southeast edge of these woods. One feature is linear and oriented north-south, and the other is elliptical, oriented east-west. A large elliptical area in the middle of the battlefield is probably the marsh area shown on several of the other maps.

A map provided by staff at PAAL is not noted in Haecker (1994) or Haecker and Mauck (1997). The map is identified as a "Sketch of the Battle Ground at Palo Alto, Texas, May 8th, 1846" and was apparently prepared by J. H. Eaton of the 3rd or 5th Infantry (unit number illegible), and has units listed in the Legend as "Detached". The map shows these units at the west side of the battlefield immediately west of the Point Isabel-Matamoros Road and along the east edge of a linear strip of woods. This narrow band of woods begins at the Road just south of the location for the two infantry units and curves northward before turning to the northeast and then east, where it crosses the Point Isabel Road. The woods then join a broad, dense band of trees extending northwest ("Thick Chaparral"). Along the east edge of this tree row, opposite the central battlefield, there appear to be three small marshes, two linear and one elliptical, which are possibly parts of Palo Alto Resaca. Further north within the trees and just west of the Road is another linear area that may represent Palo Alto Pond. Elsewhere, the map shows a large area of "Thick Chaparral" (dense brush) along the south and southeast edge of the battlefield. Within this chaparral are two linear areas, probably resaca segments. The map depicts two positions for each of the opposing military forces. In the second position for U.S. forces, two units at the west end of the battle line are shown immediately adjacent to the probable segment of the Resaca, extending across the Point Isabel Road. One possible discrepancy in the map involves the roads. Just north of the battlefield proper, the Point Isabel Road curves toward the east, while another road branches north and then northeast. The latter is identified as the "wet weather road". On several other maps the "wet weather road" branches at the south end of the battlefield. This map resembles the Henry map in many of the details. The preparation date of the Eaton map is not known; however, Henry, who joined General Taylor's command several months after the Battle of Palo Alto, may have used it. Henry's map was published in his 1847 book (see Haecker and Mauck 1997:123). Conversely, the Eaton map could have been prepared later using the Henry map as a source.

Haecker and Mauck (1997:123) note that Lt. S.D. Dobbins was in the U.S. 3rd Infantry situated at the west side of the battlefield and west of the Point Isabel-Matamoros Road. A pamphlet published a few months after the battle contained the Dobbins map (ibid.). North is toward the map bottom (see Figure 7). A scattering of woods is depicted along the east side of the battlefield, but the area further east is identified as "Thick Chaparral", with the same designation indicated again toward the south. A linear, north-south scatter of woods lies adjacent to the battlefield just west of the Road, with a marshy area at the south end. Further north, a linear feature is probably part of Palo Alto Resaca identified as a "Pond". Another linear feature at the north end of the woods, west of the Road is labeled the "Pond of Palo Alto".

Three of the Scarritt maps illuminate his perspective on the battle but provide no information regarding natural landscape features. In a fourth sketch (Haecker and Mauck 1997:50), Scarritt indicated earthworks built to protect the cannons and pack train after the battle (see later discussion of earthworks).

Landscape Modifications

The landscape of the Battle of Palo Alto has undoubtedly been modified somewhat due to natural causes, including erosion by wind, rain, and flooding; however, the most significant changes appear to result from anthropogenic sources, beginning the day after the battle. References used to document the changes include aerial photographs, historical and recent topographic maps, and various other documents. In particular, the report by Haecker (1994), the subsequent book by Haecker and Mauck (1997), and especially the thesis by Weaver (1999) were extremely useful. Details obtained from maps and air photos were given previously in discussing results of archival research. Where specific land modification locations can be identified, they are noted in Figures 24-26. Table 10 provides the key to type and general location of modifications in Figure 24, and includes a list of other changes where location is unknown or where changes represent a general modification to the landscape.

Burial of Soldiers - On either May 8th or May 9th another action modified the battlefield. U. S. soldiers buried eleven slain Mexican soldiers as well as apparently all the Americans killed. Some burials were later disturbed and possibly washed away, with the locations of the remaining burials now unknown (Haecker and Mauck 1997:51-52). Apparently a large number of Mexican soldiers had been buried by their units prior to moving south (ibid.:51).

Uncontrolled Artifact Collection - Leveling of land near the earthen fortifications removed any trace of these features, but several shallow depressions were observed during 1992 fieldwork which were apparently the result of relic hunting (Haecker and Mauck 1997:54). In one account, the landowner plowed a field and removed a large number of cannonballs which he dumped in a resaca. In another case, cannonballs found in two concentrations were given to relic collectors; and a backhoe was used on Arista Hill in search of a reported payroll chest from the battle (ibid.:55-56; Richard and Richardson 1993:31). In the middle 1980s, a landowner claimed to have discovered 200 excavations, apparently by backhoe, each about two to four feet (0.6 to 1.2 m) wide, northwest and south of Palo Alto Pond (Richard and Richardson 1993:31). The landowner reportedly found a cannon in 1978 somewhere east of the Palo Alto Resaca (probably west of Palo Alto Pond) while clearing land to grow cotton (ibid.:32).

Public Tours - U.S. troops stationed at Fort Brown provided tours of the battlefield, and troops were stationed at Palo Alto shortly after the battle (Haecker and Mauck 1997:53), which undoubtedly altered the area to some degree, but the extent and locations of specific disturbances or relic collecting are unknown.

Table 10. Modifications to Palo Alto Battlefield National Historic Site Since May 8, 1946 (see Figures 24 to 26).

Specific Area Modifications = Locations Known (or approximate)

1	Defensive earthworks for cannons and wagons at Palo Alto Pond = May 9, 1846
2	Farm/ranch/other structures and associated facilities = at least by 1847 and later
3	Earthen dams = late 1950s or early 1960s
4	Stock tanks = 1960s and 1970s
5	Natural gas pipeline = installed in 1947
6	Irrigation ditches in Palo Alto Resaca = probably between 1950 and 1962
7	Irrigation Ditch #2 = completed in 1915
8	Backhoe trenches = 2004 (current project)
9	Roads and trails = since May 8, 1846 (only a few shown in Figure 24)

Specific Area Modifications = Locations Unknown

Human burials = U. S. and Mexican personnel = on or just after May 8, 1846

General Area Modifications

Fencelines
Hydrologic Changes
Vegetational Changes
Uncontrolled relic collection (in rare cases, general collection area is known)
Effects of public tours = middle 19th and early 20th c.
Use as U. S. Army firing range = 1920s and 1930s

Ranching - Exactly when ranching began in this area is unknown; however, as noted earlier, the original Spanish land grant in 1781 was to a rancher (Weaver 1999:15). Cattle ranching continued in the area through the 19th century, possibly during the Palo Alto battle. One of the more obvious modifications to the area was the excavation of cattle tanks (stock ponds) within the resacas, at Palo Alto Pond, and across the battlefield. Built in the 1960s and 1970s (ibid.:49), these ponds were not shown on the USGS map (originally prepared from 1953 aerial photos) until the 1983 revision (see Figure 24). One tank is shown northwest of Arista Hill. Another is near the center of the battlefield about where the marsh area was situated during the battle and along side a road added to the USGS map in the 1983 revision. One is at the southeast edge of Palo Alto Pond, as the Pond is currently shown. Three are in the resaca north of the battlefield, and two are on opposite sides of a road first seen on the 1983 USGS map revision. Apparently these last two tanks were built sometime after 1962 (not seen on aerial photos taken that year) after the landowner cut *senderos* (paths) through the brush (Richard and Richardson 1993:30). The tank at the southeast edge of Palo Alto Pond was excavated about 1973 (ibid.:32).

Among other effects of ranching was overgrazing that resulted in the loss of native grasses, an increase in prickly pear, and a decrease in plant diversity (Weaver 1999:44). An additional result of overgrazing was clearing, plowing and planting of nonnative species to compensate for the loss of native grasses (ibid.:44-45). For example, toward the northwest, several areas were plowed in a concentric arrangement and then planted with an introduced species (Richards and Richardson 1993:30, Map 6). An adjacent area was plowed and planted with introduced species that later declined during a drought in the late 1920s. An area to the southeast was plowed to a depth of 12 inches but not planted (ibid.). Roads, fences, and *senderos* were cut through the brush, all probably associated with ranching activities (ibid.:Map 5).

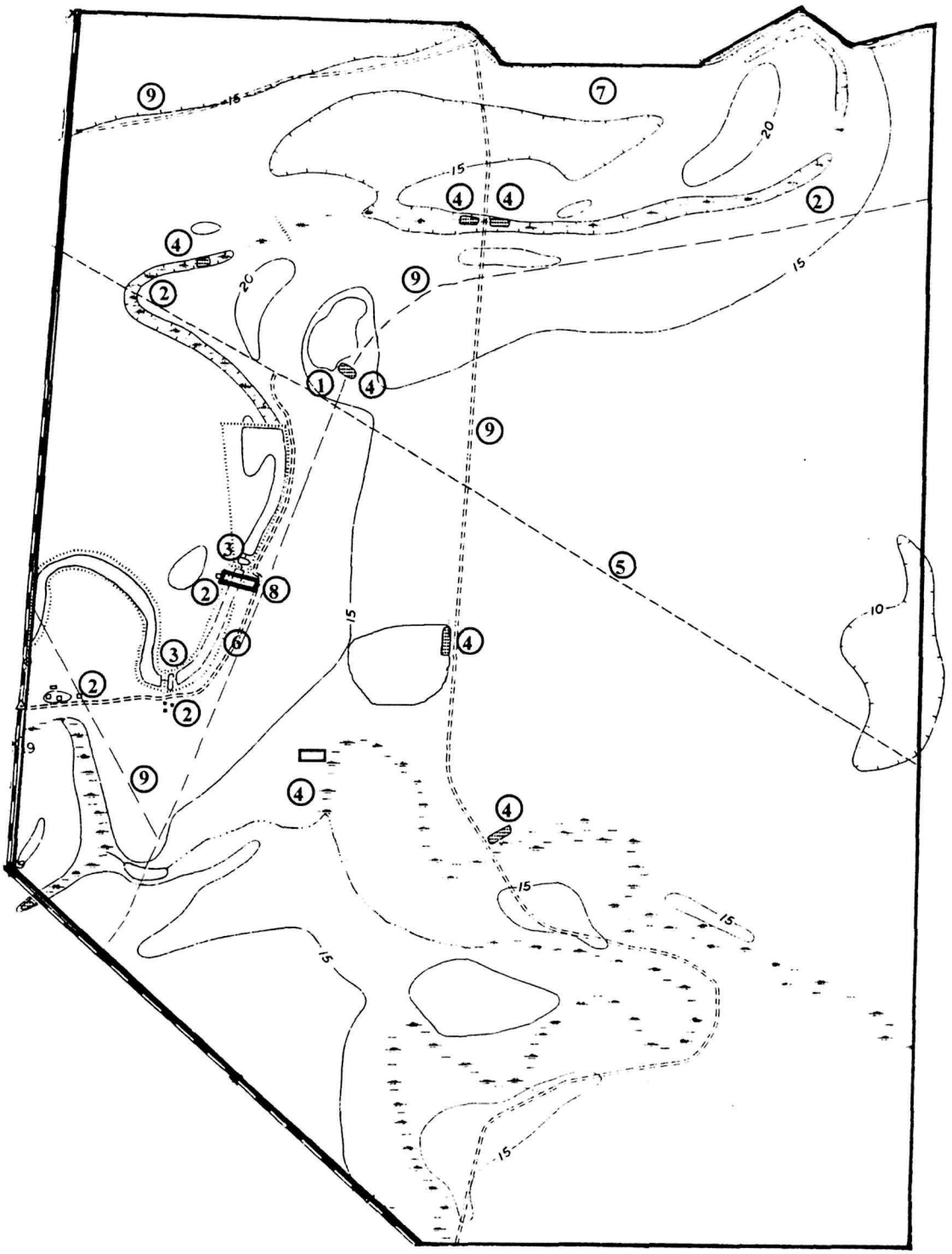


Figure 24. Modifications to land surface from May 9, 1846 to present (see Table 10; locations approximate in some cases).

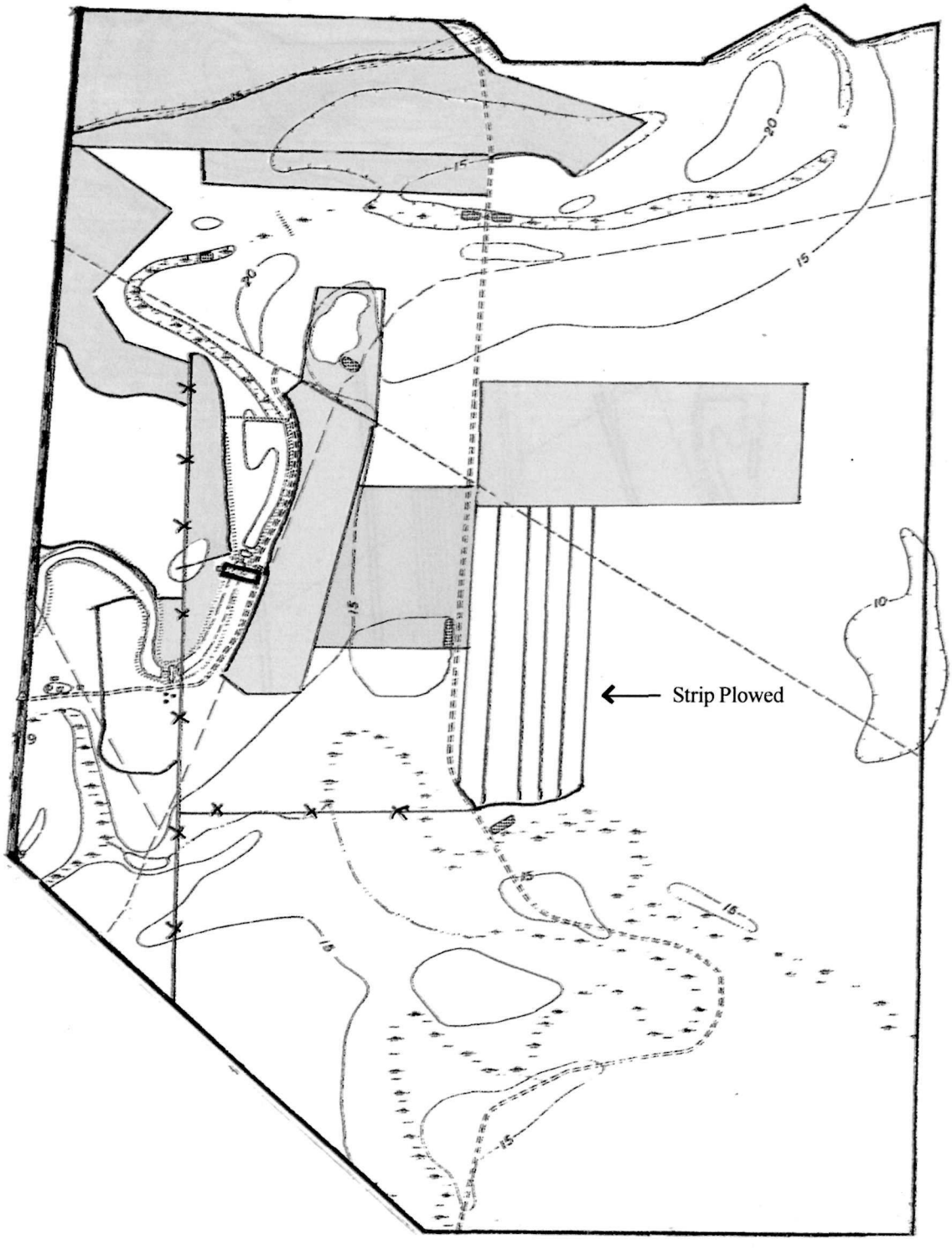


Figure 25. Approximate locations where ranching and farming activities modified the land surface and near subsurface as observed on aerial photographs.

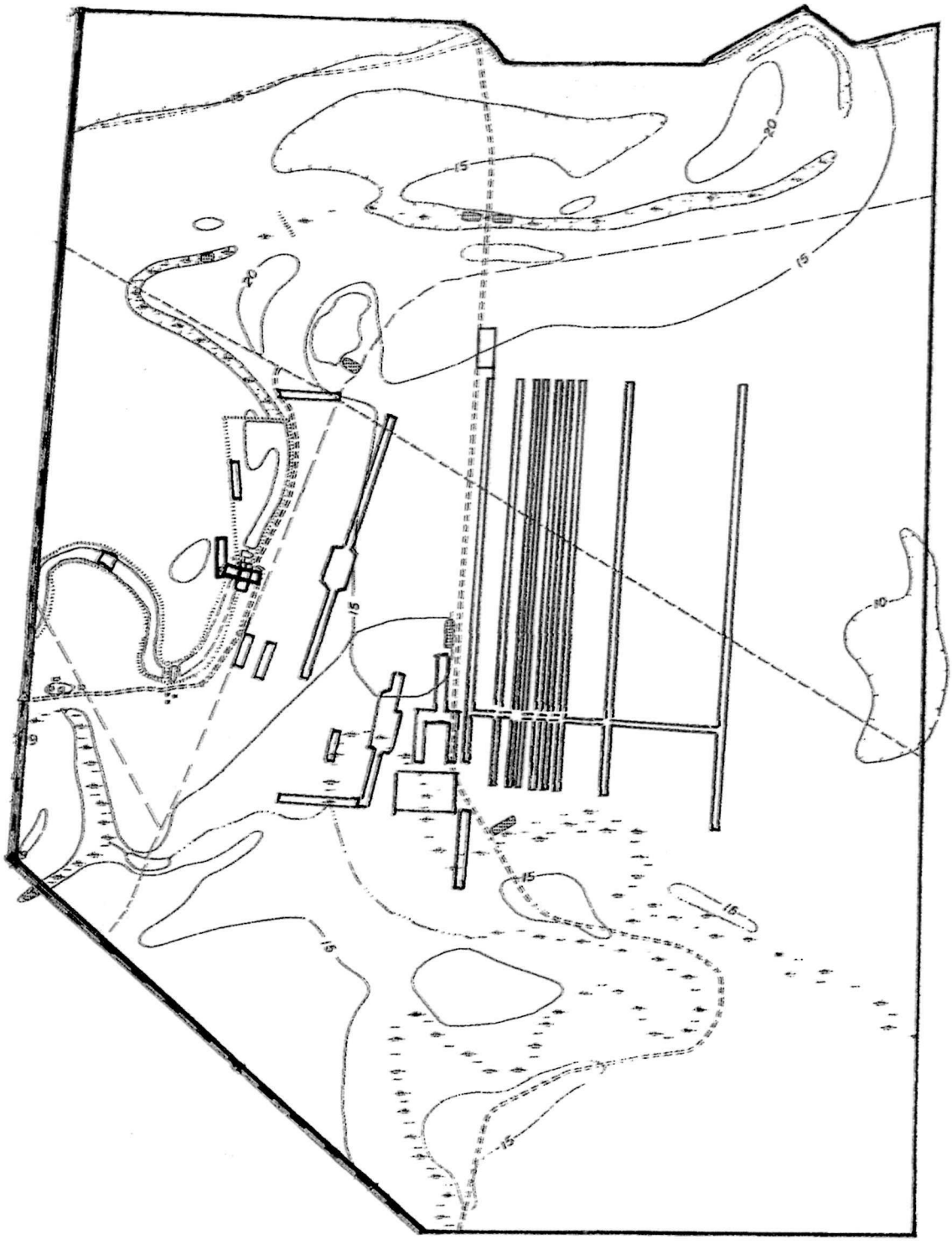


Figure 26. Approximate locations where controlled surveys with metal detectors resulted in collection of artifacts. Some were replaced (from Haecker and Mauck 1997:Figure 39 and NPS staff).

