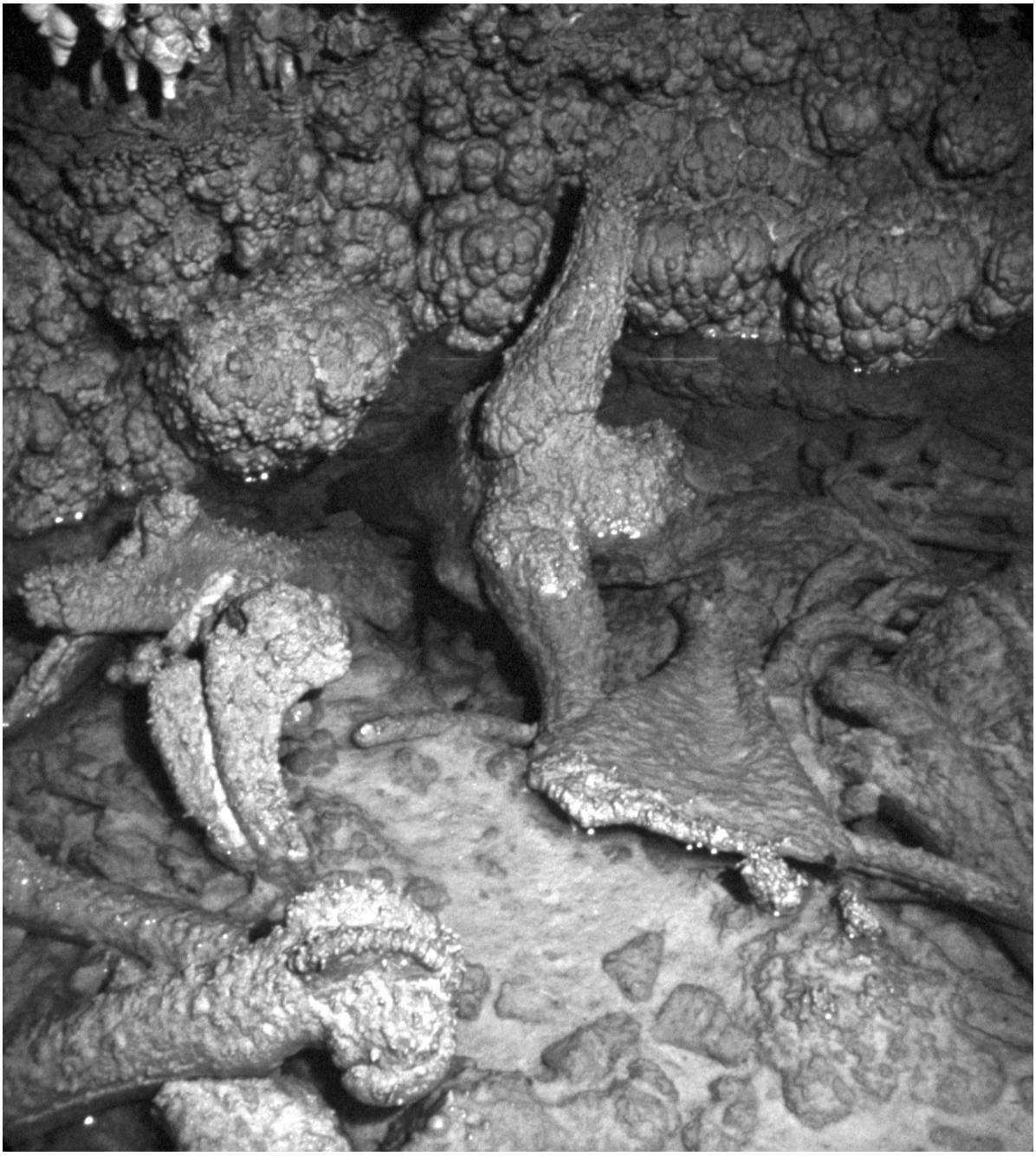
National Park Service
U.S. Department of the Interior

National Inventory & Monitoring Program

Paleontological Resource Inventory and Monitoring
Chihuahuan Desert Network



Paleontological Resource Inventory and Monitoring
Chihuahuan Desert Network

Vincent L. Santucci
Chief Ranger
George Washington Memorial Parkway

Jason P. Kenworthy
Paleontology Technician
Geologic Resources Division

Christy C. Visaggi
Paleontology Intern
University of North Carolina, Wilmington

March 2007

National Park Service, TIC #D-500

NOTE: This report provides baseline paleontological resource data to National Park Service administration and resource management staff. The report contains information regarding the location of non-renewable paleontological resources within NPS units. It is **not** intended for distribution to the general public.

On the Cover:
Shrub ox (*Euceratherium cf. sinclairi*) bones discovered in 1975 within Musk Ox Cave, Carlsbad Caverns National Park. The well-preserved bones are covered in delicate "cave popcorn." The specimen is thought to be at least 17,000 years old and is now curated at the Smithsonian National Museum of Natural History. For more information see the Carlsbad Caverns section of this report. Photo courtesy Ron Kerbo (NPS).