Aerial photos taken in 1968 show strips cut in the prairie grasses. Ground disturbance by plowing, and the introduction of new species (especially Johnson grass and buffelgrass), in addition to native cord-grass, make surface surveys for cultural remains difficult to conduct.

Cattle tank excavation, clearing, plowing, and other ranching activities such as establishing dirt access roads undoubtedly affected the soil surface and at least the near subsurface in many places (see Figures 24 and 25). These activities probably resulted in the disturbance or removal of cultural remains associated with the Palo Alto battle, as well as potentially affecting older remains.

Farming - The landowner whose property included Palo Alto Pond and the area west to Palo Alto Resaca, and possibly beyond, stated he cleared 110 acres to grow cotton and had "closed off" the south end of the resaca (location is unclear) to provide access to the field west of the resaca (Richard and Richardson 1993:32). He also reported digging several canals in the vicinity of Palo Alto Pond that were associated with the tank excavated there (ibid.). Air photos taken in 1968 show row cropping around the north meander of Palo Alto Resaca and brush clearing inside the meander (Richard and Richardson 1993:Map 5). These activities could have been associated with either ranching or farming (see Figure 25).

Fence Lines - An extensive network of fence lines exists throughout the area. These affect the land in part through excavations for fence posts, differential development of vegetation along and on each side of the fence line, and deposition of materials associated with fence construction, such as staples.

Firing Range - The U.S. army from Fort Brown used the Palo Alto area as a firing range in the late 1920s and the 1930s. As a result, 75 mm artillery "rounds exploded over the battlefield", leaving lead ball fragments scattered over the area (Richard and Richardson 1993:30; Haecker and Mauck 1997:54).

Drainage Ditch #2 - This was completed in 1915 to prevent flood waters from pooling on the prairies to the south (Weaver 1999:48; see Figure 24).

Pipeline Installation - A buried natural gas pipeline was installed across the battlefield northwest-southeast in 1949 (Richard and Richardson 1993:30), shown on the USGS topographic map prepared from 953 aerial photos (see Figure 24). As the map indicates, the pipeline disturbed a part of the resaca located northwest and southeast of the main battlefield area, and the plain where much of the battle took place. Typical activities associated with a pipeline installation include disturbance of both the surface and the subsurface across a strip several feet wide, in addition to the actual ditch where a line is laid.

Road and Trails - Among the historical maps depicting landscape and battle-related activities, Berlandier showed the Point-Isabel-Matamoros Road, a "wet weather" road branching toward the northwest just at the southwest corner of the battlefield, and Ramsey's map of 1850 shows these and another road branching toward the northwest at a point north of the battlefield. The only other road in the area appears to be the road to Los Tanques del Ramireño. This road begins near Arista Hill, proceeds around the low hills and the resaca, and then travels east-southeast. These roads are shown on the map in Figure 5.
In addition, since the battle, various dirt roads have been established across parts of the battlefield and adjacent areas, probably associated initially with the ranching and farming activities. A 1930 USGS topographic map shows an unimproved road from what is now Paredes Line Road past a structure just south of Palo Alto Resaca and then north along the east side of the Resaca (Richard and Richardson 1993:Map 1). To the north, the 1934 and 1939 aerial photos show a dirt road or trail proceeding south around the resaca and then south-west toward Palo Alto Pond where it joins a northeast-southwest road. These or similar trails appear on the photos up to 1977. Numerous other dirt roads and trails can be seen throughout PAAL, including a north-south dirt road shown on the 1983 revision of the USGS topographic map. Many of these roads and trails could be mapped if appropriate. All of these caused some degree of disturbance to the surface and near subsurface. It is unlikely any of them involved removal of surface soils.

Buildings - The 1939 aerial photos show three areas containing one or more buildings (see Figure 24, which also indicates the approximate former location of the Palo Alto House or Inn). One of these areas contains a cluster of buildings at the south end of Palo Alto Resaca near the present gate to the battlefield. The structures are on the north side of the dirt road leading east into the battlefield area. In their review of a USGS 1930 topographic map, Richard and Richardson (1993:Map 1) indicate a small structure near the Paredes Line Road gate which may be one of these buildings. A group of four buildings is shown in that area north of the road on the USGS map, according to1953 aerial photos. Perttula (1999:20), states that the grouping is primarily a late 19th to early 20th century ranch and dairy farm owned by Enrique Valentine, but no standing structures remain (Personal Communication, Rolando Garza, NPS staff). The second area with structures is further north, in a bend of this same resaca, west of Palo Alto Pond, where a single building stands with three adjacent rectangular scars. The structure is not shown on the USGS map, and traces of what may be the same structure were found by Ivey (1992, in Haecker 1994:39). Richard and Richardson (1993:32) indicate that from about 1920 to the late 1960s, this was a house, barn, corral, and water well in an area cleared from dense woods, including large mesquites. The house apparently was removed in the 1970s (ibid.). Remaining structures at this location were removed within the last year or so (Personal Communication, Rolando Garza, NPS staff). Shown initially on the 1939 photos, a third area consists of a group of buildings or a single building and associated corrals or other facilities; however, these are not on the USGS map originally prepared from 1953 aerial photos. This location is east of the current Visitor's Center for PAAL. Other air photos show buildings here, and the 1983 revision of the USGS map shows three structure symbols at this location.

Perttula and Nelson (1999:27-30) discuss the remains of the Palo Alto House or Inn (also known as the Taylor Tavern) located along Palo Alto Resaca. Apparently it opened for business in 1847 and either was abandoned in 1853 or, according to Butler (1995:64, in Perttula and Nelson 1999:27), burned down during an Indian raid (see Figure 24 for approximate location).

Controlled Artifact Collection - As noted in discussing previous archeological investigations, several surveys have been conducted at or near the battlefield, including use of metal detectors and a proton magnetometer. Texas A&M conducted a reconnaissance survey in 1976 about one-half mile southeast of the battle-field near a low hill called Loma Alta. During this survey artifacts were collected and later determined to be unrelated to the battle (Haecker and Mauck 1997:56). Texas A&M (Bond 1979) conducted an investigation in 1979 in this area and further northwest, partly within the battlefield, using metal detectors and visual inspection of the ground surface, with few battle related artifacts recovered (Haecker and Mauck 1997:57). Figure 26 shows the general areas of 1992 and 1993 surveys conducted with metal detectors (from Haecker 1994:Figure 39). Some of these areas received intensive survey, while others were merely sampled (ibid.:102). In some instances, metal detectors found artifacts that were recorded and replaced (ibid.:102). Some areas surveyed in 1979 were resurveyed in 1992 and, probably because of improvements in metal detection, additional artifacts were recovered (ibid.:101). In 2001, NPS staff conducted a limited metal detector survey at two locations within the Resaca (see Figure 26) and recovered two cannonballs, a musket ball, and a lead fragment.

Earthworks Constructed - On May 9, 1846, General Taylor ordered First Lieutenant Scarritt to remain at the battlefield and protect the wagon train while the main army moved south in pursuit of the Mexican army (Haecker and Mauck 1997:50). The wagon train was located at the south edge of Palo Alto Pond, and Scarritt responded to the order by constructing three earthen revetments around the wagon train. Four cannons were placed within the earthworks, as depicted in Scarritt's sketch map (ibid.), part of which is shown here as Figure 27. In 1893, an unnamed historian suggested that one fortification was located at the Pond facing northwest, and the other two were to the east along the wagon road (Haecker and Mauck 1997:54). These locations are approximated in Figure 24.

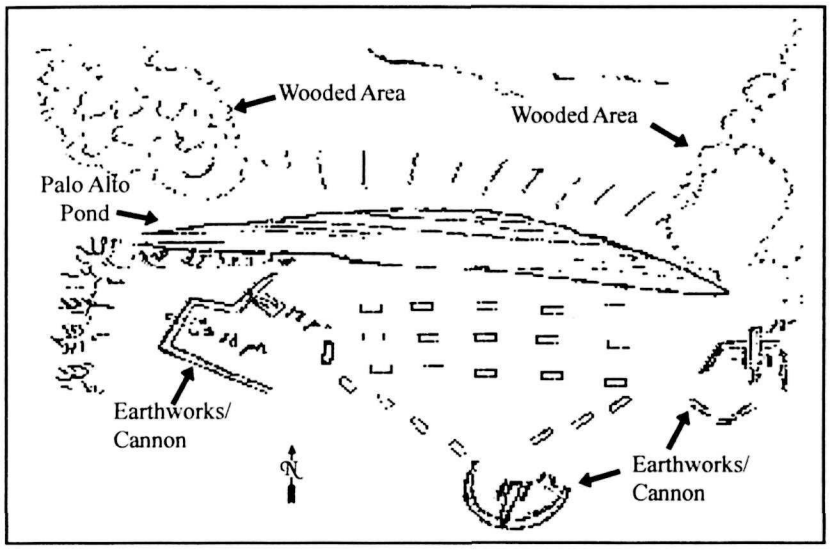


Figure 27. Earthworks constructed adjacent to Palo Alto Pond under direction of Lt. Scarrett on May 9, 1846, to protect wagon train. Adapted from sketch prepared by Lt. Scarrett, in Haecker and Mauck (1997:126)

Dam Construction - Two earthen dams were built across Palo Alto Resaca between 1950 and 1962, one just north of the current project area and another to the south, creating small ponds in the resaca channel (see Figure 24).

Irrigation Ditches - Two ditches were excavated between the earthen dams, one along each side of Palo Alto Resaca, probably between 1950 and 1962. The ditches were apparently intended to capture water in the channel, and in a pond formed by the small northern dam, so the water could be used to support farming and ranching. Measurements in the field show each ditch to be about 4.5 m wide and 0.5 m deep. These ditches were first observed on the 1962 photos, and are most clearly seen on the 1992 aerial photos.

Backhoe Trenching - As noted earlier, the backhoe trenches excavated during the current project (Figure 12) modified the landscape in a narrow segment of Palo Alto Resaca. Trench effects are thus localized and temporary except for the stratigraphic sequence within each trench. This sequence was permanently altered by excavation and refilling.

Hydrological Changes - As noted by Weaver (1999:47), the hydrological character of PAAL has been altered in three ways: by constructing stock ponds and associated drainage ditches (Figure 24); by controlling the Rio Grande flow through construction of dams, reservoirs and other control systems; and by excavating Drainage Ditch #2 (Figure 24). The stock ponds and ditches restricted the flow of rain that would ordinarily spread over adjacent land. Control of the Rio Grande flow significantly reduced prairie flooding, which had historically kept water in the resacas and other low places after hurricanes. A major change in the area water regime resulted from the excavation, begun in 1912 and apparently completed in 1915, of a large, east-west drainage ditch shown on the USGS topographic map. This ditch formed the north boundary of PAAL (ibid.:48; Richard and Richardson 1993:29). The 100-foot wide ditch, Drainage Ditch #2, was built to prevent floodwaters from collecting on the prairie and to reduce the effects of flooding on nearby towns. This ditch effectively drained a large body of water to the northwest known as El Tule Grande (Weaver 1999:48). Flooding of the prairies on a periodic basis is necessary to maintain the vegetation communities and, as a result of these changes, there has been significant alteration of the plant communities within PAAL (ibid.:50-51). According to Richard and Richardson (1993:30), the landowner recalled inundation by storm surge from two hurricanes: one in 1933 and another in 1967 (the latter was Hurricane Beulah), covering the prairie with two feet (0.6 m) of water.

Vegetation Changes - According to aerial photos and historical maps, a considerable amount of vegetation has been removed from large areas around the mostly open grassland constituting the main battlefield area. The surrounding vegetation was shown on the historical maps as "dense thickets" including mesquite. Removal of the these thickets probably was done largely in support of the earlier ranching and later farming.

Weaver (1999:73) concludes that mesquite was confined to the prairie perimeter when the battle took place. However, from her review of vegetation changes (ibid.:37-38), it is clear that honey mesquite (*Prosopis glandulosa*), and frequently associated species, such as prickly pear (*Opuntia engelmannii*), granjeno (*Celtis pallida*), and huisache (*Acacia farnesiana*), increased substantially after 1846. This is the case within the battlefield area, where accounts from the time of the battle indicate a scarcity of mesquite (ibid.:37). Now mesquite is seen as a prominent growth over large parts of PAAL. In addition to changes in the visual aspects of the battlefield, the root system of mesquite and associated species have likely disturbed the surface and at least the near subsurface of the soil.

Cultural Remains

No cultural remains were found during the current investigation where a limited area across the resaca was observed on the surface and in backhoe trenches. Cultural materials recovered by the 1992-1993 metal detector investigation are discussed in Haecker (1994:106-149) and in Haecker and Mauck (1997:134-175). Perttula (1999L18-26) and Perttula and Nelson (1999:27-30) report cultural remains observed at several locations within PAAL. In 2001, the NPS staff at PAAL conducted a limited metal detector survey at two locations within the resaca channel, as shown on Figure 26, and noted previously in this report. A few battle-related artifacts were collected.

Role of Palo Alto Resaca in the Battle

After reviewing historical maps, accounts of the Battle of Palo Alto, and the studies done by Haecker (1994) and Haecker and Mauck (1997), several natural landscape features appear significant in conducting the battle. Among these was Palo Alto Pond, where the American forces paused to allow men and animals to drink and where the wagon train was stationed during the battle. The importance of Arista Hill located to the southeast and the large marsh area within the battlefield was noted in discussing the battle. However, no feature seems more significant than Palo Alto Resaca, especially that part located along the west side of the battlefield. The current investigation took place along this segment of the resaca. Consequently, comments on the specific role of this natural feature in the battle are appropriate.

The Battle of Palo Alto occurred just at the end of a fluctuating climatic period known as the "Little Ice Age". Haecker and Mauck (1997:29) note there had been heavy rains just before the Battle. This may or may not reflect a previous period of fluctuating climate. Recent climate data indicate an average monthly rainfall in May of about 2.2 inches (5.6 cm), with the heaviest rains in September (5.2 inches; 13.2 cm). However, Weaver (1999:27) notes that May is a time of rain in the Lower Rio Grande Valley, according to the National Weather Service, and it appears there were especially heavy rains in May of 1846. In fact, an alternate route on the early maps show that the Palo Alto Plain, where the battle occurred, could be skirted by traveling on higher ground to the west. Several factors necessitated an alternate route: resacas could be marshy or contain water; low elevations and the general flatness of the plain allowed flood waters to spread easily; and scattered depressions could become marshes or contain standing water after heavy rain.

In good weather, the Matamoras road proceeded along the eastern edge of the Palo Alto Resaca where it includes a long, flat meander oriented north-northeast and south-southwest. Along this road, the Mexican forces formed a battle line to confront the U. S. forces proceeding south from Point Isabel. All the Historic-period maps reviewed show the initial battle line for the Mexican forces oriented east-west, with most of the maps indicating the left flank crossing the road and the right flank to the edge or just north of the range of low hills (near Arista Hill) extending toward the northeast. The U. S. forces first formed their battle line south of Palo Alto Pond about a mile or less to the north of the Mexican forces with the east flank not only crossing the road but extending far enough to approach a dense stand of brush. As a result, some of the U. S. units undoubtedly crossed the resaca and were stationed there at the outset of the battle.

The battle map in Haecker and Mauck (1997:Map 3) shows the Texas Ranger unit west of the resaca and the 5th Infantry unit between the road and the resaca (Figure 28 of this report). The first Berlandier sketch includes an irregular north-south line, identified as the Resaca de Palo Alto, with two units of American forces on the west side (see Figure 6 of this report).

As noted by Haecker and Mauck (1997:113), a simple overlay of the Historic-period maps with modern topographic maps is unreliable. Factors such as poor scales on the older maps, a lack of north arrows on several, the subjective placement of natural features, and the map makers' personal perspectives of the battle, result in ambiguities about the exact placement of Palo Alto Resaca. Nevertheless, several of the early maps have been overlaid to examine battle lines relative to the Resaca as it now exists. Using a few natural features (Palo Alto Pond, the large marsh area in the central battlefield, the low hills to the southeast) and the Point Isabel-Matamoros Road, four maps were created (Figures 29 through 32). There is, predictably, considerable variation in the positions of U. S. and Mexican forces relative to the resaca. Although the resulting depiction of the Resaca location is approximate, the first Berlandier sketch and the Henry map (Figures 29 and 30) show the initial U.S. battle line crossing the Matamoros Road and Palo Alto Resaca about midway on the long meander, near the current fieldwork investigation (see Figure 2).

However, as seen in Figure 31, the Stewart map indicates the U.S. battle line crossing the Matamoros Road and the Resaca further north where the meander begins to turn northwest. The right flank ends at the east edge of an area of either marsh or standing water. This may have been part of the long Resaca meander and, if so, the right flank ended near the east edge of the Resaca. There are also indications that marsh areas existed within the wooded areas and elsewhere along the north-south strip between the Resaca and the dense woods to the west. It should be noted that the Stewart map shows the entire Mexican battle line located east of the Matamoros Road rather than astraddle it as in most of the other maps. The Dobbins map (Figure 32) depicts the initial U. S. battle line crossing the Point Isabel-Matamoros Road even further north, beyond the long meander. In this instance the line would not have been across the Resaca at the outset, although after the battle lines rotated, the former west flank would have been at or near the Resaca.

Although of little value in discussing other aspects of the battle, it is possible the right flank of the U.S. line was at least adjacent to or possibly beyond the Resaca. This would have necessitated crossing a possibly marshy channel. Though not so difficult for the infantry units, the Berlandier map also shows one unit of artillery at the west end of the U.S. line. If these units were in fact west of the Resaca, their progress might have been slowed during establishment of the initial battle line and in maneuvers after the battle began.