How to cite this document:
Santucci, V.L., J.P. Kenworthy, and C.C. Visaggi, 2007. Paleontological Resource Inventory and Monitoring, Chihuahuan Desert Network. National Park Service TIC# D-500, 105 pages.



This volume is dedicated to the founding fathers of vertebrate paleontology in Texas and the Chihuahuan Desert, (from left to right) Dr. Ernest L. Lundelius, Dr. John A. Wilson, and Dr. Wann Langston, Jr., of the Texas Memorial Museum in Austin, Texas.
(Photo courtesy of David M. Stephens)

TABLE OF CONTENTS

INTRODUCTION 1

CHIHUAHUAN DESERT NETWORK MAP 2

NPS INVENTORY STRATEGIES AND METHODOLOGY 3

AMISTAD NATIONAL RECREATION AREA 9

BIG BEND NATIONAL PARK 31

CARLSBAD CAVERNS NATIONAL PARK 61

FORT DAVIS NATIONAL HISTORIC SITE 71

GUADALUPE MOUNTAINS NATIONAL PARK 73

RIO GRANDE WILD AND SCENIC RIVER 87

WHITE SANDS NATIONAL MONUMENT 99

ACKNOWLEDGEMENTS 103

APPENDIX A: GEOLOGIC TIME SCALE 105

INTRODUCTION

Paleontological resources, or fossils, are any remains of past life preserved in a geologic context. There are two main types of fossils: body fossils and trace fossils. Body fossils are the physical remains of an actual organism (shells, bones, teeth, plant leaves, etc.) while trace fossils (burrows, footprints, trackways, coprolites, etc.) preserve evidence of an organism's activity or behavior. Fossils are non-renewable natural resources that possess great scientific, educational, and interpretive value.

The establishment of baseline paleontological resource data is essential for the appropriate management of fossils found within National Park Service (NPS) areas. Although more than 180 NPS areas have been identified with paleontological resources, few parks have adequate baseline paleontological resource data.

In conjunction with the NPS Geologic Resources Division and the NPS Inventory and Monitoring (I&M) Program, paleontological resource inventories have been initiated in dozens of parks Servicewide. The approach adopted for the inventories is described in the Methodology and Inventory Strategies section of this report. This report presents paleontological resource inventory and monitoring data compiled for the parks of the Chihuahuan Desert Inventory and Monitoring Network (CHDN).

The Chihuahuan Desert Network includes seven widely separated National Park Service areas ranging from south central New Mexico to the Trans-Pecos Texas region. As shown in Figure 1, the parks in this network include: Amistad National Recreation Area (Texas; AMIS); Big Bend National Park (Texas; BIBE); Carlsbad Caverns National Park (New Mexico; CAVE); Fort Davis National Historic Site (Texas: FODA); Guadalupe Mountains National Park (Texas; GUMO) Rio Grande Wild and Scenic River (Texas; RIGR) and White Sands National Monument (New Mexico; WHSA). These parks range in size from 192 to 324,232 hectares and are located within the northern region of the Chihuahuan Desert, one of the most biologically diverse arid regions in the world. Most of the CHDN parks were established for conservation and preservation of significant natural and geologic resources (Reiser et al. 2006).

Most of the Chihuahuan Desert ecoregion consists of a series of basins and ranges. The landscape lies between 900 and 1500 m (about 3,000 to 5,000 feet), although some isolated mountain ranges in the central portion of the ecoregion may rise to more than 3,000 m (about 10,000 feet) above sea level (Reiser et al. 2006). Climatically, the CHDN parks are generally arid regions with hot summers and cool to cold, dry winters. The majority of the precipitation falls in the form of monsoonal rains during the summer months. The rainfall ranges from 150 – 500 mm (6 to 20 inches) annually. In south-central New Mexico, wind blown soils form one of the largest gypsum dune fields in the world.

Other habitat types within the Chihuahuan Desert Network parks include a diverse array of freshwater habitats, including a few large rivers, numerous seeps and springs, and smaller perennial and ephemeral streams (Reiser et al. 2006). The Rio Grande is fed by its major tributaries, the Devil's and Pecos Rivers and the Rio Conchos. The Rio Grande is the only major through-flowing river in the Chihuahuan Desert.

While most of the CHDN parks were not established specifically for paleontological resource stewardship, fossils are known from a number of the parks including Amistad National Recreation Area, Big Bend National Park, Carlsbad Caverns National Park, Guadalupe Mountains National Park, Rio Grande Wild and Scenic River and White Sands National Monument. Additional paleontological resources are known from the White Sands Missle Range, an area adjacent to White Sands National Monument.

The paleontological resources found within CHDN parks are quite diverse, span hundreds of millions of years, and in some cases are nationally or even globally significant. For example, the Permian Reef Complex located within Guadalupe Mountains National Park represents a globally significant and diverse faunal assemblage and the park contains the international standard for the Middle Permian Guadalupian Series. Big Bend National Park preserves an important record of Cretaceous vertebrates including

dinosaurs, turtles, crocodiles, and the largest known pterosaur. Additionally, a stratigraphic sequence which spans the Cretaceous – Tertiary boundary occurs within BIBE. This sequence contains important assemblages of early mammals which span the Mesozoic /Cenozoic boundary.

Collectively, the paleontological resources of the Chihuahuan Desert Network contribute much to a greater understanding of the history of life on earth. Continued paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the National Park Service. Although more than 180 parks have already been identified as containing paleontological resources, much of what is to be known about the history of life on earth remains to be discovered.

Vincent L. Santucci, Jason P. Kenworthy, and Christy C. Visaggi—March 2007

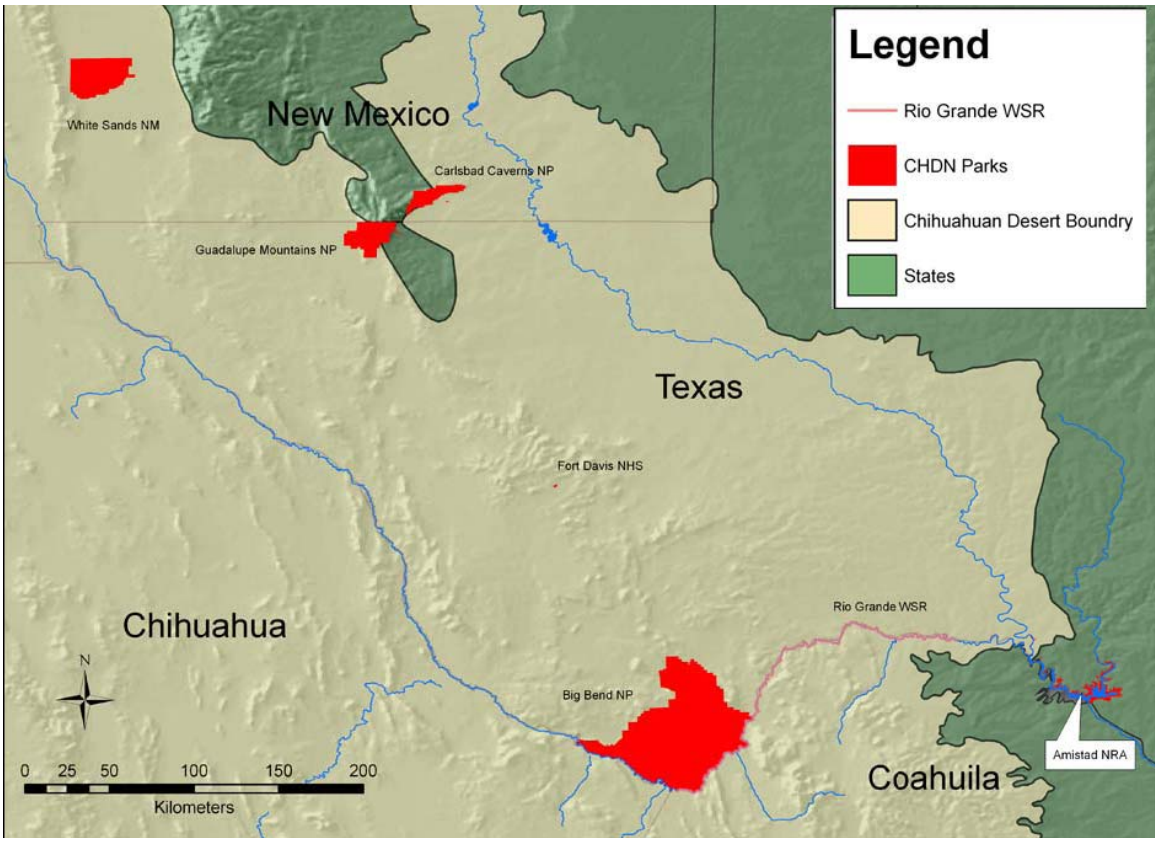


Figure 1. Map of Chihuahuan Desert I&M Network parks. Map courtesy NPS/CHDN (Reiser et al. 2006).

PALEONTOLOGICAL RESOURCE INVENTORY STRATEGIES AND METHODOLOGY

In order to better document fossil occurrences and to provide baseline paleontological resource data in National Park Service areas, the NPS Geologic Resources Division (GRD) and the NPS Inventory and Monitoring Program (I&M) have established three paleontological resource inventory strategies. These strategies include: comprehensive park-specific paleontological resource inventories, Servicewide thematic paleontological resource inventories, and Inventory & Monitoring Network paleontological resource inventories. Each of the paleontological resource inventory strategies are established with their own goals and objectives. An article outlining basic paleontological resource monitoring strategies and potential threats to fossil resources is presented by Santucci and Koch (2003).