As the battle proceeded, U.S. cannon fire was causing havoc with the Mexican forces. General Arista directed General Torrejón to attack the U. S. right flank west of Palo Alto Resaca with lancers and cannons (Haecker and Mauck 1997:38-41, Map 4). The lancers apparently crossed Palo Alto Resaca without difficulty but encountered a deeper resaca within the wooded area (chaparral) where their horses bogged down (ibid.:38). This deeper resaca may have been a western segment of the Palo Alto Resaca, as suggested by Figures 29 through 32. General Torrejón's artillery was held up even more but finally managed to cross the marshy areas (ibid.:41). The delay helped U.S. infantry units and cannons enter the area and, with the tactics used and support from Texas Rangers, repulse Torrejón's cavalry twice, causing the Mexican forces to retreat back over the Resaca and rejoin their main force (ibid.:39-41, Map 4). The suggested crossings of the Resaca by Torrejón's cavalry were in the lower meanders of Palo Alto Resaca (ibid.:Map 4), south of the current project area; but the actual fighting that ensued probably occurred further northwest. Throughout the course of the battle, the combination of woods and marshes was reportedly "difficult to overcome" by the Mexican forces (ibid:110), especially with regard to deploying their cannons.

In any event, Palo Alto Resaca proved an obstacle to movement for the Mexican forces during the battle, especially attempts by General Torrejón's lancers and artillery to attack the American right flank (see Haecker and Mauck 1997:105), as did the large marsh area in the center of the battlefield, and dense brush. Although there is no clear indication that the U.S. forces had similar problems, it seems likely that they did.

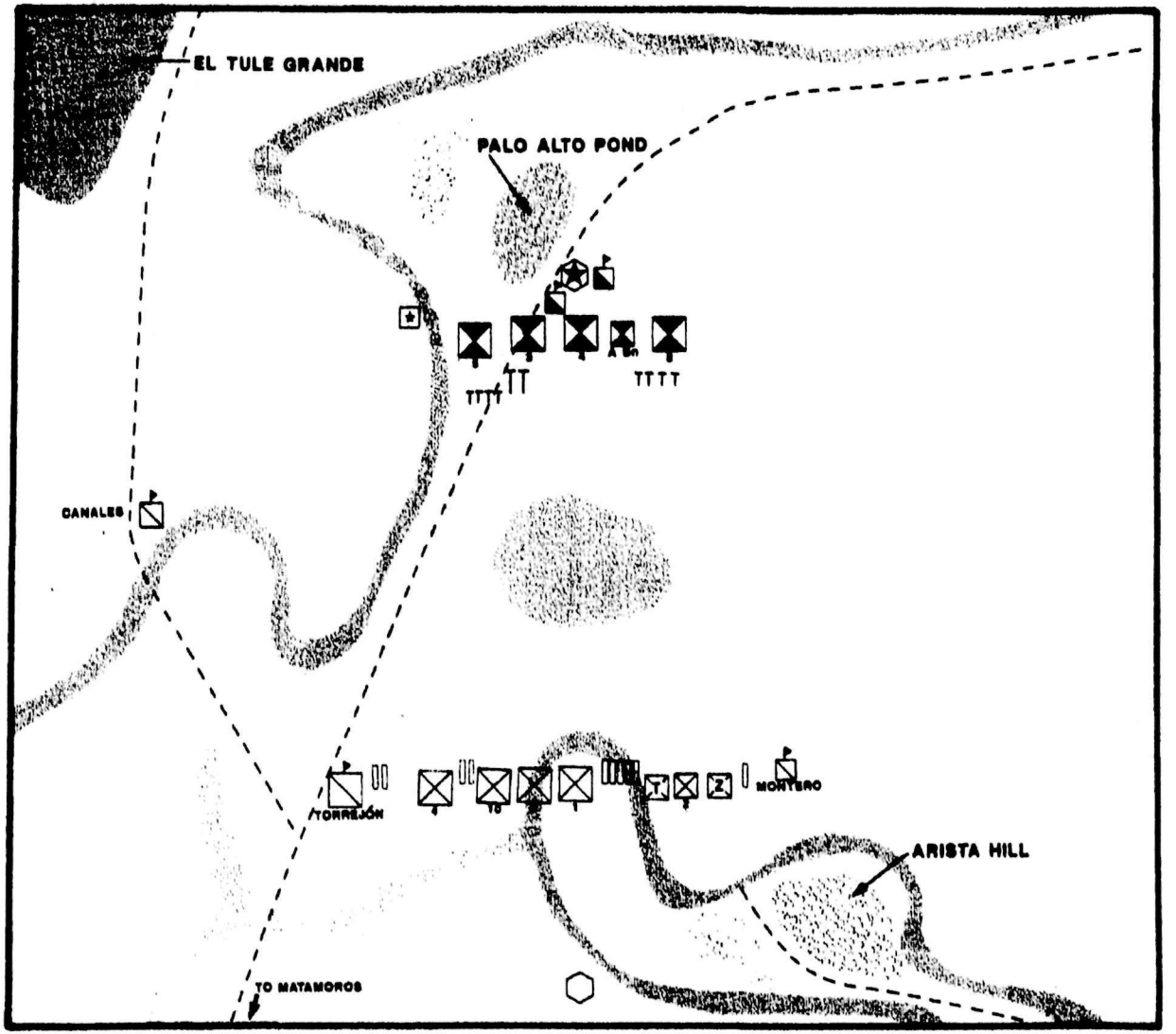


Figure 28. Map showing locations for initial battle lines of U.S. and Mexican forces at Battle of Palo Alto aadapted from Haecker and Mauck (1987:map 3). Courtesy of National Park Service.

Comment - On the Berlandier, Henry, and Stewart maps, the pack train and Palo Alto Pond are in the same general relationship to Palo Alto Resaca and in close proximity to a prominent bend in the Resaca (see Figures 29, 30 and 32). However, on the Dobbins map, the pack train is shown further north, placing Palo Alto Pond off the map. Although a long, linear feature is identified on the Dobbins map as Palo Alto Pond, it is more likely a bend of the Resaca as shown on Figure 32. On the Berlandier and Henry maps, the initial line of the American forces is near the center of the long meander bend; whereas, on the Stewart and Dobbins maps, the line crosses the Resaca further north, just before the meander bends northwest. The alignment of American forces relative to the Resaca is slightly different on the maps. On the Dobbins map, the west flank does not reach the Resaca; however, the line crossed the Resaca after the forces were repositioned ("second position", on Dobbins' map). The initial Mexican line is essentially parallel to the American line on all the maps and is situated south of the Resaca meander. Considering the locations of Palo Alto Pond, the Point Isabel Road, the pack train, the initial aligment of the American and Mexican forces, and the relationship of all these features to Palo Alto Resaca, it appears that Map 3 from Haecker and Mauck (1997:30; Figure 28 in this report) matches the Stewart map (Figure 31) and the USGS topographic map most closely.

Significance of the Battle of Palo Alto

The Battle of Palo Alto, on 8 May 1846, is recognized as "the first major (military) engagement of the U.S.-Mexican War and the first time the United States fought a major war on foreign soil" (Thompson, 2001:2). Infantry, cavalry, and artillery units of the Mexican and United States armies, aided by militias, conducted a series of brief, but intense attacks, defensive maneuvers, and counter-attacks throughout the hot afternoon (Haecker and Mauck 1997). In the end, the Mexican forces withdrew and the U.S. prevailed, but the significance of these actions went far beyond the Rio Grande delta. The term "manifest destiny" was first used in reference to American expansionism through the proposed annexation of Texas and other territories; and as a result of the war and subsequent treaties, the size of the United States increased by half by 1848 (Calvert and De Leon 1990). Scholars will long debate the methods and consequences of nation building, but it is in part because of the events at Palo Alto that the United States of America stretches "from sea to shining sea."

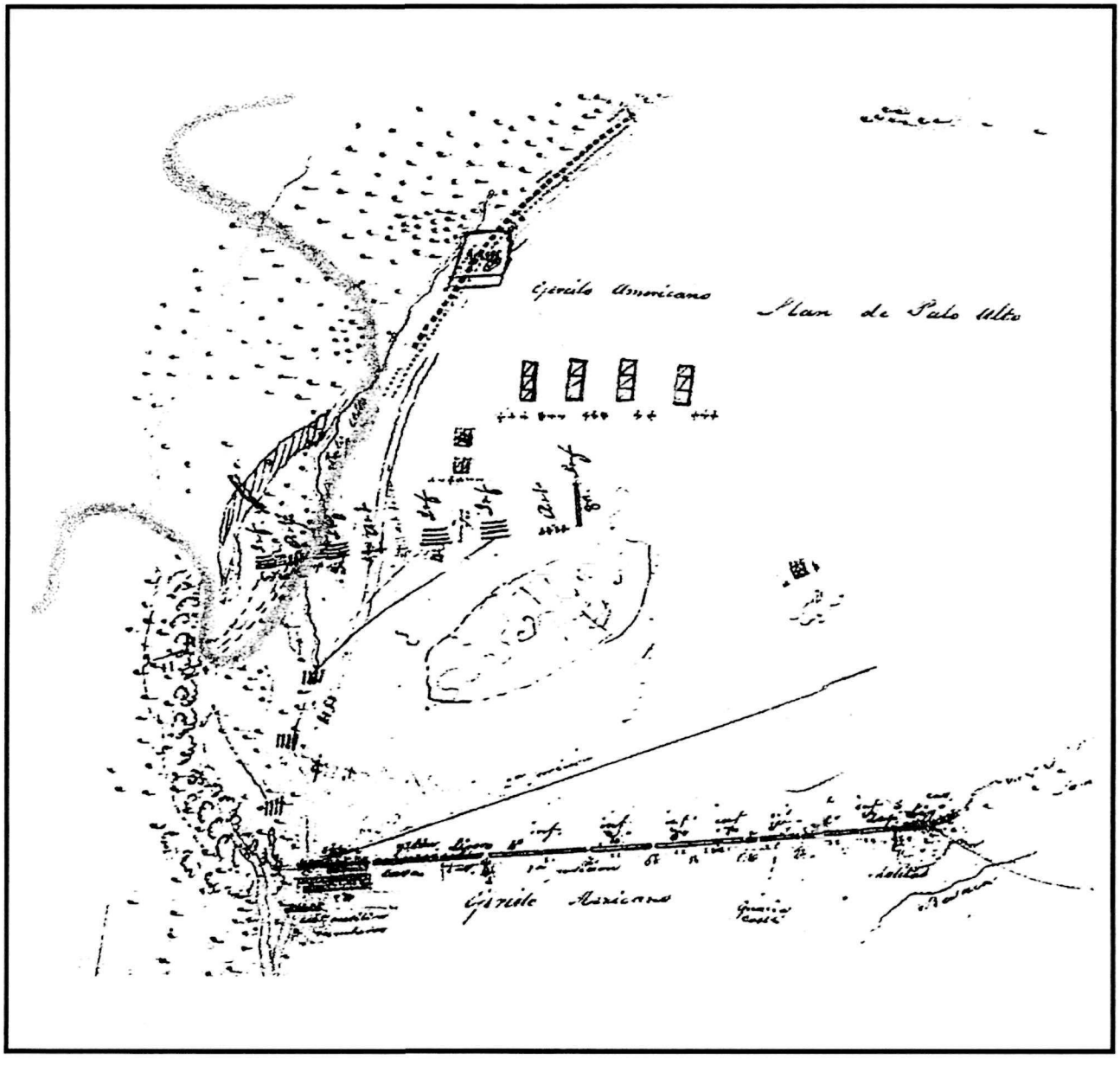


Figure 29. Part of Palo Alto Resaca from USGS topographic map superimposed on first map of Palo Alto battle sketched by Berlandier. Shows possible relationship between U.S. and Mexican forces and the Resaca. (Location of Resaca is very approximate, based on natural and cultural features common to both maps.)

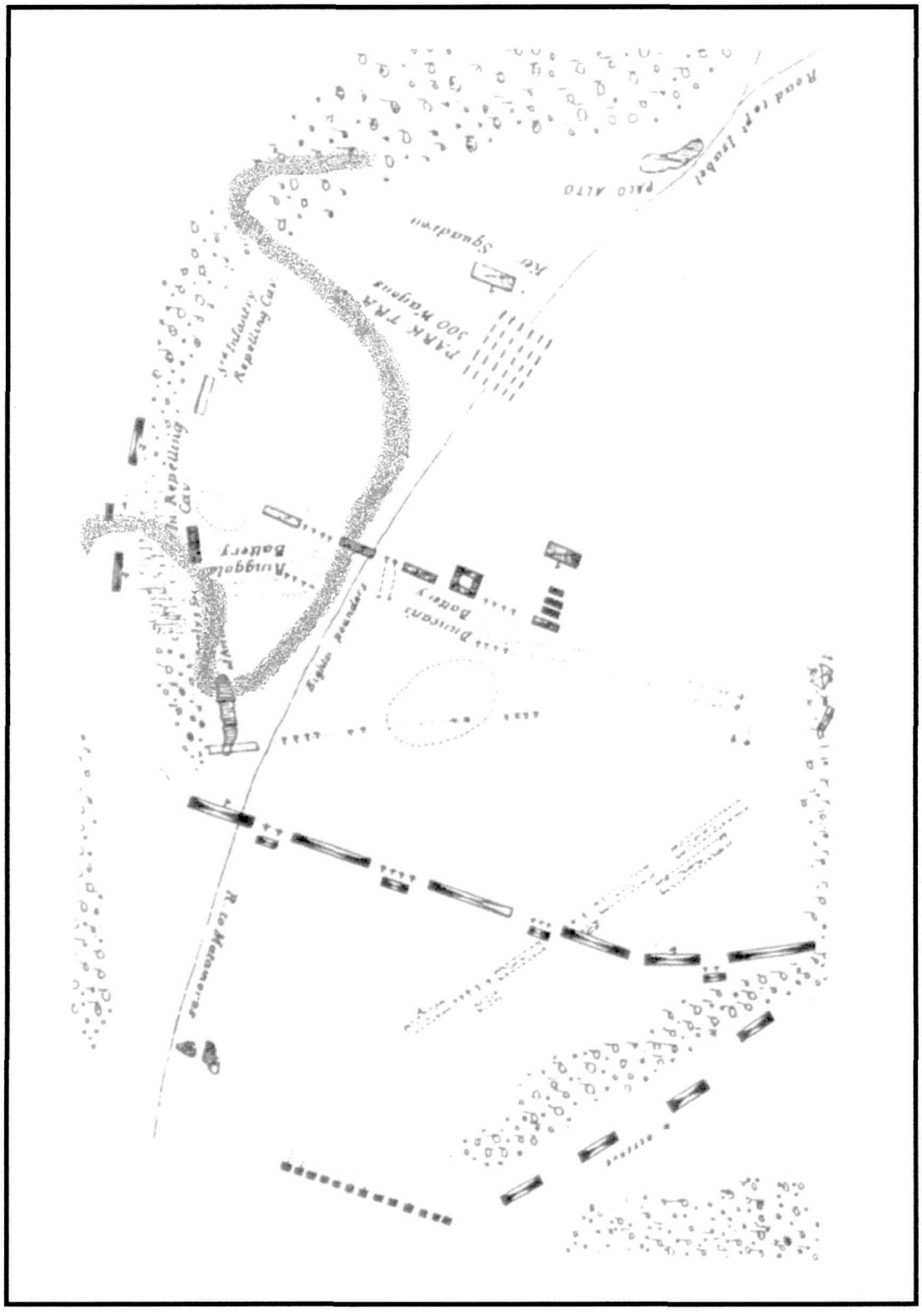


Figure 30. Part of Palo Alto Resaca from USGS topographic map superimposed on map of Palo Alto battle sketched by Captain Henry. Shows possible relationship between U.S. and Mexican forces and the Resaca. (Location of Resaca is very approximate, based on natural and cultural features common to both maps.)



Figure 31. Part of Palo Alto Resaca from USGS topographic map superimposed on map of Palo Alto battle sketched by J. Stewart. Shows possible relationship between U.S. and Mexican forces and the Resaca. (Location of Resaca is very approximate, based on natural and cultural features common to both maps.)

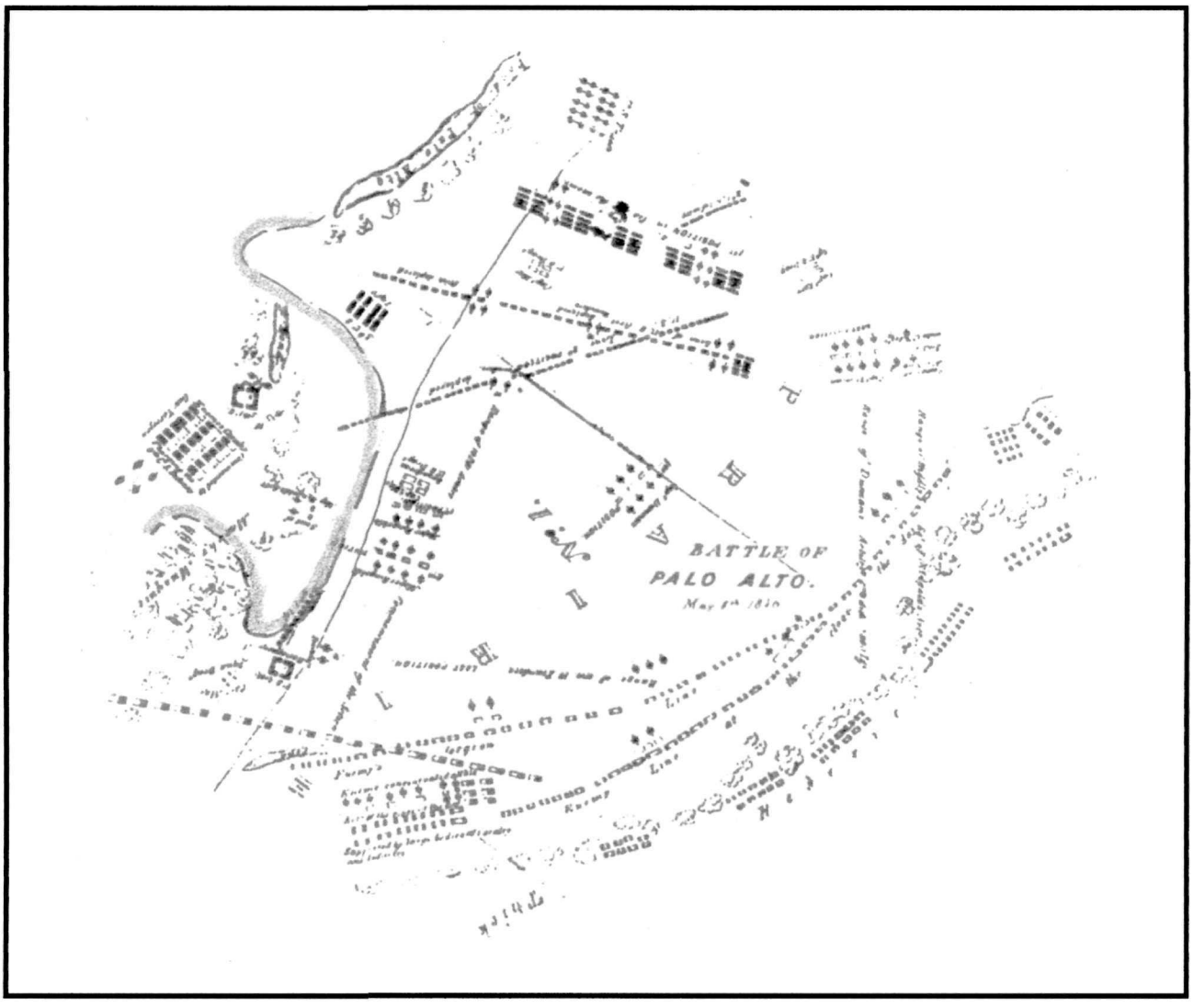


Figure 32. Part of Palo Alto Resaca from USGS topographic map superimposed on map of Palo Alto battle sketched by Lt. Dobbins. Shows possible relationship between U.S. and Mexican forces and the Resaca. (Location of Resaca is very approximate, based on natural and cultural features common to both maps.)