Comprehensive Park Paleontological Resource Inventories
Comprehensive park inventories are designed to identify all known paleontological resources within a single park unit. Comprehensive park inventories involve the assembly of a team of specialists from within the NPS and from educational institutions and cooperators. These specialists work together with the park to identify and address all aspects of the paleontological resources within the targeted park, including resource management, museum curation, law enforcement, and interpretation. The goals and objectives of a park-specific paleontological resource inventory are detailed by Santucci (2000). An important component of many comprehensive paleontological inventories is to provide paleontology-specific training for park staff. Such park-specific comprehensive paleontological resource inventories have been completed at Yellowstone NP (first park to complete inventory), Arches NP, Bighorn Canyon NRA, Death Valley NP, Grand Teton NP, Santa Monica NRA, Walnut Canyon NM, and Zion NP.

Servicewide Thematic Paleontological Resource Inventories
Servicewide thematic paleontological resource inventories are designed to compile data regarding specific types of paleontological resources which occur in parks throughout the NPS. The first thematic paleontological resource inventory accomplished was an inventory of fossil vertebrate tracks from NPS areas (Santucci et al. 1998). Through this thematic inventory, a total of nineteen NPS units were identified as preserving fossil vertebrate tracks. Subsequent discoveries have increased the number of parks identified with fossil vertebrate tracks to twenty-five and warranted an updated publication (Santucci et al. 2006). Another example of a thematic paleontological resource inventory is the inventory of paleontological resources associated with NPS caves (Santucci et al. 2001). Fossils occur in two contexts relative to caves. First, fossils can be preserved in the marine limestones in which caves develop. Second, the remains of Pleistocene / Holocene animals and plants that lived, died or were transported into caves after death are common types of cave fossils. The NPS Cave Paleontological Resource study initially identified thirty-five parks with cave fossils. Servicewide thematic inventories have also been initiated for fossil fish (Hunt et al. 2006) and fossils found in cultural resource contexts (Kenworthy and Santucci 2006).

Inventory and Monitoring Network Paleontological Resource Inventories
The third paleontological resource inventory strategy is the Inventory & Monitoring Network-based inventory strategy. Network-based paleontological resource inventories are designed to compile baseline paleontological resource data for each of the parks assigned to a particular network. Network-based inventories have been completed for nearly half of the 32 I&M Networks including: the Eastern Rivers and Mountains, Greater Yellowstone, Mediterranean Coast, Mid-Atlantic, Mojave Desert, National Capital Region, Northeast Coastal and Barrier, Northern Colorado Plateau, Rocky Mountain, Southern Plains, Southwestern Alaska, and Upper Columbia Basin networks. The NPS I&M Program will be providing funding to complete paleontological resource summaries for the remaining networks by FY2009. Summaries for the Pacific Islands, San Francisco Bay Area, and Southern Colorado Plateau are currently underway and the Gulf Coast Network summary is in the final review phase (December 2006). Citations for the completed reports are included in the Additional References section of this publication.

Inventory and Monitoring Network Paleontological Resource Inventory Methodology

The Network-based paleontological inventories were funded directly by the individual networks from 2002-2006. In FY2006, the National I&M Program provided funds to complete reports for the remaining networks between FY2006-2009. This Chihuahuan Desert Network summary is the first report completed utilizing National I&M Program money. Funds provide stipends or salary for contractors, interns, or paleontological technicians who perform data mining activities. The Chihuahuan Desert Network report represents a multi-faceted approach toward the completion of the report. To efficiently utilize available funding, data mining work for the CHDN paleontology summary was performed concurrently by a paleontology intern through the Student Conservation Association, a paleontology technician from the NPS Geologic Resources Division, in addition to the senior author. Funding for the CHDN report was made available through the National Park Service Inventory and Monitoring Program. A brief summary outlining the basic techniques used to assemble an I&M Network-based inventory is presented below.

The most valuable component of any paleontological resource inventory is an intensive literature search. Various databases contain citations for geology or paleontology themed publications. GeoRef, established by the American Geological Institute, is the primary database for geology references and contains millions of references from the mid 1700s through today. GeoRef, available in both online or CD-ROM versions, is accessible at many major university libraries. The NPS NatureBib (which supersedes PaleoBib) is an internet-based database for scientific citations presented as bibliographic references. NatureBib is a work in progress and does not yet contain a comprehensive paleontology bibliography. The USGS Library in Reston, Virginia is a premier repository for geologic publications, and houses most of the publications obtained for the network-based paleontological resource inventories. Additionally, museum libraries such as the Smithsonian Institution's National Museum of Natural History, and university libraries provide access to a wide range of geological and paleontological publications. Individual state geological surveys are also excellent sources of information and geologists familiar with local geology and paleontology.

The literature search also includes gray (unpublished) literature searches of individual park files, museum archives, local newspapers, field notes, etc. These are often excellent sources of anecdotal information about park resources. In addition to literature searches, interviews with park staff, university faculty, geologists from the USGS and state surveys, and even local amateur geologists or paleontologists can yield information regarding park paleontological resources. These interviews frequently result in capturing data that may otherwise be undocumented and potentially lost or unrecognized. As part of the bibliographic searches, a search for geologic maps associated with each park is undertaken. Tim Connors, a geologist with the NPS Geologic Resources Division, maintains a database of geological map coverage for many parks in the NPS. In addition, the USGS National Geologic Map Database (NGMDB; see citation below in Additional References section) lists maps for a given geographic area or place name. The NGMDB also provides information on where to obtain maps. Geologic maps show the type of rocks and the associated geological formations present within a park area. These maps alone will often indicate the potential for paleontological resources to occur within a park.

Fossils are most commonly found in sedimentary rocks such as sandstones, shales, and limestones. Fossils, with few exceptions, are not typically found within igneous rocks (volcanic, or of molten origin) or metamorphic rocks (mechanically and chemically altered) due to the extreme heat and/or pressure associated with the origin and history of these rock types. The nomenclature for geologic formations can be confusing. The NGMDB also includes a searchable lexicon of valid geologic formation names. This lexicon provides a basic summary for each formation and summarizes current and past usage of the various formation names found in the literature. It also provides an annotated bibliography for each formation. The lexicon is very useful in cleaning up nomenclatural confusion.

The information from all these various sources for each park is then compiled and summarized in a written report and developed into individual datasets. The reports undergo peer review by professional geologists, paleontologists, and staff from each park for accuracy before being submitted to the network. This report is designed to consolidate baseline paleontological resource data for each park to support management operations and decision-making. Therefore, the reports are written in NPS language and in additional to the scientific information, the reports address issues of resource management, protection, and interpretation.

The paleontological resource inventory reports synthesize information regarding the scope and significance of fossils documented from each park. Fossils are assessed and organized based upon taxonomy, stratigraphy, and paleoecology. Taxonomically, paleontological resources can be divided into four groups: paleobotany (fossil plants), invertebrates (animals without backbones), vertebrates (animals with backbones), and trace fossils (evidence of biological activity such as track, trace, burrow, etc.). Stratigraphically, fossils typically have a finite range and occurrence in geologic time (a geologic time scale is included in Appendix A). The period between the first occurrence and final occurrence of a fossil species is referred to as the stratigraphic range zone. Thus specific groups of fossils may be identified directly with a particular stratigraphic unit or stratigraphic range. Likewise, rock units often represent specific ancient sedimentary depositional environments. Paleoecologically, fossil groups may occur primarily, or in some instances only, in specific environmental conditions (temperature, aquatic, terrestrial, etc.). Thus many fossils may be useful as indicators of past environmental conditions. The reports are organized stratigraphically presenting the geologic and paleontologic information chronologically from oldest to youngest. Important fossils documented from localities outside a park are often reported in the park inventory, as this data may indicate the potential for fossils in similar stratigraphic units exposed within park boundaries.

Given the tremendous diversity of past life, the existence of life for over a billion years, and the range of environments to which life has adapted, there is a broad spectrum of research interests in paleontology. It is not surprising that most of what is to be learned about the history of life remains to be discovered. Through research, more than 180 NPS areas have been identified as containing paleontological resources. However, the paleontological research for a particular park may vary widely from an incidental fossil discovery to over a century of intensive paleontological investigations. The inventory reports include information on the history of paleontological research, descriptions of current cooperative projects, identification of any museum or universities serving as repositories for park fossils, and a comprehensive list of publications related to paleontological research associated with the park. Organizationally, the reports include any and all bibliographies that may be associated to a park's paleontological resources. However, bibliographic data are subdivided in the report into those cited in the narrative (References Cited) and other associated bibliographies (Additional References). The cooperative projects section highlights projects, if any, that the park has funded or supported relating to paleontological resources. Formal datasets are established for known associated paleontological collections, research, or activities.

Paleontological Resource Management Legislation and Guidance

I&M Network reports such as this one are meant to provide network parks with sound baseline paleontological resource data. These data can then be utilized to stimulate future research, interpretation, education, or resource management projects. The proper management of resources identified through these inventories is mandated by many NPS policies. For example, the 2006 National Park Service Management Policies (§1.4.6) stipulates that paleontological resources are considered park resources and values that are subject to the "no impairment" standard set forth by the NPS Organic Act in 1916. Basic guidelines for management of paleontological resources are found in sections 4.8.2 and 4.8.2.1 of the 2006 NPS Management Policies. Another legislative protection afforded to paleontological resources is found in the NPS Omnibus Management Act of 1998. Section 207, with the following statement, "Information concerning the nature and specific location of…paleontological objects within the units of the National Park System…may be withheld from the public source," safeguards paleontological locality information from requests under the Freedom of Information Act.