SUMMARY AND CONCLUSIONS

The present, limited geoarcheological investigation of the Palo Alto Battlefield National Historic Site produced a number of findings, interpretations, and data assessments. With the assistance and cooperation of the National Park Service staff, all objectives of this project were met or exceeded. Geomorphic, stratigraphic, isotopic, palynological, and historical data were convergent, providing a consistent indication of prehistoric and historic environmental conditions. Direct and indirect effects on the battlefield after 1846 were compiled and assessed.

Middle to Late Holocene Epoch

Investigation of the stratigraphy and geomorphology of the Palo Alto Resaca study area and vicinity afforded detailed evidence of the nature of PAAL and vicinity during the Middle to Late Holocene Epoch (~5000 BP to Historic Era). The geomorphic setting was the Rio Grande delta plain, a low-relief depositional landform created by rapid sedimentation at the river's mouth. Whereas much of the Rio Grande watershed was arid, it was so large and covered such varied terrain that enormous quantities of precipitation and runoff were captured and carried downstream. As a result, high-magnitude floods were common. Each major flood inundated a large area of the delta plain, depositing silty fine-sandy mineral sediment and organic matter derived from source areas upstream. The delta plain was, however, flat. As sediment accumulated at one locality, flow was diverted laterally, causing a continual shift in the site of local deposition with each flood event. These conditions persisted for thousands of years, producing a thick sequence of essentially homogenous deposits spread across the vast delta-plain landform. The geographic extent of the modern delta plain is essentially identical to that in late prehistory, but the environmental conditions and geomorphic processes operating today are very different. Land- and water-resource exploitation increased profoundly in the late Nineteenth and Twentieth Centuries, permanently altering the delta plain.

Until the late 1800s, the Rio Grande was virtually unaffected by water impoundment or withdrawal anywhere in its watershed. Frequent flooding affected every part of the delta plain. The resulting rapid accretion of fluvial sediment inhibited development of well-defined soil horizons. Soil horizons are created by internal differentiation and other changes within the deposits, such as preferential movement and concentration of clays and organic matter. These processes are gradual, but the periods between floods were simply too brief to allow significant horizonation prior to burial beneath a fresh layer of sediment. These deposits were, however, porous, and the iron minerals they contained oxidized quickly, as thin layers of newly accumulated sediment dried and were exposed to air. When the ferrous sedimentary particles oxidized, the delta-plain deposits acquired a rusty coloration, and were primarily brown or reddish brown in hue. The Rio Grande drainage basin encompasses much of New Mexico, western Texas, and northern Mexico, where the bedrock and soils are often rich in iron and reddened. Sediment that was ultimately deposited on the delta plain may have been red when it was initially eroded elsewhere in the watershed, but fluvial transport tends to remove the iron oxide coating from sedimentary particles. Therefore, much of the reddening (rubification) of the delta-plain soils must have occurred *in situ*, after deposition.

The bulk of mineral sediment deposited in the delta plain probably was transported from arid, high-relief areas in the Rio Grande drainage basin far upstream. Steep slopes and limited vegetative ground cover in those regions enhanced erosion and increased the amount of mineral sediment available for stream transport. Conversely, the aridic terrain would have been a poor source of organic matter. The river-transported organic materials primarily were derived from the lush riparian woodlands in the relatively humid environment of the subtropical upper delta plain. Flora of the PAAL, in the lower delta plain, included brush and wetland species, but much of this area was coastal prairie as it is today. Yet both the palynological and carbon isotopic evidence demonstrated that most of the organic matter in the delta-plain soil was from trees. The origin of the distinctive delta-plain soils thus reflects a dichotomy, with separate mineral- and organic-sediment source areas outside of the PAAL.

These brown or reddish brown silty fine-sandy soils, with minimal horizonation, contained organic matter from tree species along the river channel upstream. Subsequent changes in the local landscape modified the prevailing pedogenic conditions.

By the middle Holocene Epoch, the delta plain was crisscrossed by numerous meandering ephemeral streams of the distributary-channel network. The main channel of the Rio Grande may have shifted southward, reducing the frequency and volume of widespread flood-water inundation in the vicinity of PAAL. Only during exceptional floods did the river overflow all or most of the delta plain. Instead, flood water may have been largely confined within the distributary channels. The distributary channels were unstable, subject to avulsion and infilling whenever the main channel changed course, whereas each major flood incised new distributary channels. At PAAL, the Palo Alto Resaca channel cut through the older delta-plain deposits between 4700 and 3000 BP, probably about 3100 to 3500 BP. The absence of coarse bedload sediment from the base of the resaca deposits indicates that this channel was cut off from the Rio Grande almost immediately. Thereafter, the channel was a resaca, which gradually filled with fine-grained, organic-rich suspended sediment. Little organic matter reached the resaca from the riparian woodlands upstream. Instead, local sources of organic materials predominated. Initially, the surrounding coastal prairie was the principal source, but contributions from aquatic vegetation living within the resaca became more important through time, perhaps as the water depth decreased due to infilling. Both surface water and ground water sustained the aquatic habitat, which was perennial or nearly so.

Historic Period and Date of the Battle

Historical descriptions of the Rio Grande delta plain and PAAL vicinity decidedly agree that in the 1800s this was an expansive prairie, with isolated brushlands and numerous wetlands. The area had been part of a large cattle ranch since the Spanish Colonial period, but there is no record of brush clearing, cultivation, or intensive grazing, or of any type of construction until the mid to late 1800s. Trees were found along the river channel upstream, but most of the delta plain had no extensive woodlands. The name Palo Alto, which may be translated as "Tall Timber" or "Tall Brush," apparently referred to the dense thicket of mature mesquite on the western side of Palo Alto Resaca. The resaca itself was a chain of ponds and marshes and was probably deep enough to reach the water table, thus remaining wet year-round. Rain and increasingly rare flood waters also pooled in small closed depressions at various places across the plain on a seasonal basis.

The Battle of Palo Alto was fought in this context. Despite recent rains, the plains were relatively dry, but the resaca and ponds were wet and therefore played a strategic role by restricting movement of the combatants. So, too, did the brushlands, although perhaps to a lesser degree. Haecker and Mauck's (1997, Maps 3-5) reconstruction of the battle lines depicts the Mexican forces in particular as aligned within the resaca, both initially and in subsequent positions as the battle ensued. The present investigation provided no direct evidence to refute this interpretation, but the apparent wetness of the resaca makes this somewhat unlikely. If the Mexican companies were arrayed from east-southeast to west-northwest, possibly stretching from Arista Hill on the right flank to the main road on the left, they would have avoided the resaca in their rear (see discussion of the possible role of Arista Hill elsewhere in this report). Such an alignment would reduce the distance between the U.S. and Mexican forces, at least as the engagement began. There are, in fact, discrepancies in the historical estimates of the distance. Perhaps the U.S. and Mexican lines were not initially parallel, such that the distance varied from flank to flank. In the absence of further archival and archeological investigations, these alternative views of the battle must be considered hypothetical only.

At the time of the Battle, the landscape was essentially natural. The U.S. artillery position near Palo Alto Pond was reinforced with small earthworks, presumably built from soil excavated at the site of the gun emplacements. Speculation that the levees along Palo Alto Resaca might have been built as defensive structures during the battle is unsupported by findings from the current investigation.

The primary and wet-weather roads were unimproved pathways, but they crossed the resaca at two or more locations. There may have been other ill-defined crossing points as well, where the resaca could be traversed under most conditions. If so, these points might have been used by travelers or even by cattle on occasion, but whether the combatants utilized pre-existing pathways other than the roads is uncertain. There is no known historical account or other evidence of construction along the roads or paths, either at the resaca or elsewhere.

Post-Battle

After 1846, the battlefield was changed in three principal ways: 1) regional and local water resources were significantly reduced by restriction of riverine flow and flooding, deliberate drainage of wetlands, and withdrawal of ground water; 2) at the battlefield, native brushlands were partly cleared, prairie grasses were heavily grazed, and small areas were cultivated; and 3) buildings, dams, ditches, and livestock watering ponds were constructed in a few places along Palo Alto Resaca and nearby. Mesquite and other woody shrubs increased as the native grasses were disturbed and other conditions altered. Despite these changes, much of the intrinsic character of the battlefield has remained essentially intact to the present, although most of the wetland habitat is no longer permanent. Construction and restoration efforts by the National Park Service began in 1993 with the dedication of Palo Alto Battlefield National Historic Site.

The ditches excavated in the late 1950s or early 1960s on both sides of Palo Alto Resaca had a number of consequences. They primarily carried water that was stored behind a small dam to the livestock watering ponds downstream. Placement of the excavated earth on the resaca's banks created levees or levee-like earthen mounds. The levees may have been intended to protect the water-retention improvements against hurricane surges or riverine floods, which were very infrequent yet still possible prior to construction of Amistad Reservoir on the Rio Grande. The earth placed on the banks also may have unintentionally protected the 1846 land surface along the resaca. Riverine sedimentation slowed in the decades following the battle, as dams and water diversions increased throughout the Rio Grande drainage basin. Even using the relatively low mean rate of net sediment accretion determined, using radiocarbon assays, 0.431 mm/yr, the depth of burial of this surface over the 158-yr interim would have been only 68 mm or approximately 2.7 inches to the present. It is, therefore, likely that the surface on which the excavated soil was placed was essentially the 1846 landform, assuming that surface had not been locally eroded or otherwise affected. Results of the present investigation indicate that, at least in those areas examined during this study, the surface buried beneath the levee on the western side of the resaca was intact, whereas the eastern bank may have been scraped during excavation of the ditch. The levees may have helped preserve battle-related artifacts and part of the 1846 ground surface.

EVALUATION

Methods

Archival Research - The time available for archival research in support of this project was limited; however, because of extensive work done during previous investigations, and research conducted by the National Park Service staff, a number of Historic-period maps, aerial photos, and documents were available. Most were obtained from National Park Service staff at PAAL or from their headquarters in Brownsville. These helped immeasurably in assessing the landscape in the immediate vicinity of the project area and in other parts of PAAL. The documents were also useful in determining the disturbances throughout that have occurred since the battle took place in May 1846. The report by Haecker (1994) and the book by Haecker and Mauck (1997) were invaluable in understanding the location of battle-related activities, the overall conduct of the battle, and the role of various natural features that probably affected the conduct if not the outcome of the battle.

A number of differences and similarities existed in the available maps. The differences in map detail result from several factors. Those prepared during the battle represent the perspective of the map maker from their unique viewpoint and, depending on their location, likely would provide more accurate information nearest to their position, with decreasing accuracy for more distant features. From a ground-level view, it seems unlikely that features, such as the roads, could be drawn with much accuracy throughout the entire battlefield area. Those maps drawn during the battle may have been prepared at different times so again the depiction of unit locations, for example, could have varied accordingly. It appears also that in a few cases the map preparation may have been curtailed due to the needs of the battle. In addition, some of the maps were generated from memory, notes, and other informants after the battle was completed. In some instances, the maps were compiled from several months to one or more years after the battle took place using various sources, including those maps prepared by others during or just after the battle. As a result, some of the details that are common to the otherwise different perspectives result not from actually documenting particular features or events but rather from using common sources to prepare the later maps.

Even though the available maps were invaluable, considerably more research seems appropriate, especially in the archives of Mexican libraries, museums, and other facilities, as well as in U.S. archives. Official reports prepared by the military units and reports prepared by the medical staff, similar to those provided at permanent military station would be particularly useful. It seems likely that additional Historic-period maps of the battle will be found in both Mexican and U.S. archives, and that such maps could shed light on differences among in the currently available maps.

Three sets of overlapping aerial photographs were provided as digital images that provided stereoscopic coverage (with the original prints viewed briefly while in the field). Single images from several years were available, mostly in a digital format. Access to good quality photographic prints with stereoscopic coverage from these same years would have been more useful.

Backhoe Trenching - The series of backhoe trenches proposed by NPS were the only appropriate means for efficiently meeting the project objective regarding possible disturbances that have occurred in this part of Palo Alto Resaca and, in particular, the amount and location of overburden that may have resulted from excavation of two ditches along this Resaca. Eight backhoe trench locations were selected in the field to assess the resaca channel, both channel banks, and, for comparison, the adjacent land on either side. The dates selected for conducting the fieldwork were necessary to allow the resaca to dry reasonably well, after a substantial period of rainfall in the area, and prior to the onset of the hurricane season. Most of the resulting trenches were above the water table, but a few were excavated to a depth that allowed water to seep in slowly, although this did not significantly affect the study of the soil profiles.

Special Analyses - Four sediment samples were submitted for a variety of specialized analyses. The radiocarbon assays produced excellent dates, which provided a temporal framework for assessing the development of Palo Alto Resaca in the study area (see Appendix C). The associated carbon stable-isotope values provided information on the vegetation communities existing at those times, as did the results of the palynological analyses. A relatively extensive set of pollen remains were contained in the samples, resulting in a valuable record of plant species existing at PAAL over time (see Appendix A). No diatoms were found in the samples, probably because of unsuitable preservational conditions in the Resaca (see Appendix B). Nevertheless, the potential for obtaining paleoenvironmental information from diatoms would justify a further attempt to use this method. All of these methods would be applicable in any future geoarcheological investigation.

Results

Archival Research - Several Historic-period maps of the Palo Alto battle were available as sketches. Despite the lack of accurate scale (although many contained a bar scale), and the lack of north arrows on some, they provided one of the most useful sources of information available about the location of battle activities and the conduct of the battle. The relationship between the various natural features and the military units could be discerned, although the specific unit locations varied among some of the maps. In particular, the role of Palo Alto Resaca in the battle was evident, and the Resaca was clearly important to the conduct of the battle.

The aerial photographs were of considerable importance in assessing changes between 1934 and 2000 not only in the Resaca where fieldwork was conducted but also in other parts of the battlefield and adjacent areas. Changes included the effects of land use activities that have modified the landscape since the battle. Assessment of these modifications to the landscape should aid the NPS in its efforts to restore the battlefield to the original condition.

Backhoe Trenching - As shown in this report, backhoe trenches allowed the preparation of soil profiles to locate the probable original land surface, the degree of previous disturbance of land surface and subsurface, and the amount and location of backdirt to be removed. As a result of these analyses, the original surface, as it existed during the battle, may now be recoverable. In addition, assessment of land modifications throughout the battlefield and adjacent areas, especially where excavations have occurred, make possible an evaluation of other areas by methods similar to those used in the current investigation.

RECOMMENDATIONS

Steps to Restore Palo Alto Resaca

1. Review of aerial photographs suggests that the two ditches encountered during current fieldwork extend between the two earthen dams located along this segment of Palo Alto Resaca. If necessary, field examination should be conducted to determine whether this assessment is correct. The results of the field check and this geoarcheological investigation, as shown in Figure 13, show the extent and location of backdirt removed from these two ditches at this one location. Similar investigations should be conducted along the banks of Palo Alto Resaca between the two dams.

2. If the resulting information shows a similar pattern of backdirt placement along the banks in other parts of the resaca between the dams, the backdirt should be systematically removed from both banks. In doing so, care should be taken to insure any cultural materials residing on the original surface are not disturbed. Available evidence indicates that the levee (mound of backdirt) on the western side of the resaca may preserve the 1846 land surface and, therefore, may overlie battle-related artifacts, whereas the eastern bank of the resaca may have been scraped during excavation of the ditch on that side, prior to placement of the backdirt. Additional geoarcheological test excavations are needed to assess these preliminary conclusions (see Additional Field Research, below). If cultural materials are found, their provenience should be documented, then the materials should be collected and processed.

3. The present floor of each ditch is slightly lower than the remainder of the resaca (see Figure 17), so it might be possible to spread the backdirt along the edges of the Resaca. If this is unacceptable, the best course of action might be to dispose of the backdirt at a location unlikely to have been part of the former battle or to contain other archeological remains unrelated to the battle.

4. Historical records and the results of the present investigation indicate the resaca contained standing freshwater at the time of the battle and was a marsh environment with perennial, standing or slow-moving surface water. The water table was high and probably chemically stratified, such that freshwater from precipitation, runoff, and occasional widespread flooding of the delta plain was buoyed on brackish ground water, and reached the ground surface within the resaca. Restoration of these conditions, possibly by artificial means, would be a major step in reestablishing the 1848 appearance of the battleground. It is, however, unlikely that natural, mid-Nineteenth Century hydrologic conditions could be restored because of inherent conflicts with major drainage and water-use infrastructures now in use throughout the region. One alternative might be to add freshwater to the resaca during dry periods. A dedicated water source such as a water well linked to the resaca by a buried waterline might be required. Other possible sources might include existing runoff-diversion/irrigation channels north of PAAL, although water-quality issues might then have to be addressed, as well. Studies specifically directed to these issues would be required.

Additional Archival Research

1. Conduct a thorough review of the archival materials already available (Historic-period maps, reports, books, aerial photographs, and other materials) in an attempt to gain a detailed understanding of (a) natural and cultural features existing at the time of the battle, (b) organization and movement of U.S. and Mexican forces before, during, and immediately after the battle, (c) other factors indicative of locations of landscape disturbances during the battle, and (d) activities in and around the battlefield from the time the battle was completed up to the present. The present report reviewed battlefield events and subsequent land-use changes in and near the Palo Alto Resaca project area. This report could serve as a model for organizing similar investigations throughout PAAL.

2. Conduct additional research in Mexican archives, the National Archives in the Washington, D. C. area, and other locations with potential for (a) additional maps of the battle; (b) the location of burials of any soldiers killed in association with the battle; (c) journals, diaries, letters, and other sources for information on movements of military units during the battle, and battleground condition during and just before the battle; (d) the role natural features played in conducting the battle; and (e) information on weapons or other items left behind, intentionally or otherwise. For example, some data indicate that a light artillery unit may have occupied Arista Hill on the Mexican right flank, at least at the start of the battle. Additional archival support of these data would establish a rationale for archeological field investigation of Arista Hill and surroundings on a priority basis. Evidence suggesting alignment of the Mexican forces north of the resaca (that is located near the south edge of the battlefield) would be consistent with the present geoarcheological finding that the resaca was probably too wet at the time of the battle to allow the Mexican forces to operate within it.