Paleontological resource management issues were the subject of a Report of the Secretary of the Interior in May 2000. That report, an "Assessment of Fossil Management on Federal & Indian Lands" summarized a number of principles relating to paleontological resources and their management from a federal government point of view. The report was also prepared in response to a congressional request for an assessment of the need for a unified federal policy on the collection, storage and preservation of fossils and for standards that would maximize the availability of fossils for scientific study. The Paleontological Resources Management section of Natural Resource Management Reference Manual 77 provides guidance and additional information regarding the implementation and continuation of paleontological resource management programs. Links to the above documents are listed in the Additional References section. The Geologic Resources Division is also coordinating the assembly of a geologic resource monitoring manual. This manual includes chapters on various geologic resources, including *in situ* paleontological resources, and a set of monitoring vital signs that may be applicable to a variety of parks. It represents the next phase in paleontological resource management, following the initial research inventory (represented by this report) of potential fossils and any subsequent field work to identify fossils within a park. Currently the draft monitoring manual is undergoing peer review. Contact the Geologic Resources Division for more information or to obtain a copy of the report when it is available.

Our knowledge of the fossil record is only a good as our previous field season. The potential for new paleontological discoveries is proportionally related to our understanding as managers and stewards of this non-renewable evidence of life from the past. We believe that the baseline information provided in these reports and the resulting increased understanding of paleontological resources will inevitably result in paving the way for future fossil discoveries in NPS areas.

Additional References and Websites of Interest

Hunt, R.K., V.L. Santucci and J.P. Kenworthy. 2006. A preliminary inventory of fossil fish from NPS units. Pages 63-69 *in* Lucas, S.G., et al. America's Antiquities (Proceedings of the 7th Federal Fossil Conference). New Mexico Museum of Natural History & Science, Albuquerque, NM. Bulletin 34.

Kenworthy, J.P. and V.L. Santucci. 2003. Paleontological Resource Inventory and Monitoring, Southwestern Alaska Network. National Park Service TIC# D-93. 27 pages.

Kenworthy, J.P. and V.L. Santucci. 2003. Paleontological Resource Inventory and Monitoring, Northeast Coastal and Barrier Network. National Park Service TIC# D-340. 28 pages.

Kenworthy, J.P. and V.L. Santucci. 2004. Paleontological Resource Inventory and Monitoring, National Capital Network. National Park Service TIC# D-289. 97 pages.

Kenworthy, J.P. and V.L. Santucci. 2006. A preliminary inventory of NPS paleontological resources found in cultural resource contexts, Part 1: General Overview. Pages 70-76 *in* Lucas, S. G., et al. America's Antiquities (Proceedings of the 7th Federal Fossil Conference). New Mexico Museum of Natural History & Science, Albuquerque, NM. Bulletin 34.

Kenworthy, J.P., V.L. Santucci, and C.C. Visaggi. In Review. Paleontological Resource Inventory and Monitoring, Gulf Coast Network. National Park Service TIC# D-750.

Kenworthy, J.P., C.C. Visaggi, and V.L. Santucci. 2006. Paleontological Resource Inventory and Monitoring, Mid-Atlantic Network. National Park Service TIC# D-800. 85 pages.

Kenworthy, J.P., V.L. Santucci, M. McNerney, and K. Snell. 2005. Paleontological Resource Inventory and Monitoring, Upper Columbia Basin Network. National Park Service TIC# D-259. 71 pages.

Koch, A.L. and V.L. Santucci. 2002. Paleontological Resource Inventory and Monitoring, Northern Colorado Plateau Network. National Park Service TIC# D-206. 44 pages.

Koch, A.L. and V.L. Santucci. 2003. Paleontological Resource Inventory and Monitoring, Southern Plains Network. National Park Service TIC# D-107. 34 pages.

Koch, A.L. and V.L. Santucci. 2003. Paleontological Resource Inventory and Monitoring, Greater Yellowstone Network. National Park Service TIC# D-1025. 20 pages.

Koch, A.L. and V.L. Santucci. 2003. Paleontological Resource Inventory and Monitoring, Mediterranean Coast Network. National Park Service TIC# D-177. 27 pages.

Koch, A.L. and V.L. Santucci. 2004. Paleontological Resource Inventory and Monitoring, Eastern Rivers and Mountains Network. National Park Service TIC# D-265. 50 pages.

Koch, A.L., J.P. Kenworthy, and V.L. Santucci. 2004. Paleontological Resource Inventory and Monitoring, Rocky Mountain Network. National Park Service TIC# D-436. 47 pages.

Reiser, M.H., Y. Garcia, W.H Reid, and J.T. Richie, 2006. Chihuahuan Desert Network Vital Signs Monitoring Plan: Phase I. National Park Service, Chihuahuan Desert Network, Las Cruces, New Mexico, 83 p.