3. Obtain aerial photographic prints (not digital copies) from federal, state, and commercial sources to provide stereoscopic coverage of the entire Palo Alto Battlefield National Historic Site. Emphasis should be placed on obtaining large-scale (1:10,000 to 1:6,000 or better), black-and-white aerial photos of the highest possible quality. Range of coverage should begin with the earliest available date flown and approximately every 10 years thereafter until the latest date. These should be analyzed by an experienced photo interpreter familiar with the history of the battle, the battlefield, and the surrounding area to establish locations of previously unidentified natural or cultural features shown on Historic-period maps or noted in battle descriptions, including the Point Isabel-Matamoros Road and alternate "wet weather" road, indications of battle-related ground disturbances (i.e., earthworks, burials), and any area occupations since the battle.

Additional Field Research

1. Use the results of new archival research and previous investigations (see, e.g., Perttula 1999; Perttula and Nelson 1999) to conduct archeological investigations of various Historic-period occupations. These investigations should address each group of farm and ranch homes and associated facilities that existed within the National Battlefield, and include a search for any cultural remains associated with the battle at those locations. In particular, the Palo Alto House or Inn should be studied to determine the history of construction, operation, and manner by which it was removed (see Perttula and Nelson 1999). As proposed by Haecker (1994:155), conduct similar investigations of the associated community established in that area. Include, as a specific objective, a search for cultural remains associated with the battle or the suggestion of a Commanche attack on the Palo Alto House.

2. Conduct geoarcheological investigations, based on archival research, near Palo Alto Pond, including shallow backhoe trenching, in an attempt to locate former positions for the earthworks constructed the day following the battle and, using appropriate metal detectors with skilled operators and, if feasible, shovel tests, attempt to locate any cultural remains associated with the placement of cannons in those defensive earthworks. Using similar methods, search for information relating to the maintenance of the wagon train in that area before, during, and just after the battle. Include a search for remains associated with "Worth's Camp", the U. S. military encampment of March 24-27, 1846 (Haecker 1994:155).

3. Conduct further geoarcheological investigations, based on archival research, in key areas of the battlefield, especially the area west of Palo Alto Resaca where the Mexican cavalry and the U.S. infantry, artillery, and Texas Rangers engaged. Use of appropriate metal detectors and skilled operators are preferred for locating battle-related cultural remains; however, in areas of potentially sensitive subsurface materials, such as human remains, the use of geophysical methods, hand excavations, and shallow backhoe trenches might be appropriate.

4. Use information gained from analysis of stereoscopic aerial photographic prints, together with other archival information, to conduct geoarcheological investigations of areas potentially associated with the battle that did not previously received systematic investigation. In particular, if there is further evidence that a light artillery unit operated on Arista Hill and that Mexican forces camped there during the last night before proceeding south, the area should be investigated for cultural materials through backhoe trenching to determine the soil profile and overburden, and by shovel test excavations.

5. Conduct a geoarcheological investigation to determine the validity of applying the term "levee" for resaca banks throughout the battlefield, by excavating backhoe trenches and preparing soil profiles and descriptions in selected areas throughout PAAL. Cultural remains encountered in this effort should be recovered, analyzed, and documented.

6. Excavate backhoe trenches along the banks of resaca segments showing evidence of ditching or other excavations which might have added overburden to ground surface extant during the 1846 battle. In the absence of contradictory evidence, particular attention should be given to the levee on the western side of the resaca, although a deliberate search for intact remnants of the 1846 land surface should be made at points on the eastern side, as well. A geoarcheological investigation comparable to that just completed, but broader in scope and with additional resources, would address this and related questions. Such a study would also provide further evidence regarding the appearance of PAAL and vicinity during the prehistoric past and the Historic Era, particularly the time of the battle, as well as prevailing environmental conditions.

7. Use backhoe trenches to assess the extent of overburden adjacent to open stock tanks. Trenches should also be excavated around filled tanks to determine whether adjacent backfill soil has been completely removed, or further effort is needed to expose the battlefield surface. Fill in stock tanks associated with Palo Alto Pond and the marshy area within the central battlefield, with the possibility they would return to their original condition (see Haecker and Mauck 1997:105).

8. Use the combined results of additional archival research, analysis of aerial photographs, and geoarcheological investigations, to appropriately revise or reinforce previous interpretations of locations and movements for Mexican and U. S. forces during the battle, and the locations of specific battle-related activities.

9. Conduct a soil survey of the PAAL to improve general soil data relative to that provided by the existing, largely inappropriate, Cameron County soil survey. Data from a site-specific soil survey would improve vegetation management, site restoration, interpretive efforts, and planning for future development.

APPENDICES

Appendix A: Pollen

Appendix B: Diatoms

Appendix C: Radiocarbon and carbon stable-isotope analyses

Appendix D: Major Storms

Appendix E: Historical descriptions

APPENDIX A
Preliminary Report on Pollen Analyses of Resaca Deposits from BHT-4, Palo Alto Battlefield National Historic Site, Cameron County, Texas

Bruce M. Albert

Introduction

Four samples from a palaeochannel or "resaca" at BHT-4 were analyzed. (See main text for description and illustration of the stratigraphic sequence.) In terms of pollen catchment, the transport of grains to the site likely took place primarily by means of water in the period of active channel flow, and then primarily by air transport after the active channel was cut off. The pollen record indicates progressive reduction in tree pollen through time as the channel was in-filled and then cut off from the primary Rio Grande fluvial network. This progression may result from local alteration of the water table due to geological factors, rather than climate change. Excepting pine transported over long distances, tree pollen is dominated by oak (*Quercus virginiana*?), with secondary elements of elm (*Ulmus crassifolia*?). Traces of ash (*Fraxinus berlandierana*?), as well as pecan (*Carya illinoinensis*?) are present. The latter are significant, as they attest to the presence of relatively luxuriant riparian fringe vegetation. Wetland plants primarily include sedges (Family Cyperaceae), swamp loosestrife (Family Lythraceae), and cat-tail (*Typha*). These taxa are typical of slack-water situations. Dry land herbaceous taxa are found at significantly high levels and are dominated by grasses and composites, but halophytes (Family Chenopodiaceae) become more common through time.

Laboratory Technique

Soil matrix samples of 10 cubic cms were first reduced mechanically after treatment in a 5% solution of sodium hexa-metaphosphate deflocculant and distilled water. These samples remained in solution 48 hours to fully separate organic and inorganic particulate matter. Deflocculated sample material was filtered through a 177 micron brass screen, and then mechanically filtrated through an eight micron nitex screen. The latter process was assisted by turbation via a modified Gilson "SS-15" device. Chemical reduction resulted from adding HCl, KOH, and HF, then applying a second HCl to remove silico-fluorides, followed by an acetolysis solution of 10% H_2SO_4 and 90% acetic anhydride for one minute, with glacial acetic acid pre- and post-treatment. A *Lycopodium*-spike was added for purposes of calculating pollen concentration (see below). After distilled water washings, samples were de-hydrated (twice) in pure ETOH, dyed, and mounted in a substrate of 2000 viscosity silicone oil for light microscopic work.

Pollen counts of circa 200 grains were achieved by light microscopic work at x400 magnification. Some taxonomic identifications were made at x1000 magnification after adding immersion oil. Absolute pollen concentrations were calculated relative to a known quantity of added *Lycopodium* spores (Table A1). Grain identifications are presented in Tables A2 and A3 below. Pollen condition was pristine, with no undue over-representation by degradation-resistant species in lower levels. Apparently, variations in concentration resulted from other factors.

Table A1. Absolute pollen concentration in samples from BHT-4.

Sample number	Depth below ground surface (cm)	Pollen concentration (grains per cubic cm)
1	13-28	2115
2	80-100	1489
3	130-155	789
4	205-235	204

Pollen Taphonomy

Pollen concentration values decline considerably with resaca deposit depth, raising questions regarding pollen taphonomy inconsistancy. Because pollen grains are visually in good condition to depth, and there is no over-representation of degradation-resistant types at depth (cf. Faegri et al. 1989; Traverse 1988), pollen degradation as an agent is probably not taphonomically significant. Rather, differences in pollen recruitment, particularly the role of air vs. water transport, is likely the main component of variation in pollen concentration from sample to sample (cf. Tauber 1965; Anderson 1974; Bonny 1976, 1978; and Jacobson and Bradshaw 1981).

The termination of water flow in the resaca would lead to a transformation of pollen recruitment from one dominated by water transport to one dominated by air transport. Water flow initially prevented settling of grains of low specific gravity (= 0.3; Firbas 1949; cf. Allen 1965) and pollen concentration was low. After the channel was cut off, the resulting resaca formed a sediment trap. Air transport, unless limited by forested, wind-blocking conditions, might sometimes deposit greater quantities of pollen (cf. Anderson 1974).

Later spectra from BHT-4 contain greater relative quantities of pollen from Chenopodiaceae, a taxon with relatively profuse pollen production characteristics (cf. Rybnickova and Rybnicek 1971). Hence, higher pollen concentrations in upper levels are most likely due to factors of water vs. air "sorting" and differential productivity of later emergent herbaceous taxa such as those of the halophytic Chenopodiaceae (e.g., *Atriplex*).

Description of Pollen Spectra

Pollen spectra reconstructed from analyses of BHT-4 deposits are enumerated in Tables A2 and A3 and illustrated in Figure 22 in the main report. Generally, excepting pine pollen (long-distance transport), the local and regional tree pollen is comprised primarily of oak (probably, of live oak, *Quercus virginiana*), with a secondary representation by elm (*Ulmus crassifolia*?). A further representation by ash (*Fraxinus berlandieriana*?) and *Carya* (almost certainly, pecan[1]) is evident in pre-modern times. The present distribution of these taxa is denuded in the Rio Grande valley. A decline in tree pollen is clearly observable in the data below, perhaps as a result of geomorphological factors.

[1] Microscopic analyses by the author of modern pollen samples from The University of Texas at Austin Department of Geography collection indicate that *Carya illinoinensis* pollen exhibits a more "robust" pore structure than do other Juglandaceae (hickory family) species on average. Specimens of *Carya* pollen from the Palo Alto project area (BHT-4) exhibit uniformly robust aperture features like those of *C. illinoinensis*, with a distinctive exine thickening at the pore and large average pore sizes exceeding 2.5 μm.

Table A2. Absolute pollen counts of samples from BHT-4.

Group and taxon	Sample number (in italics) and depth below ground surface (cm) *1*: 13-28	*2*: 80-100	*3*: 130-155	*4*: 205-235
Long-distance transported pollen				
Pinus	11	20	10	13
Ephedra	-	-	1	-
Tree and shrub pollen				
Quercus	6	19	28	25
Ulmus	1	1	6	-
Celtis	-	-	-	1
Carya	-	-	1	3
Fraxinus	-	1	-	-
Wetland pollen				
Typha domingensis	3	3	4	2
Cyperaceae	16	2	11	22
Lythraceae	-	1	-	-
Apiaceae	4	1	-	-
Grassland pollen				
Poaceae	26	61	57	54
Senecio-type	15	29	7	11
Centaurea	-	-	1	-
Ambrosia	3	5	6	-
Asteraceae (genus undet.)	28	21	18	15
Mixed wetland and grassland pollen				
Chenopodiaceae	88	29	21	24
Added *Lycopodium*	59	81	130	502

Despite the decline, herbaceous wetland pollen types are consistently represented, particularly sedge (which also thrives in seasonally dry soils). However, cat-tail pollen is present in low values, attesting to the persistence of at least some perennial water pools. An isolate of Lythraceae (probably swamp loose-strife) is also indicative of slow-moving waters in the lower, earlier aspect of the evolutionary sequence. Although of ambiguous value, significant quantities of the chenopod pollen type should be mentioned here since the general Chenopodiaceae represents not only terrestrial saltbush, but several salt-tolerant wetland species as well.

Terrestrial herbs include grasses, composites, and halophytes (one or more genus of terrestrial Chenopodiaceae) primarily. The high forbic values expressed in these spectra are typical of sub-tropical (as opposed to mesic) grasslands. An increase in halophytes at the terminus of the sequence seems to mirror the decline in tree pollen, further indicating changes in local, if not regional, environmental conditions.

Table A3. Relative pollen percentages in samples from BHT-4.

Group and taxon	Sample number (in italics) and depth below ground surface (cm) *1*: 13-28	*2*: 80-100	*3*: 130-155	*4*: 205-235
Long-distance transported pollen				
Pinus	5.5	10.4	5.8	7.6
Ephedra	-	-	0.6	-
Tree and shrub pollen				
Quercus	3.0	9.8	16.4	14.7
Ulmus	0.5	0.5	3.5	-
Celtis	-	-	-	0.6
Carya	-	-	0.6	1.8
Fraxinus	-	0.5	-	-
Wetland pollen				
Typha domingensis	1.5	1.6	2.3	1.2
Cyperaceae	8.0	1.0	6.4	12.9
Lythraceae	-	0.5	-	-
Apiaceae	2.0	0.5	0.0	0.0
Grassland pollen				
Poaceae	12.9	31.6	33.3	31.8
Senecio-type	7.5	15.0	4.1	6.5
Centaurea	-	-	0.6	-
Ambrosia	1.5	2.6	3.5	-
Asteraceae (genus undet.)	13.9	10.9	10.5	8.8
Mixed wetland and grassland pollen				
Chenopodiaceae	43.8	15.0	12.3	14.1

From these observations, a simple zonation of the outline diagram (Fig. 22 in the main report) is suggested along the following lines:

Zone 1: 80-235 cm, *Quercus*-Poaceae-Asteraceae. This zone is dominated by oak, grasses, and non-halophytic forbs. A general decline in tree pollen may be noted in the progression of time within this zone. Tree pollen in the order of 10-15% is indicative of a verdantly vegetated riparian zone. There is, however, little reason to believe that the woodland canopy extends far beyond the riparian zone (cf. Rybnickova and Rybnicek 1971; Anderson 1974).

Zone 2: 13-28 cm, Chenopodiaceae- Poaceae-Asteraceae. This zone is dominated by non-tree pollen, including a high representation by halophytes (Chenopodiaceae, such as *Atriplex* and wetland chenopods).

Conclusions

An intact pollen sequence is present in the resaca deposits at Palo Alto Resaca to depths of greater than two meters below surface. Pollen preservation may be characterized as good-to-pristine, possibly due in some cases to initial subaqueous deposition. Variations in pollen concentration within this sequence are likely the result of factors of differential pollen recruitment mechanics, considering geologic factors and the relatively high pollen productivity of the emergent, highly anemophilous Chenopodiaceae vegetation.

Given the dependence of air borne pollen recruitment on factors of site aerodynamics, it can be inferred that wind transport became more important as the wind-shielding canopy surrounding the resaca was denuded (cf. Tauber 1965; Anderson, 1974). Tree pollen at BHT-4 will thus decline in a non-linear fashion, because lower tree cover in this situation will not only lower local arboreal pollen recruitment absolutely, but the denudation itself will also serve to increase the relative influx of regional wind-borne pollen from non-forested interfluvial areas.

A progressive deforestation of the riparian verge is thus registered herein, with a concurrent rise in halophytes indicative of progressive drying of local soils in either terrestrial or wetland situations. Moreover, this xeric trend is possibly the result of geologic factors. High forbic pollen percentages exhibited throughout the sequence are typical of drier or warmer sub-tropical grassland areas.

In general, there is an over-representation of riparian verge vegetation in the BHT-4 samples due to the proximity of the (palaeo-) channel. Oak is the primary arboreal taxon within this zone, with an admixture of elm. This riparian vegetation in lower levels also includes both ash and pecan. The latter phenomena further suggest that the river valley flora of the lower Rio Grande delta also included these taxa in the past (cf. Turner et al. 2003). The occurrence of *Carya* and *Fraxinus* are regionally significant as these are not long-distance transport types due to aerodynamic characteristics of the pollen grains (cf. Faegri et al. 1989; Bryant and Holloway 1985). In support of this, it should finally be noted that in the regional context, the author has also recovered significant quantities of *Carya* and *Fraxinus* pollen from early Holocene deposits in northern Mexico, from an eight-meter deep sequence in the foothills of the Sierra Madre Oriental near Saltillo (Albert 2003). Quantities of these types then decline in the middle Holocene at the same site (Albert 2004). A regional presence of pecan and ash in the Rio Grande valley during the earlier Holocene should be considered then with the above, partially coeval palynological evidence in mind.

Bibliography

Albert, B. M.

2003 Pollen analysis of the Saltillo Upper Arroyo, Unit B, Monoliths 1-3 Sequence. Manuscript on file: Geo-Archaeology Laboratory, Department of Geography, University of Texas at Austin, Austin.

2004 Preliminary Letter Report (#4) on Pollen analysis of Sediments from Upper Arroyo near Saltillo, Unit D, Monolith 2. Manuscript on file: Geo-Archaeology Laboratory, Department of Geography, University of Texas at Austin, Austin.

Allen, J. R. L.

1965 A Review of the Origin and Characteristics of Recent Alluvial Sediments. *Sedimentology* 5: 89-191.

Anderson, S. T.

1974 Wind Conditions and Pollen Deposition in a Mixed Deciduous Forest. *Grana* 14: 57-77.

Bonny, A. P.

1976 Recruitment of Pollen to the Seston and Sediment of Some Lake District Lakes. *Journal of Ecology* 64: 859-887.

1978 The Effect of Pollen Recruitment Processes on Pollen Distribution over the Sediment Surface of a Small Lake in Cumbria. *Journal of Ecology* 66: 385-416.

Bryant, V. M., and R. G. Holloway
1985 A Late-Quaternary Paleoenvironmental Record of Texas: An Overview of the Pollen Evidence. In *Pollen Records of Late-Quaternary North American Sediments*, edited by V.M. Bryant and R.G. Holloway, pp. 39-70. American Association of Stratigraphic Palynologists, Dallas, Texas.

Faegri, K., J. Iversen, P. E. Kaland, and K. Krzywisnki
1989 *Textbook of Pollen Analysis*, 3rd ed. Chichester: John Wiley and Sons.

Firbas, F.
1949 *Waldgeschichte Mitteleuropas*. Band 1. Jena: Gustav Fischer.

Jacobson, G., and R.H.W. Bradshaw
1981 The Selection of Sites for Paleovegetational Studies. *Quaternary Research* 16: 80-96.

Rybnickova, E., and K Rybnicek.
1971 The Determination and Elimination of Local Elements in Pollen Spectra from Different Sediments. *Review of Palaeobotany and Palynology* 11: 165-76.

Tauber, H.
1965 Differential Pollen Dispersion and the Interpretation of Pollen Diagrams. *Danmarks Geologiske Undersøgelse. II Raekke*. Copenhagen: National Museum.

Traverse, A.
1988 *Paleopalynology*. Winchester, Massachusetts: Unwin Hyman.

Turner, B.L., H. Nichols, G. Denny, and O. Doron
2003 *Atlas of the Vascular Plants of Texas*. BRIT Press, Fort Worth, Texas.

APPENDIX B
DIATOM PALEOECOLOGY OF SEDIMENT SAMPLES FROM THE PALO ALTO BATTLE-FIELD NATIONAL HISTORIC SITE NEAR BROWNSVILLE, CAMERON COUNTY, TEXAS

Prepared by:
Barbara M. Winsborough, PhD
Winsborough Consulting
23606 Round Mountain Circle,
Leander, Texas 78641
bwinsbor@io.com

October, 2004
(Revised)

APPENDIX B

Diatom Paleoecology of Sediment Samples from the Palo Alto Battlefield National Historic Site near Brownsville, Cameron County, Texas

Barbara M. Winsborough

Introduction

This investigation represents the diatom component of a multidisciplinary project aimed at establishing, through sediment analysis, a comprehensive environmental history of the Rio Grande delta flood plain associated with the Palo Alto Battlefield National Historic Site. The purpose of diatom analysis is to determine whether diatoms can provide information about events such as freshwater floods and hurricane storm surges and about paleoenvironmental conditions of salinity, water depth, quality, quantity and duration of flow in resacas, distributary channels, and delta plains.

Diatoms are unicellular, eukaryotic, pigmented, photosynthetic algae distinguished by the possession of a silica cell wall known as a frustule. Collectively, diatoms occupy a wide variety of terrestrial, marine, and nonmarine aquatic habitats, both natural and man-made, including the following: dry and damp soil, wet walls, canals, hatcheries, water and sewage treatment facilities, and cooling towers; sabkhas, estuaries, lagoons, bays, and oceans; caves, seeps, springs, travertine accumulations, ephemeral pools, fens, bogs, marshes, swamps, streams, ponds, and lakes; and on snow and ice, invertebrates, fish, turtles, birds, whales and other mammals. Diatoms can be readily identified to species level, and most are cosmopolitan, found in many parts of the world under similar environmental conditions. The majority of modern diatoms also have a long geological record. Water quality directly affects diatom species composition, and a large and growing body of information exists on the range of ecological tolerance of many common taxa. The conditions that govern species distribution and population dynamics today probably had comparable effects in the past. For these reasons, and because diatoms are often found in large numbers in sedimentary deposits and are well preserved, they are ideally suited for use in paleoenvironmental reconstruction.

Diatom populations develop on all submerged surfaces receiving an adequate amount of daylight, even in deep, clear water (photic zone). These diatoms provide information regarding local paleoenvironmental conditions. Meteorological events and climate changes are inferred from these data. Depending on temporal resolution, immediate changes in diatom assemblage composition may reflect a response to short-term disturbances such as local flooding caused by rain events in the drainage basin. Long-lasting shifts in diatom populations can be related to salinity trends indicative of sustained or long-term climate changes, such as drought periods.

Methods

Four samples from Backhoe Trench 4 (BHT-4) were submitted to Winsborough Consulting to determine the quality of diatom preservation, and record the presence of any other pertinent biogenic material. Provenance of the samples is as follows (see additional discussion and illustrations in main text):

Sample 1C, 13-28 cm depth, A. horizon,
Sample 2C, 80-100 cm depth, Agy horizon,
Sample 3C, 130-155 cm depth, Bgyc horizon,
Sample 4E, 205-235 cm depth, Byb horizon.

In preparation for microscopic analysis, samples were cleaned of organic material and soluble minerals by boiling first in hydrogen peroxide and then in nitric acid. The oxidized, decalcified material was rinsed repeatedly until the rinse water reached a pH of approximately 6 to 7. A few drops of cleaned material was air-dried on glass coverslips, which were then mounted on glass slides using HYRAX©.

This synthetic resin has a high index of refraction, and was developed to aid in resolving details of diatom cell-wall morphology. Two slides of each sample were prepared and scanned, and the results of the two slides were combined. Slides were scanned at 1500x and all recognizable biogenic material was recorded.

Results

A thorough scan of two slides of each sample showed no diatoms preserved in the material. Nor were there diatom fragments present to suggest diatoms had been in the original sediment but were later destroyed by differential dissolution of the siliceous frustules. Nonetheless, this is almost certainly the explanation for the complete absence of diatoms (see DISCUSSION, below).

Sample 1C contained one round pollen grain, numerous reddish spherical bodies that are probably precipitates of soil bacteria which react with iron and manganese, and a lot of dark woody material (ligneous and other residues from vascular plants). There were also a few phytoliths and some eroded fragments of sponge spicules.

Sample 2C contained some evidence of the same kind of bacterial precipitates, but lacked the woody material, sponge, and phytolith components.

Sample 3C contained bacteria and woody particles, but no phytoliths, diatoms, or pollen.

Sample 4E lacked the bacterial precipitates and woody material, but contained an abundance of unknown structures, each 30-40 micrometers long, in the shape of a double-ended sheaf of wheat or fuzzy dumbbell, with a central round shank and ends bluntly expanded. These structures (siliceous?) were not diatom frustules and did not appear to be typical phytoliths, which have rounded club-shaped ends. These structures may be gypsum, but do not look like typical gypsum crystals, which were common in the sediment prior to sample processing.

Discussion

BHT-4 material contained an abundance of small, red-tinted, mineralic spheres which may have been deposited by sulfate-reducing bacteria. Bacterially mediated sulfate reduction occurs just beneath the benthic surface. Gypsum, a hydrated calcium sulfate mineral, was common in the sediment, indicating an abundance of sulfate. The bacteria use oxygen from sulfate (SO_4) to metabolize organic matter, producing bicarbonate and hydrogen sulfide (see De Craven et al. 1999). The hydrogen sulfide reacts with ferrous iron (mobilized from detrital iron oxide minerals through bacterial reduction) to form elemental sulfur, metastable monosulfides, and, ultimately, pyrite, an iron sulfide mineral. Later oxidation of pyrite in the soil profile produces the spheres of ferric iron oxide.

The complete absence of diatoms from BHT-4 sediment samples can probably be attributed to three factors: the abundance of organic matter in the palustrine sediment; low free oxygen concentrations in the sediment; and saturation of the sediment with water containing high concentrations of sulfate in solution. As palustrine sediment accumulates, the organic matter quickly reacts with the available oxygen to produce carbon dioxide, which enters aqueous solution as bicarbonate. Very little additional oxygen infiltrates beneath the benthic surface, and the concentration of free oxygen in the sediment decreases rapidly with burial depth. The sediment only a few millimeters beneath the benthic surface becomes anoxic. Sediment that is anoxic, but rich in both organic matter and dissolved sulfate, provides conditions in which sulfate-reducing bacteria thrive (Postgate 1972). These and other anaerobic bacteria (Archeae) mediate chemical reactions that produce ammonia, causing the sedimentary microenvironment to become moderately to strongly basic, with hydrogen-ion activity (pH) greater than 9.5. Diatom frustules dissolve at elevated pH, removing them from the sedimentary record. That diatoms were abundant in the resaca prior to burial is therefore a virtual certainty, although no modern samples were collected or examined.

References

De Craven, M., R. Swennen, E. M. Keppens, C. I. Macaulay, and K. Kiriakoulakis
1999 Bacterially Mediated Formation of Carbonate Concretions in the Oligocene Boom Clay of Northern Belgium. *Journal of Sedimentary Research* 69(5):1098-1106.

Postgate, John
1972 Sulfate Reduction—Microbial. in *The Encyclopedia of Geochemistry and Environmental Sciences*, edited by R.W. Fairbridge, pp. 1127-1129. Van Nostrand Reinhold, New York.

APPENDIX C

Radiocarbon Date Comment Form
Illinois State Geological Survey
615 East Peabody Drive
Champaign, Illinois 61820
Telephone: (217) 244-2192

ISGS-5679

Age: **390 ± 70 Radiocarbon Years BP** $\delta^{13}C$ = -19.5 per mil PDB

Sample: BHT4 Sample 1A

Site: Palo Alto Battlefield site

Material: Soil A horizon

Location: 8.5 km north of Brownsville, TX

County: Cameron State: TX Country: U.S.A.

Latitude: 26°01'26" N Longitude: 97°28'21" W

Stratigraphic Position:
From A horizon, 12-28 cm.

Submitted by: Samuel McCulloch

Submitters Institution: National Park Service.

Year collected: 2004 By: Chris Caran

Comment By (initials only): __ __ __
Comment: _____

_____

_____

_____

_____

_____

_____

_____

_____

Please check this form for accuracy, fill in any blanks, and return to the ISGS within two weeks (see reverse side for instructions).
October 28, 2004

Radiocarbon Date Comment Form
Illinois State Geological Survey
615 East Peabody Drive
Champaign, Illinois 61820
Telephone: (217) 244-2192

ISGS-5682

Age: **1190 ± 70 Radiocarbon Years BP** $\delta^{13}C$ = -18.0 per mil PDB

Sample: BHT4 Sample 2A

Site: Palo Alto Battlefield site

Material: Soil Ag horizon

Location: 8.5 km north of Brownsivlle,TX

County: Cameron State: TX Country: U.S.A.

Latitude: 26°01'26" N Longitude: 97°28'21" W

Stratigraphic Position:
From 80-100 cm below surface.

Submitted by: Samuel McCulloch

Submitters Institution: Natioanal Park Service.

Year collected: 2004 By: Chris Caran

Comment By (initials only): __ __ __
Comment: _____

_____

_____

_____

_____

_____

_____

_____

_____

Please check this form for accuracy, fill in any blanks, and return to the ISGS within two weeks (see reverse side for instructions).
November 5, 2004

Radiocarbon Date Comment Form
Illinois State Geological Survey
615 East Peabody Drive
Champaign, Illinois 61820
Telephone: (217) 244-2192

ISGS-5670

Age: **2990 ± 70 Radiocarbon Years BP** $\delta^{13}C$ = -17.3 per mil PDB

Sample: BHT4 3A

Site: Palo Alto Battlefield site

Material: Soil

Location: 8.5km north of Brownsville, Cameron Co. TX

County: Cameron State: TX Country: U.S.A.

Latitude: 26°01'26" N Longitude: 97°28'21" W

Stratigraphic Position:
From stratum 3, Bgyc horizon, 130-155cm.

Submitted by: Chris Caran

Submitters Institution: Quaternary Consulting in TX

Year collected: 2004 By: Chris Caran

Comment By (initials only): __ __ __
Comment: _____

_____

_____

_____

_____

_____

_____

_____

_____

Please check this form for accuracy, fill in any blanks, and return to the ISGS within two weeks (see reverse side for instructions).
October 8, 2004

Radiocarbon Date Comment Form
Illinois State Geological Survey
615 East Peabody Drive
Champaign, Illinois 61820
Telephone: (217) 244-2192

ISGS-5669

Age: **4730 ± 70 Radiocarbon Years BP** $\delta^{13}C$ = -19.2 per mil PDB

Sample: 4A

Site: Palo Atlo Battlefiled site

Material: Soil

Location: 8.5km north of Brownsville, Cameron Co. TX

County: Cameron State: TX Country: U.S.A.

Latitude: 26°01'26" N Longitude: 97°28'21" W

Stratigraphic Position:
From stratum 4, Bg horizon, 205-235cm.

Submitted by: Chris Caran

Submitters Institution: Quaternary Consulting of TX

Year collected: 2004 By: Chris Caran

Comment By (initials only): __ __ __
Comment: _____

_____

_____

_____

_____

_____

_____

_____

_____

Please check this form for accuracy, fill in any blanks, and return t
the ISGS within two weeks (see reverse side for instructions).
October 8, 2004

APPENDIX D

Major Storms Affecting the Palo Alto Battlefield National Historic Site, 1553 to 2004[a].

Year	Date (m/d)	Affected area	Category[b]	Deaths	Remarks
			Hurricanes and Tropical Storms		
1553	?	Lower coast	?	1700	Remained off Texas shore. Three ships sunk, others damaged.
1791	?	Lower coast	2/3	?	Padre Island and part of mainland submerged by storm surge, killing 50,000 cattle.
1828	?	Lower coast	1	?	High water at Corpus Christi.
1829	07/09	Lower Rio Grande	?	?	No data.
1829	09/10	Lower coast	1	?	Coast inundated. High tides at mouth of Rio Grande. Buildings destroyed at Port Isabel.
1831	08/18	Lower coast	1	?	Landfall near mouth of Rio Grande. Flooding and destruction of buildings at Port Isabel and vicinity.
1834	09/?	Lower coast	1	?	Buildings destroyed at Port Isabel
1835	08/18	Entire coast	2	14 (in TX?)	"Antigua Hurricane". Landfall at mouth of Rio Grande. Padre Island and part of mainland submerged by storm surge, destroying many buildings and ships.
1835	09/13	Brownsville area	1	?	Landfall in northeastern Mexico near Brownsville.
1837	09/27-10/10	Entire coast	2/3	?	"Racer's Storm." Severe offshore. Land falls: Yucatan and Matamoros, Mexico; Corpus Christi; Galveston; Mobile, AL. Destroyed Brazos Santiago, TX. Extensive coastal flooding. Galveston military garrison evacuated as storm surge rose 6 to 7 ft.
1838	09/?	Lower coast	1	?	High tides. Buildings destroyed at Port Isabel.
1840	09/?	Brownsville area	1	?	Villages at mouth of Rio Grande destroyed.

Year	Date (m/d)	Affected area	Category[b]	Deaths	Remarks
1842	08/30-09/08	Brownsville area	1	?	"Antje Hurricane," after dismasted schooner "Antje". Landfall at Victoria, Mexico. Coastal flooding and severe damage from northeastern Mexico to mouth of Rio Grande.
1844	08/04-06	Brownsville area	2/3	70 (in TX?)	Landfall at mouth of Rio Grande, destroying all buildings.
1848	10/17	Lower coast	1	?	High tides as far north as Corpus Christi. Island near Port Isabel flooded with 2 ft of water.
1857	?	Port Isabel	?	?	"Tidal wave" reported.
1865	09/13	Lower coast	?	?	Town of Bagdad at mouth of Rio Grande inundated.
1867	10/01-07	Entire coast	2/3	Many lives	Towns of Bagdad and Clarksville destroyed. Galveston flooded. Railway bridge, 30 buildings destroyed. Texas's first "Million Dollar" hurricane.
1872	09/?	Port Isabel	1	?	No data.
1874	09/02-07	Lower coast	?	?	Landfall in northeastern Mexico, moved into Texas.
1875	09/24-27	Entire coast	1	?	Remained off Texas shore.
1876	09/16-17	Padre Island	2	?	Heavy gale and waves 8 to 10 ft.
1877	09/14-21	Entire coast	1	?	Storm surge 10.5 ft at Indianola.
1880	08/04-16	Lower coast	2/3	?	Landfall at Matamoros, Mexico, moved along Texas coast causing damage.
1880	10/12-13	Brownsville	2/3	Many lives	Brownsville struck, nearly destroyed. Telegraph wires downed from Indianola to Brownsville and up river.
1884	10/?	Brownsville	?	?	Small tropical disturbance in Mexico. Rainfall 16" at Brownsville.
1885	09/16-23	Entire coast	1	?	Center remained offshore. Rainfall 16.53" at Galveston.
1886	08/12-21	Entire coast	4/5	20+	Indianola destroyed, with no structure undamaged. Extensive damage in Houston.

Year	Date (m/d)	Affected area	Category[b]	Deaths	Remarks
1886	09/14-25	Lower coast	1	Few lives	Rainfall 25.98" near Brownsville. Storm surge reported at Port Isabel.
1887	09/11-22	Brownsville	1	14	Pressure 28.93" of mercury. Rainfall 10.78".
1891	07/03-17	Entire coast	1	?	Part of Galveston flooded.
1892	09/25-27	No data	?	?	No data.
1895	08/22-29	Lower coast	?	?	Landfall was 80 mi south of Brownsville.
1895	10/02-07	Entire coast	?	?	Cyclonic storm below hurricane intensity passed close to Brownsville and struck Galveston area.
1902	06/19-07/01	Middle, lower coasts	1	?	Struck at Port O'Connor and passed 30 mi off Rio Grande delta.
1909	06/25-30	Lower coast	?	?	No data.
1909	08/20-28	Lower coast	2	? (in TX)	In Mexico, 1500+ killed. Storm surge washed over parts of Padre Island.
1910	08/23-31	Lower coast	?	?	Cyclonic storm struck a few miles south of Rio Grande.
1910	09/05-14	Lower coast	2	?	Struck at mouth of Rio Grande. Padre Island completely flooded. Winds of 120 mph. Pressure 965 mb. Little damage inland.
1912	10/11-16	Lower coast	1	?	Struck between Mesquite Ricon Island/ Laguna Madre and Baffin Bay/Mustang Island. Winds 100 mph. Minor damage at Corpus Christi and Brownsville.
1913	06/22-28	Lower coast	1	?	Torrential rains passed inland at mouth of Rio Grande. Record rainfall of over 20".
1916	08/12-19	Lower coast	3	20	Padre Island flooded. Driftwood appeared on the mainland shore of Laguna Madre. Steamer Nicaragua wrecked on Padre Island. Pressure 948 mb.
1920	09/24	Entire coast	2	?	Large storm in the Gulf with very large pressure system. Storm made landfall at Houma, LA. "Tidal wave" reported at Port Isabel.

Year	Date (m/d)	Affected area	Category[b]	Deaths	Remarks
1921	06/15-26	Entire coast	1	?	Landfall near Victoria. Center crossed Palacios, Wharton, and Wallis. Wind 49 to 60 mph at Houston, 110 mph at Port O'Connor. Pressure 929 mb.
1921	09/06-10	Lower coast	?	275	Most deaths from flooding, 224 along Balcones Escarpment, central Texas. Rainfall 23.11" at Taylor, 36.41" at Thrall, TX (24-hr record for continental US). Water 5 to 7 ft deep in downtown San Antonio.
1922	06/13-16	Lower Rio Grande Valley	?	0	Rio Grande floods were highest on record.
1925	09/06-07	Lower coast	?	0	Heavy rains in Brownsville.
1931	06/24-28	Lower coast	?	0	Rainfall 8.03".
1933	06/27-07/06	Lower coast	?	?	Landfall between Tampico and Brownsville, causing several deaths. Storm surge 5 ft at Port Aransas.
1933	07/25-08/05	Brownsville	2	0	Heavy rains damaged Brownsville. Pressure 975 mb. Winds 72 mph.
1933	08/28-09/05	Brownsville	3	40	Many weak buildings destroyed, especially in Harlingen. Corpus Christi flooded with 2 to 3 ft of runoff in the business district. Southern half of Padre Island abandoned for ranching after this storm, which cut more than 40 washover channels, some a mile wide. Pressure 949 mb. More than 500 injured.
1934	08/26-09/01	Entire coast	?	0	Remained offshore.
1936	09/10-14	Lower coast	?	0	Landfall south of Corpus Christi.
1947	07/31-08/02	Lower coast	?	0	Widespread heavy rainfall. Rainfall 9.78" at Raymondville.
1950	10/01-04	Lower coast	?	0	Hurricane How. Storm surge 4 ft at Padre Island.
1954	06/24-28	Lower coast	1	38	Hurricane Alice. Rio Grande reached record flood stages. Rainfall 26" across South Texas.
1958	06/14-16	Lower coast	1	1	Tropical Storm Alma. Pressure 997.3 mb. Rainfall 20" at Medina, TX. Death in surf at Galveston.