Santucci, V.L. 1998. The Yellowstone Paleontological Survey. Yellowstone Center for Resources, Yellowstone NP, WY. YCR-NR-98-1. 54 pages (http://www2.nature.nps.gov/geology/paleontology/surveys/yell.pdf)

Santucci, V.L. 2000. What constitutes a comprehensive National Park Service paleontological survey? Online information: (http://www2.nature.nps.gov/geology/paleontology/surveys/survey_outline.htm)

Santucci, V.L., A.P. Hunt, and M.G. Lockley. 1998. Fossil vertebrate tracks in National Park Service areas. Dakoterra 5:107-114.

Santucci, V.L., A.P. Hunt, T.G. Nyborg, and J.P. Kenworthy. 2006. Additional fossil vertebrate tracks in National Park Service areas. In Lucas, S.G., et al. (eds.), America's Antiquities: 100 Years of Managing Fossils on Federal Lands. Proceedings of the 7th Federal Fossil Conference, New Mexico Museum of Natural History and Science Bulletin No. 34: 152-158.

Santucci, V.L., J.P. Kenworthy, and R. Kerbo, 2001. An inventory of paleontological resources associated with National Park Service Caves. NPS Geological Resources Division, Denver. Technical Report NPS/NRGRD/GRDTR-01/02. (TIC# D-2231). 50 pages. (http://www2.nature.nps.gov/geology/paleontology/pub/cavepaleo.pdf)

Santucci, V.L., J.P. Kenworthy, and C.C. Visaggi, 2007. Paleontological Resource Inventory and Monitoring, Chihuahuan Desert Network. Nationlal Park Service TIC# D-500, 101 pages.

Santucci, V.L. and A.L. Koch. 2003. Paleontological resource monitoring strategies for the National Park Service. Park Science 22(1): 22-25.

Santucci, V.L. and A.L. Koch. 2004. Paleontological Resource Inventory and Monitoring, Mojave Desert Network. National Park Service TIC# D-305. 50 pages.

General CHDN Information

Chihuahuan Desert I&M Network: http://www.nature.nps.gov/im/units/chdn/index.cfm

Geological Survey Websites

New Mexico Bureau of Geology and Mineral Resources (Socorro): http://geoinfo.nmt.edu/
Texas Bureau of Economic Geology (Austin): http://www.beg.utexas.edu/

U.S. Geological Survey: http://www.usgs.gov
Geological Society of America: http://www.geosociety.org
American Geological Institute: http://www.agiweb.org

Library catalogs

U.S. Geological Survey Library Catalog: http://igsrglib03.er.usgs.gov:8080/#focus

Smithsonian Institution Libraries Catalog: http://www.siris.si.edu/

Museums

Texas Memorial Museum (Austin): http://www.utexas.edu/tmm/exhibits/index.html
Smithsonian National Museum of Natural History Dept. of Paleobiology: http://www.nmnh.si.edu/paleo//

Resource Management/Legislation Documents

NPS 2006 Management Policies (§1.4; Park Management): http://www.nps.gov/policy/mp/chapter1.htm
NPS 2006 Management Policies (§4.8.2.1; Paleontological Resources): http://www.nps.gov/policy/mp/chapter4.htm
NPS 1998 Omnibus Management Act (paleontological resource summary): http://www2.nature.nps.gov/geology/paleontology/paleo_5_1/index.htm
NPS Natural Resource Management Reference Manual #77 (paleontology section): http://www.nature.nps.gov/rm77/paleo.cfm
Assessment of Fossil Management on Federal & Indian Lands: http://www.fs.fed.us/geology/fossil.pdf

National Park Service Paleontology Program sites

NPS Geologic Resources Division: http://www2.nature.nps.gov/geology/
NPS Paleontology Program: http://www2.nature.nps.gov/geology/paleontology/
NPS Park Paleontology Newsletter: http://www2.nature.nps.gov/geology/paleontology/news/newsletter.htm
I&M Network paleontological resource summary project website and PDFs of all reports (InsideNPS): http://inside.nps.gov/waso/custommenu.cfm?lv=4&prg=753&id=4518

Other geology/paleontology tools

Bates, R.L. and J.A. Jackson (editors). American Geological Institute dictionary of geological terms (3rd Edition). Bantam Doubleday Dell Publishing Group, New York.

U.S. Geological Survey Geologic Terms Glossary: http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html

Topozone (interactive access to all USGS topographic maps): http://www.topozone.com

U.S. Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/

U.S. Geological Survey Geologic Names Lexicon (GEOLEX; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html

U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features): http://geonames.usgs.gov/pls/gnispublic/

Paleobiology Database (search for fossil taxonomy, localities, or geologic formations): http://paleodb.org/cgi-bin/bridge.pl

Paleontology Portal (general fossil info based on geographic location or geologic time): http://www.paleoportal.org/

University of California-Berkeley Museum of Paleontology online paleontology exhibits: http://www.ucmp.berkeley.edu/

U.S. Geological Survey, description of physiographic provinces: http://tapestry.usgs.gov/Default.html