Year	Date (m/d)	Affected area	Category[b]	Deaths	Remarks
1958	08/30-09/06	Entire coast	1	1	Hurricane Ella. Shrimp trawler lost at Galveston. Flooding across Galveston Island. Pressure 989 mb.
1961	09/03-15	Entire coast	4	34	Hurricane Carla. Pressure 931 mb. Wind 175 mph. Hurricane winds along coast from just north of Brownsville to Port Arthur. Storm surge 22 ft at Port Lavaca. Tornadoes: 26. Injuries: 465. At the time of its landfall, Hurricane Carla was the largest on record.
1967	09/05-22	Brownsville	3/4	15	Hurricane Beulah. Wind 150 mph. Pressure 950 mb. Storm surge 20 ft at Padre Island, 12 ft at Port Isabel. Tornadoes: 115. Extensive coastal and inland flooding.
1971	09/03-18	Entire coast	1	0	Hurricane Edith. Storm surge 6 ft at Sabine Pass.
1975	08/24-09/01	Lower coast	?	0	Tropical Storm Caroline. Landfall 100 miles south of Brownsville. Pressure 963 mb. Severe in Mexico.
1978	08/30-31	Lower coast	?	33	Tropical Storm Amelia. Pressure 1005 mb. Rainfall 26" in 12 hr north of Abilene.
1980	08/01-11	Lower coast	3	15 (in TX)	Hurricane Allen. Pressure 945 mb. Wind 165 kts. Storm surge 12 ft at Port Mansfield. Storm cut 68 washover channels on Padre Island, spawned 29 tornadoes, destroyed 2 offshore oil rigs, and killed 13 in helicopter crash while evacuating a rig. Other deaths: 234 in Caribbean.
1993	06/18-21	Lower coast	1	0	Tropical Storm Arlene. Heavy rainfall.
1999	08/18-25	Lower coast	4	0	Hurricane Bret. Small storm, less than 40 mi. wide. Landfall in sparsely populated area. Estimated damage: $60 million.

This discontinuous record covers the 451-year period from 1553 to 2004. With few exceptions, the effects these storms may have had at the Palo Alto Battlefield National Historic Site (PABNHS) are not known. Available records indicate that some of the storms produced very heavy rains that spread far inland and caused the Rio Grande and its distributary channels to overflow across the delta plain. Other storms resulted in localized flooding, lightning, and wind damage, and perhaps spawned a tornado. A few large, intense storms made landfall nearby, creating storm surges that may have inundated the lowest elevations within the site, particularly along the resacas. In 1967, Hurricane Beulah had all of these effects, although its storm surge fell just short of reaching the PABNHS. The geological record of a single storm event may be difficult to recognize, but the collective impact of hurricanes and tropical storms occurring over thousands of years was certainly felt.

MAJOR FLOODS AT RIO GRANDE RIVER GAUGES

Year	Date	Affected area	Gauge ht. (ft)[c]	Deaths	Remarks
1865	06/?	Lower Rio Grande Valley	62.5	?	From records at Laredo, Webb Co. Highest flood level since at least 1745.
1899	06/15	Lower Rio Grande Valley	~37.4	?	From records at Laredo, Webb Co.
1900	04/07	Lower Rio Grande Valley	~35.7	?	From records at Laredo, Webb Co.
1904	09/17	Lower Rio Grande Valley	~32.3	?	From records at Laredo, Webb Co.
1905	07/01	Lower Rio Grande Valley	~36.8	?	From records at Laredo, Webb Co.
1914	10/24	Lower Rio Grande Valley	~32.8	?	From records at Laredo, Webb Co.
1919	09/18	Lower Rio Grande Valley	~40.3	?	From records at Laredo, Webb Co.
1922	06/20	Lower Rio Grande Valley	~50.9	?	From records at Laredo, Webb Co.
1925	05/31	Lower Rio Grande Valley	34.5	?	From records at Laredo, Webb Co.
1932	09/03	Lower Rio Grande Valley	52.2	?	From records at Laredo, Webb Co.
1935	06/16	Lower Rio Grande Valley	35.1	?	From records at Laredo, Webb Co.
1942	09/14	Brownsville	33.2	?	From records at Brownsville. Highest flood level at this gauging station.
1948	06/26	Lower Rio Grande Valley	47.8	?	From records at Laredo, Webb Co.
1954	06/30	Lower Rio Grande Valley	61.4	?	From records at Laredo, Webb Co.

[a] At the time these lists were compiled, the records of the data sources were current through 2003. No major tropical storms, hurricanes, or riverine floods affected the Palo Alto Battlefield National Historic Site after 1999.

[b] Saffir-Simpson Hurricane Damage-Potential scale. Most estimates of intensity are from Weather Research Center (undated). The intensity of tropical storms and hurricanes prior to 1900 was estimated without benefit of instrument records or with only minimal records.

[c] Gauge height (ft). Gauge height of a flood is the height of the water above a datum representing normal flow conditions at that location. A river is flooding if the water level is higher than the river bank at the gauging station. Major floods are those in which the water level is significantly higher than the river bank and/or continues to overtop the bank for an extended period. The two gauges for which records are included here are at Laredo, Webb Co., and Brownsville, Cameron Co. The gauge at Laredo is ~310 river-miles upstream from the gauge at Brownsville. This list includes major floods at Laredo because

that gauging station has the longest period of record of any on the lower Rio Grande, and because floods there also may have affected areas downstream. The record from the Brownsville gauging station is comparatively short and somewhat compromised because that gauge went into use after numerous dams and water diversions had been constructed upstream and along principal tributaries. Some of the records from the Laredo station were affected by construction of a large dam in New Mexico in 1915 and by other dams built in the 1950s and later. These discontinuous records indicate some specific dates and the general frequency and magnitude of riverine flooding in the PABNHS vicinity over the 259-year period from 1745 to 2004.

Data sources

Griffiths, J. F., and Greg Ainsworth

1981 *One hundred years of Texas weather, 1880-1979*. College Station, Texas, Texas A&M University, Office of the State Climatologist Monograph Series Number 1, 205 p.

Griffiths, J. F., and Janine Bryan

1987 *The climates of Texas counties*. Austin, Texas, University of Texas at Austin, Natural Fibers Information Center, 569 p.

Lyons, W. A.

1997 *The handy weather answer book*. 2nd ed.: Detroit, Michigan, Visible Ink, 397 p.

National Weather Service (www.nws.noaa.gov), unpublished data.

Patterson, J. L.

1965 *Magnitude and frequency of floods in the United States*. Part 8. Western Gulf of Mexico basins: Washington, D. C., Department of the Interior, Geological Survey Water-Supply Paper 1682, 506 p.

Weather Research Center (3227 Audley St., Houston, Texas 77098, 713-529-3076, wrc@wxresearch.org), unpublished data.

APPENDIX E.
SELECTED HISTORICAL DESCRIPTIONS OF ENVIRONMENTAL CONDITIONS AT THE PALO ALTO BATTLEFIELD AND VICINITY

Rio Grande

Berlandier[1] described the lower Rio Grande near its mouth, as it appeared in December, 1829: *The Rio Bravo del Norte* [Rio Grande], *from Matamoros* [community in Mexico, on the opposite bank from Brownsville] *as far as its opening into the Gulf* [Gulf of Mexico], *has only a moderate current, sometimes even very slow, according to the seasons. Its waters, flowing through low-lying lands without any slope, have traced an extremely winding course where the force of the current is lost.... The banks, most often very steep and clayey, are subject to much crumbling. This erosion results from the cracking of the earthen banks during the summer, and from the undermining action of the water. Every two or five years, the periods at which the river is believed to swell, the course changes direction. The current, which formerly flowed through such and such a place, leaves only a pool* [banco or oxbow lake, or resaca or abandoned distributary channel] *and opens a channel somewhere else....* [The river] *is constant neither in its direction nor its rises* (Berlandier 1980:441-442).

Lloyd[2] also described this reach of the Rio Grande and its flora, as it appeared in 1891: *After passing Brownsville the river is so winding that a straight line drawn to its mouth would cross about equal parts of Texas and Mexican territory and the channel changes every season in half a dozen places keeping the border owners of land in continuous tribulation... All the country was a jungle along the river, but it is now so thickly settled, that most of it has long since been cleared, and the timber is now principally in occasional strips along the river...Reaching to the edge of the river, or separated from it by the strips of timber already referred to, is a wide plain sometimes covered with small brush, or with coarse gama grass and still further south is a soft sandy expanse covered with a rank bunch grass.* (as quoted by Schmidly 2002:320)

Rio Grande delta plain

Berlandier described the eastern Rio Grande delta plain on the Mexican side of the Rio Grande near its mouth, as it appeared in December, 1829, with later comments regarding events of October, 1837. These descriptions would have applied equally well to much of the terrain on the northern side of the river:
The right [southern] *bank of the Rio Bravo* [Rio Grande]*...is often inundated by the overflows of that river, for the land is so low-lying that the waters cannot be contained within the confines of their course. These overflows render the roads useless and produce swamps called esteros* [ephemeral, but persistent ponds or small lakes], *which often last for several years without drying up* (Berlandier 1980:439).

These plains are likely to be flooded by the Rio Bravo [Rio Grande], *or by the waters of the Gulf* [Gulf of Mexico] *when storms from the east drive waves violently against the mainland, as happened in October, 1837. When it is only the river that overflows, a continuous series of swamps is formed on both sides of the road. The vegetation of that region is wholly maritime. As the land is very salty, only some grasses or herbaceous plants are encountered sporadically, although there are some clumps of trees on the banks of the river* (Berlandier 1980:440).

Berlandier described an intermittent distributary channel (resaca) and the flora on the northern side of the Rio Grande near its mouth, as it appeared in December, 1829: [At Boca Chica, an outpost near the mouth of the river],...*we observed that all the terrain between the Rio Bravo* [Rio Grande] *and the arm* [probably Resaca del Rancho Viejo] *which in flood time detaches itself from the river and flows into the bay of Brazos de Santiago* [South Bay] *was low-lying and easily flooded. Also, there were still some ponds of brackish water, driven by the winds into the hollows* [forming small lakes].... *When the sea is very stormy, the breakers leap the dunes* [on Padre Island, a barrier island east of Laguna Madre] *close to Boca Chica and establish salty lakes or ponds, which sometimes join the bed of the river. Arborescent vegetation is almost excluded from these localities: some scarce shrubs are found only on the edges of the Rio Bravo* [Rio Grande], while some thickets [are] scattered on the plain.... [Approximately 1 km north of the Rio Grande]...*we crossed the arm...At that time the bed of the arm was merely muddy. In times of drought the waters which flow through that channel are often lost before reaching the bay* [that is, the channel was a resaca, already isolated from the main channel of Rio Grande by 1829, and conveying river water only during floods]. *That arm is nothing but an overflow of the Rio Bravo* [Rio Grande], *which encounters hollows* [shallow depressions along the bank] *precisely at a place where the current beats against a sharp curve* [possibly near Villa Nueva, just west of Brownsville, particularly if Berlandier misidentified the Resaca de la Palma as a branch of the nearby Resaca del Rancho Viejo]. *The river consequently flows over the bank, where the water follows a course which chance has laid out for it.... When the arm of which we have just spoken fills with water, the route* [road] *is completely interrupted. On that road one encounters fewer ranchos and fewer esteros than on the opposite* [southern] *bank of the Rio Bravo* [Rio Grande], *but, in exchange, the countryside is prettier. Forests are rare. The mezquite* [sic] *is very sparse, and all the ground is covered with prairies and thickets. Before arriving at Matamoros* [that is, across the river from Matamoros, which is on the southern bank of the Rio Grande], *however, one travels for quite a long time through a small forest situated on the banks of the river* (Berlandier 1980:440-441).

Domenech[3] described a resaca and its flora, which were probably located very near the Rio Grande, as they appeared in November, 1851:...*we reached the banks of a large resaca of limpid transparency. It formed an oval regularly-shaped lake, skirted, as though by a frame-work with palm trees, cedars* [probably Montezuma bald cypress], *green oaks and sycamores, while wild vines connected one with another by their graceful garlands, and a verdant slope adorned with fern and flowers, trended from the* [foot] *of the trees to the water's edge* (as quoted by Richard and Richardson 1993:34-35).

Lloyd also described the typical resaca habitat, as it appeared in 1891: *The Rio Grande from about 10 miles* [16 km] *north of Brownsville to its mouth is characterized by its numerous outlets, "resacas," that act as drainage channels for the river whenever it has an overflow which is always in the Fall, September and October. This overplus forms numerous lagoons which generally last all the year though of lessening extent; and, as the waters evaporate they become brackish and even in a few instances decidedly or entirely salt* (as quoted by Schmidly 2002:319).

Lloyd described the soils and flora of the delta plain, as they appeared in 1891: *The ground, generally speaking, away from the red clayey soil of the river is a rich black loam free from rocks or pebbles of any kind...The principal trees of the Lower Rio Grande Valley to a point some few leagues north of Brownsville are the Hackberry, Elm, Ash, Mesquite, Huisache, and Mulberry. The Ebony...still are a most important tree...and a few Anaqua near Brownsville. Retama, Lignum, Vital, the Colima and Palo Brazil are common along the lagunas, and Coma (a well known fruit) are scattered amongst the chaparral. Two Koeberlinias occur on the edge of the region subject to flood and Willow generally along the river and...Palmetto occur* [at] *Brownsville.... A few Yucca of large size—the Maquez* [sic]—

...and the prickly pear which line all the belt beyond the valley of the river with a few Echinocactus and one species of Mammalaria are the sole representatives of the cactus family.... Sunflowers grow up in rank patches filling all the dry lagunas until they are leveled by another rise [in water level], *and wild ipecac is abundant in the southern part of the district.... A wild blackberry ripening in May and June is also abundant in the lower part of the region* (as quoted by Schmidly 2002:320).

Domenech described the area immediately southeast of the Palo Alto prairie, as it appeared in 1851: *The route from Isabella Point* [Port Isabel, to] *Brownsville lies for some distance along the bay; then turning to the left* [south] *it enters a vast marshy plain, indented with natural salt-pits.... This plain at its north-western extremity joins that of the Palo-Alto in which was fought the first battle between the Americans...and the Mexicans.... We then passed over glades and prairies where the earth was so light and soft that sometimes it gave way under our horses feet. The rancheros call these tierras falsas (treacherous grounds): after rain they are very dangerous; man and horse sometimes sink and disappear in them, as in shaking prairies* (as quoted by Richard and Richardson 1993:34).

Note: The "tierras falsas" were probably resacas in which water-saturated clay was sealed beneath unstable crusts composed of thin layers of sun-dried saline or gypy clay. Whether "man and horse sink and disappear in them" is doubtful, but anyone walking across these surfaces might have become trapped in the mud, at least temporarily.

Berlandier described the habitat and flora of the northern Rio Grande delta plain, as it appeared in April, 1834: *...we were obliged to go in search of fresh water quite far away* [from the Laguna Madre], *in some small lakes choked with reeds and a Typha known as tule* [cattail, *Typha domingensis*] (Berlandier 1980:542).

Meade[4] described the thorn brush of the delta plain, as it appeared in 1846: *There is a thicket in this country—Chaparral—which is almost impassable when you are off the road, and which consists of thick, thorny bushes, that tear your clothes to pieces in trying to get through them* (as quoted by Weaver 1999:21).

Palo Alto Battlefield

Curtis[5] described the Palo Alto Battlefield, as it appeared on October 23, 1846, five months after the battle, in which he was not a participant: *Palo Alto is a large open prairie, several miles in diameter. It is quite level, and grown up with grass as high as the girths of our horses. There are ponds of clear water in many places, especially on that part of the field where the Mexican line rested. At the time of the battle it* [the prairie, that is, areas between the ponds] *was all dry* (Curtis 1994:54).

On October 26, Curtis noted that: *...dry weather for the past month has materially affected the grass and other vegetables* [in the town of Matamoros].... *In the chaperal* [sic] *and on the prairies the grass in many places is three feet* [1 m] *high but rather coarse* (Curtis 1994:55).

Note: Taken together, these observations appear to indicate that ponds at Palo Alto had remained full for at least a month and that prairie grass there had withstood the dry weather better than had vegetation in the community 19 km to the south.

Grant[6] also described the grass which covered the prairie, as it appeared in May, 1846: *...where we were the grass was tall, reaching to the shoulders of the men, very stiff, and each stock* [stalk] *was pointed at the top, and hard and almost as sharp as a darning needle* (as quoted by Weaver 1999:24).

Curtis described a resaca at Resaca de la Palma Battlefield, near Palo Alto Battlefield, as it appeared on October 20, 1846: *The Resaca de la palma* [sic] *dry river, takes its name from the ground.* [sic] *It looks like the bed of a river which has become a pond* (Curtis 1994:52).

Note: These statements provide a reasonable definition of the word "resaca." The resaca retained standing water despite recent dry conditions. The reason that Curtis described the resaca as dry may have been because it was not flowing at the time.

References Cited

Berlandier, Jean Louis

1980 *Journey to Mexico during the Years 1826 to 1834*. Translated by Sheila M. Ohlendorf, Josette M. Bigelow, and Mary M. Slandifer. Texas State Historical Association and the Center for Studies in Texas History, The University of Texas at Austin.

Curtis, S.R.

1994 *Mexico Under Fire*. Edited and annotated by J.E. Chance. Texas Christian University Press, Fort Worth.

Richard, Norman L., and Alfred T. Richardson

1993 *Biological Inventory, Natural History, and Human Impact of Palo Alto National Battlefield.* Biology Department, The University of Texas at Brownsville.

Schmidly, David J.

2002 *Texas Natural History: A Century of Change*. Texas Tech University Press.

Weaver, Karen S.

1999 *Pre-European Texas: Vegetation Change on Palo Alto Battlefield National Historic Site.* Unpublished Master's Thesis, Texas A&M University at Corpus Christi, Corpus Christi, Texas.

---

[1] Jean Louis Berlandier, naturalist for the Mexican Boundary Commission and botanical collector in Texas and Mexico, in southern Texas during much of the period from 1826 to 1851 (Berlandier 1980, Vol. 2).

[2] William Lloyd, federal agent for the Biological Survey of Texas, in southern Texas from 1890 to1892 (Bailey 1905; Schmidly 2002).

[3] Emmanuel Henri Dieudonne Domenech, Catholic priest and missionary (Abbe), in southern Texas during much of the period from 1846 to 1852 (Weniger 1984; Richard and Richardson 1993; Tyler 1996, Vol. 2).

[4] George C. Meade, Lieutenant, United States Army, in southern Texas during part of the U.S.-Mexican War, 1846 (Weems 1974; Weaver 1999).

[5] Samuel Ryan Curtis, Colonel, 3rd Ohio Volunteer Regiment, in southern Texas during part of the U.S.-Mexican War, 1846 (Curtis 1994).

[6] Ulysses Simpson Grant, Lieutenant, United States Army, in southern Texas during part of the U.S.-Mexican War, 1846 (Weems 1974; Weaver 1999).

REFERENCES CITED

Albert, B. M.
2004 Appendix I: Pollen Analyses, 41AT168. In *Variations on a Theme: Burned Clay Middens in South Central Texas, Data Recovery at 41AT168, the Camber Site*, by Jeff Turpin, pp. 95-104. TAS, Inc., Cultural Resources Report 19, Austin, Texas.

Antevs, Ernst
1955 Geologic-Climatic Dating in the West. *American Antiquity* 20(4):317-335.

Baker, R. C.
1965 *Reconnaissance Investigation of the Ground-WaterResources of the Lower Rio Grande Basin Texas*. Texas Water Commission Bulletin 6519, Austin, Texas.

Baker, Victor R., and Margarida Maria Penteado-Orellana
1977 Adjustment to Quaternary Climatic Change by the Colorado River in Central Texas. *Journal of Geology* 85:395-422.

Baxter, Edward P., and Kay L. Killen
1976 *A Study of the Palo Alto Battleground, Cameron County, Texas*. Texas A&M University Anthropology Laboratory Report 33, College Station.

Black, Stephen L.
1989 South Texas Plains (Chapter 4). In *From the Gulf to the Rio Grande: Human Adaptation in Central, South, and Lower Pecos, Texas*, by T. R. Hester, S. L. Black, D. G. Steele, B. W. Olive, A. A. Fox, K. J. Reinhard, and L. C. Bement, p. 39-62. Arkansas Archeological Survey Research Series No. 33, Fayetteville.

Blair, W. Frank
1950 The Biotic Provinces of Texas. *The Texas Journal of Science* 2(1):93-117.

Bond, Clell L.
1979 *Palo Alto Battlefield: A Magnetometer and Metal Detector Survey*. Cultural Resources Laboratory Report 4, Texas A&M University, College Station.

Bousman, C. Britt
1998 Paleoenvironmental Change in Central Texas: The Palynological Evidence. *Plains Anthropologist* 43(164):201-219.

Bousman, C. Britt, and David O. Brown
1998 Setting the Stage: Previous Paleoclimatic Research in Texas and Surrounding Areas. *Plains Anthropologist* 43(164):105-110.

Boutton, T. W.
1991a Stable Carbon Isotope Ratios of Natural Materials: I. Sample Preparation and Mass Spectrometric Analysis. In *Carbon Isotope Techniques*, edited by D. C. Coleman and Brian Fry, pp. 155-171. Academic Press, Inc., San Diego, California.

1991b Stable Carbon Isotope Ratios of Natural Materials: II. Atmospheric, Terrestrial, Marine, and Freshwater Environments. In *Carbon Isotope Techniques*, edited by D.C. Coleman and Bryan Fry, pp. 173-185. Academic Press, Inc., San Diego, California.

Bowman, Sheridan
1990 *Radiocarbon Dating*. University of California Press. Berkeley, California.

Boyd, James B., and Timothy K. Perttula
2000 The Desertification of South Texas and Northeastern Mexico and its Effects on Archaeological Sites. *La Tierra* 27(3):6-21.

Brewton, J. L., F. Owen, Saul Aronow, and V. E. Barnes
1976 *Geologic Atlas of Texas, McAllen-Brownsville Sheet*. Bureau of Economic Geology, The University of Texas at Austin.

Brown, David O.
1998 Late Holocene Climates of North-Central Texas. *Plains Anthropologist* 43(164):157-172.

Brown, David O., Dana Anthony, S. C. Caran, J. T. Jones, and Dave Severinson
2002 Cultural Resources Survey of the Proposed Port of Brownsville International Crossing, Cameron County, Texas. Blanton & Associates, Inc., Austin, Texas.

Brown, L.F., Jr., J.L. Brewton, T.J. Evans, J.H. McGowen, W.A. White, C.G. Groat, and W.L. Fisher
1980 *Environmental Geologic Atlas of the Texas Coastal Zone - Brownsville-Harlingen Area.* Bureau of Economic Geology, The University of Texas at Austin.

Brown, L. F., Jr., R. A. Morton, J. H. McGowen, C. W. Kreitler, and W. L. Fisher
1976 *Natural Hazards of the Texas Coastal Zone*. Bureau of Economic Geology, The University of Texas at Austin.

Bryant, V. M., Jr., and R. G. Holloway
1985 A Late Quaternary Paleoenvironmental Record of Texas: An Overview of the Pollen Evidence. In *Pollen Records of Late-Quaternary North American Sediments*, edited by V. M. Bryant, Jr., and R. G. Holloway, p. 39-70. American Association of Stratigraphic Palynologist Foundation, Dallas.

Bryant, Vaughn M., Jr., and Harry J. Shafer
1977 The Late Quaternary Paleoenvironment of Texas: A Model for the Archeologist. *Bulletin of the Texas Archeological Society* 48:1-25.

Butler, S. R. (editor)
1995 *Historic Sites of the Mexican War in the United States, Part One: Texas*. The Descendants of Mexican War Veterans, Richardson, Texas.

Butzer, Karl W.
1982 *Archaeology as Human Ecology*. Cambridge University Press, New York.

Calvert, R. A., and Arnoldo De Leon
1990 *The History of Texas*. Harlan Davidson, Inc. Arlington Heights, Illinois

Campbell, T. N., and T. J. Campbell
1981 *Historic Indian Groups of the Choke Canyon Reservoir and Surrounding Area, Southern Texas*. Choke Canyon Series Volume 1, Center for Archaeological Research, The University of Texas at San Antonio.

Caran, S. Christopher
1998 Quaternary Paleoenvironmental and Paleoclimatic Reconstruction: A Discussion and Critique, with Examples from the Southern High Plains. *Plains Anthropologist* 43(164):111-124.

Chipman, Donald E.
1992 *Spanish Texas, 1519 - 1821*. University of Texas Press, Austin.

Correll, D. S., and M.C. Johnston
1970 *Manual of the Vascular Plants of Texas*. Texas Research Foundation. Renner, Texas.

Faegri, K., J. Iversen, P. E. Kaland, and K. Krzywisnki
1989 *Textbook of Pollen Analysis*. John Wiley & Sons, Chichester, England.

Fagan, B.
2000 *The Little Ice Age: How Climates Made History, 1300-1850*. Basic Books, New York.

Faure, Gunter
1986 *Principles of Isotope Geology*, 2nd ed. John Wiley & Sons, New York, New York.

Fenneman, N. M.
1946 *Physical Divisions of the United States*. United States Department of the Interior, Geological Survey. Washington, D. C.

Ferguson, W. K.
1986 *The Texas Landscape —The Geographic Provinces of Texas*. Texas Mosaics. Austin, Texas.

Ferring, C. R.
1986 Rates of Fluvial Sedimentation: Implications for Archaeological Variability. *Geoarchaeology* 1(3):259-274.

Foster, William C.
1995 *Spanish Expeditions into Texas, 1689-1768*. University of Texas Press, Austin.

Fox, Anne A.
1989 Historic Anglo-European Exploration and Colonization (Chapter 7). In *From the Gulf to the Rio Grande: Human Adaptations in Central, South, and Lower Pecos, Texas*, by T. R. Hester, S. L. Black, D. G. Steele, B. W. Olive, A. A. Fox, K. J. Reinhard, and L. C. Bement, p. 85-92. Arkansas Archeological Survey Research Series No. 33, Fayetteville.

Garza, Alicia A.
1996 Port Isabel, Texas. In *The New Handbook of Texas*, edited by R. Tyler. 6 Volumes. The Texas State Historical Association, Austin.

Garza, Alicia A., and Christopher Long
1996 Cameron County. In *The New Handbook of Texas*, edited by R. Tyler. 6 Volumes. The Texas State Historical Association, Austin.

Geological Survey
1983 *Los Fresnos, Texas*. United States Department of the Interior. Washington, D. C.

1985 *State of Texas*. United States Department of the Interior. Washington, D. C.

Goh, K. M.
1991 Carbon Dating. In *Carbon Isotope Techniques*, edited by Coleman and Brian Fry, pp. 125-145. Academic Press, Inc., San Diego, California.

Griffiths, J. F., and Greg Ainsworth
1981 *One Hundred Years of Texas Weather, 1880-1979*. Texas A&M University. Office of the State Climatologist, College Station, Texas.

Griffiths, J. F., and Janine Bryan
1987 *The Climates of Texas Counties*. Office of the State Climatologist, The University of Texas at Austin.

Grozier, R. U., A. E. Hulme, E. E. Schroeder, and D. C. Hahl
1968 *Floods of Hurricane Beulah in South Texas and Northeastern Mexico, September- October, 1967*. Texas Water Development Board Report 83. Austin, Texas.

Haecker, Charles M.
1994 *A Thunder of Cannon: Archeology of the Mexican-American War Battlefield of Palo Alto*. Southwest Cultural Resources Center Professional Paper No. 2. National Park Service, Divisions of Anthropology and History, Southwest Regional Office, Santa Fe, New Mexico.

Haecker, Charles M., and Jeffrey G. Mauck
1997 *On the Prairie of Palo Alto: Historical Archaeology of the U.S. - Mexican War Battlefield*. Texas A&M University Press, College Station.

Hatch, Stephan L., and Jennifer Pluhar
1993 *Texas Range Plants*. Texas A&M University Press, College Station.

Hatch, Stephan L., Kancheedpuram N. Gandhi, and Larry E. Brown
1990 *Checklist of the Vascular Plants of Texas*. Texas A&M University, College Station.

Heath, R, C.
1983 *Basic Ground-Water Hydrology*. United States Geological Survey Water Supply Paper 2220, Washington, D. C.

Hem, J. D.
1992 *Study and Interpretation of the Chemical Charateristics of Natural Water*. United States Department of the Interior. Geological Survey Water-Supply Paper 2254, Washington, D. C.

Hester, Thomas R.
1980 *Digging Into South Texas Prehistory*. Corona Publishing Company, San Antonio.

1989a Introduction. In *From the Gulf to the Rio Grande: Human Adaptations in Central, South, and Lower Pecos, Texas*, by T. R. Hester, S. L. Black, D. G. Steele, B. W. Olive, A. A. Fox, K. J. Reinhard, and L. C. Bement, pp. 1-4. Arkansas Archeological Survey Research Series No. 33, Fayetteville.

1989b Historic Native American Populations (Chapter 6). In *From the Gulf to the Rio Grande: Human Adaptations in Central, South, and Lower Pecos, Texas*, by T. R. Hester, S. L. Black, D. G. Steele, B. W. Olive, A. A. Fox, K. J. Reinhard, and L. C. Bement, p. 77-84. Arkansas Archeological Survey Research Series No. 33, Fayetteville.

1995a The Prehistory of South Texas. *Bulletin of the Texas Archeological Society* 66:427-459.

1995b Notes on South Texas Archaeology: 1995:3 - The Protohistoric Period in Southern Texas. *La Tierra* 22(3):1-3.

Hindes, V. Kay
1995 Native American and European Contact in the Lower Medina River Valley. *La Tierra* 22(2):25-33.

Huebner, Jeffrey A.
1991 Late Prehistoric Bison Populations in Central and Southern Texas. *Plains Anthropologist* 36(137):343-358.

Ivey, Jake
1992 Reconnaissance Report on the Palo Alto Battlefield. Report on file with the National Park Service, Southwest Regional Office, Division of History, Santa Fe.

Johnson, Elmer H.
1931 The Natural Regions of Texas. *The University of Texas Bulletin* No. 3113, Austin.

Jones, Stanley, and J. K. Wipff
2003 *A 2003 Updated Checklist of the Vascular Plants of Texas*. Botanical Research Center, Bryan, Texas.

Lantz, Randall N.
2003 *Groundwater Monitoring Well Installation Report, Palo Alto Battlefield National Historic Site, Cameron County, Texas*. Enercon Services, Inc., Dallas, Texas.

Larkin, Thomas J., and George W. Bomar
1983 *Climatic Atlas of Texas*. Texas Department of Water Resources, Austin.

Libby, W. F.
1955 *Radiocarbon Dating*, 2nd ed. University of Chicago Press, Chicago, Illinois.

Lohse, E.A.
1958 Mouth of Rio Grande, Stop III, Third Day. *Annual Field Trip Guidebook*, pp. 55-56, Gulf Coast Association of Geological Societies.

Mallouf, Robert J., Barbara J. Baskin, and Kay L. Killen
1977 *A Predictive Assessment of Cultural Resources in Hidalgo and Willacy Counties, Texas.* Archeological Survey Report 23, Texas Historical Commission, Austin.

Mook, W. G. (editor)
1980 *The Principles and Applications of Radiocarbon Dating*. Elsevier, Amsterdam, The Netherlands.

Morisawa, Marie
1968 *Streams, their dynamics and morphology*. McGraw-Hill Book Company, New York, New York.

Neck, R. W.
1985 *Paleoecological Implications of a Holocene Fossil Assemblage, Lower Rio Grande, Cameron County, Texas*. Texas Memorial Museum Pearce-Sellards Series 41, Austin, Texas.

Norwine, Jim
1978 A Question of Climate: Hot or Cold? In *Climate and Human Ecology*, edited by Jim Norwine, pp. 11-21. D. Armstrong Co., Inc., Houston, Texas.

Paine, J.G.
1991 Late Quaterary Depositional Units, Sea Level, and Vertical Movement Along the Central Texas Coast. University of Texas at Austin, Doctoral dissertation. Austin, Texas.

Patterson, J. L.
1965 *Magnitude and Frequency of Floods in the United States. Part 8. Western Gulf of Mexico Basins*. United States Department of the Interior, Geological Survey Water-Supply Paper 1682, Washington, D. C.

Peña, José Enrique de la
1975 *With Santa Anna in Texas: A Personal Narrative of the Revolution*. Translated and edited by Carmen Perry. Texas A&M University Press, College Station.

Perttula, Timothy K.
1999 Archeological Investigations of Mexican-American War Battlefields and Related Sites in Texas. Part I: Introduction and Discussion of Sites on The Palo Alto Battlefield. *La Tierra* 26(3):18-26.

Perttula, Timothy K., and Bo Nelson
1999 Archeological Investigations of Mexican-American War Battlefields and Related Sites in Texas. Part II: The Palo Alto House or Inn (41CF92-9), Also Known as the Taylor Tavern. *La Tierra* 26(3):27-30.

Postgate, John
1972 Sulfate Reduction—Microbial. In *The Encyclopedia of Geochemistry and Environmental Sciences*, edited by R.W. Fairbridge, pp. 1127-1129. Van Nostrand Reinhold Company, New York, New York.

Pryor, W. A., K. J. Fulton, and L. K. Harrison
1975 Stratigraphy, Petrology, and Paleontology of Several Holocene Rio Grande Delta Distributary Systems in Cameron County, Texas. *Annual Meeting Abstracts* 2: 61 , American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists.

1976 Subsurface Stratigraphy and Depositional Environments of Several Holocene Rio Grande Delta Distributaries, Cameron County, Texas. *Bulletin of the Corpus Christi Geological Society* 18:7- 14.

Richard, Norman L., and Alfred T. Richardson
1993 *Biological Inventory, Natural History, and Human Impact of Palo Alto National Battlefield.* Biology Department, The University of Texas at Brownsville.

Ricklis, Robert A.
1995 Prehistoric Occupation of the Central and Lower Texas Coast: A Regional Overview. *Bulletin of the Texas Archeological Society* 66:265-300.

Ricklis, Robert A, and Kim A. Cox
1998 Holocene Climatic and Environmental Change in the Texas Coastal Zone: Some Geoarcheological and Ecofactual Indicators. *Plains Anthropologist* 43(164):125-136.

Riggio, R. F., G. W. Bomar, and T. J. Larkin
1987 *Texas Drought: Its Recent History (1931-1985).* Texas Water Commission LP 87-04, Austin, Texas.

Salinas, Martín
1990 *Indians of the Rio Grande Delta.* University of Texas Press, Austin.

Schmidly, David J.
2004 *The Mammals of Texas.* Revised Edition. University of Texas Press, Austin.

Schneider, Stephen H., and Randi Londer
1984 *The Coevolution of Climate and Life.* Sierra Club Books, San Francisco.

Shafer, Harry
1974 *An Archeological Reconnaissance of the Brownsville Railway Relocation Study Area.* Anthro pology Laboratory Report No. 1, Texas A&M University, College Station, Texas.

Shafer, Harry J., and Clell L. Bond
1983 An Archeological Review of the Central Texas Coast. *Bulletin of the Texas Archeological Society* 54:271-285.

Soil Survey Division Staff
1993 *Soil Survey Manual*, United States Department of Agriculture Handbook Number 18, Washington, D.C.

Steely, James Wright (compiler)
1984 *A Catalog of Texas Properties in the National Register of Historic Places*. Texas Historical Commission, Austin.

Strahler, A. N.
1964 Quantitative Geomorphology of Drainage Basins and Channel Networks. In *Handbook of Applied Hydrology—A Compendium of Water-Resources Technology*, edited by V. T. Chow, Sec. 4: 39-76, McGraw-Hill, New York.

Stuiver, M. and P.J. Reimer
1993 Radiocarbon Calibration Program Rev 4.3. *Radiocarbon* 35:215-230.

Taylor, R. E.
1987 *Radiocarbon Dating: An Archaeological Perspective*. Academic Press, Inc., Orlando, Florida.

Thompson, Jerry
2001 *Palo Alto Battlefield National Historic Site*. Southwest Parks and Monuments Association.

Turner, B. L., Holly Nichols, Geoffrey Denny, and Oded Doron
2003 *Atlas of the Vascular Plants of Texas*. Two volumes. BRIT Press, Fort Worth, Texas.

Turner, Ellen Sue, and Thomas R. Hester
1999 *A Field Guide to Stone Artifacts of Texas Indians*. Second Edition. Gulf Publishing Company, Houston.

Waters, M. R.
1992 *Principles of Geoarchaeology—A North American Perspective*. The University of Arizona Press, Tucson, Arizona.

Weaver, Karen S.
1999 *Pre-European Texas: Vegetation Change on Palo Alto Battlefield National Historic Site*. Unpublished Master's Thesis, Texas A&M University at Corpus Christi, Corpus Christi, Texas.

Weems, J.E.
1974 *To Conquer a Peace - The War Between the United States and Mexico*. Texas A&M Press, College Station, Texas.

Weniger, Del
1984 *The Explorers' Texas*. Eakin Press, Austin.

Williams, Dewayne, Charles M. Thompson, and Jerry L. Jacobs
1977 *Soil Survey of Cameron County, Texas*. Soil Conservation Service, U.S. Department of Agriculture, in cooperation with the Texas Agricultural Experiment Station.

Winker, C. D.
1991 Northwestern Gulf Coastal Plain. In *Quaternary Nonglacial Geology: Conterminous U. S.*, edited by R. B. Morrison. Volume K-2, The Geology of North America, Geological Society of America, Boulder, Colorado.