AMISTAD NATIONAL RECREATION AREA

Amistad National Recreation Area (AMIS) was authorized on November 28, 1990 to *"….provide for public outdoor recreation use and enjoyment of the lands and waters associated with the United States portion of the reservoir known as Lake Amistad, located on the boundary between the United States and Mexico; and protect the scenic, scientific, cultural and other value contributing to the public enjoyment of such lands and waters…."*. The Amistad Reservoir on the Rio Grande River was created through the construction of the Amistad Dam in 1969. The recreation area has been managed through a cooperative agreement with the International Boundary and Water Commission since November 1965. AMIS is located at a convergence of the Chihuahuan Desert, the Edwards Plateau Savannah, and the Tamaulipan Mezquital Ecoregions. Riparian, shoreline, inundation zone and upland desert ecosystems support terrestrial species diversity. Aquatic species occur in the lake and sections of the Devils, Rio Grande, and Pecos Rivers.

Paleontological resources are abundant in southwest Texas and Amistad NRA is no exception. Fossiliferous rocks consist mostly of clays and limestones from the Upper and Lower Cretaceous; however, archeological excavations of local rock shelters often yield Quaternary fauna and flora. Stratigraphic units exposed inside the park include the Salmon Peak Limestone, Devils River Limestone, Del Rio Clay, Buda Limestone, and Boquillas Formation. Fossils reported from other units in the vicinity such as the Eagle Ford Group and Austin Chalk are additionally reviewed as part of this investigation. Though Cretaceous sections inside Amistad National Recreation Area are rich in ancient marine invertebrates, limited records exist for fossils found on National Park Service land.

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

Geological scoping sessions, sponsored by the NPS Geologic Resources Division, were not yet conducted for Amistad National Recreation Area. Similarly, until 2006, there has been little focus on paleontological resources at AMIS. Jones (1993) is one of the first investigators to assess the fossils resources within the recreation area. Geologic cores obtained by the International Boundary and Water Commission (IBWC) may be taken from localities within the current boundary of Amistad NRA. The cores include sections from the Salmon Peak Limestone which contain microfossils, brachiopods, clams, echinoids, and ichnofossils. Reports by Humphreys (1984ab), Zahm et al. (1995ab), Kerans et al. (1995), Kerans (2002), and Scott (2002ab) may reference fossiliferous localities of Salmon Peak Limestone and Devil's River Limestone from within the boundaries of AMIS. Additionally, fossils are reported in a number of geologic road guides including: Smith and Brown (1983), Webster and Bolden (1983, 1984), Smith et al. (1984), and Spearing (1991).

In response to a technical assistance request to establish baseline paleontological resource data and to formally document paleontological localities at Amistad NRA, paleontology intern Christy Visaggi visited the area for three weeks in March 2006. Field work conducted by Visaggi covered 24 in-park localities, 8 Val Verde County road-cuts, and 2 neighboring sites managed by the Shumla School (Visaggi 2006). During January 2007 paleontological resources at Seminole Canyon State Park and Historic Site and a new in-park locality were evaluated. Information obtained through this research that shall be incorporated into a wayside exhibit which focuses on the geology and fossils of AMIS. Fossils derived from Cretaceous units were the focus of all field studies as Quaternary specimens are heavily documented as a result of archaeological salvage operations prior to the formation of the reservoir.

The most common fossils at Amistad NRA are large rudist bivalves, *Nerinea* snails, and *Ilymatogyra arietina* oysters. Fragmentary echinoids, ammonoids, scallops, and burrows created by worms and crustaceans are also frequently found. Microfossils may include forams, bryozoans, ostracodes, and algae based on previous work in and around the park. Several fossils specimens collected inside park boundaries by Visaggi are now accessioned in the AMIS collections and records for pre-existing fossils housed at the park are updated.

Six particularly significant park areas are in the process of being registered as official NPS localities offering the potential for heightened protection and preservation of *in situ* fossils. Though current park programs mainly focus on cultural resources, much potential exists for increased opportunities in management and interpretation of paleontological resources. Documentation of localities and improved fossil identification resulting from March 2006 research as well as a shared interest in developing educational programs through the Shumla School impart a strong basis for the future of paleontology at Amistad National Recreation Area (Visaggi 2006).

Devils River Limestone (Lower Cretaceous)
The grand cliffs that bound the Pecos River in the vicinity of AMIS are composed of Lower Cretaceous Devils River Limestone (Barnes 1977). This unit extends east from western Texas in a band along the Rio Grande until the Pecos River (Smith et al. 2000), upon which exist some of the most complete exposures of Lower Cretaceous rock in North America (Kerans et al. 1995). Smith and Brown (1983) report on fossil mollusks and ichnofossils from a locality on the Pecos River within the boundaries of AMIS. Patches of this locally dolomitized limestone may outcrop on the Rio Grande near the farthest edge of the park; however, cliffs along the water between Langtry and the Pecos River junction are more prominent (Barnes 1977). These massive layers contain a variety of fossils including ammonites (Young 1961, 1979, Scott 2002b), rudist bivalves (Coogan 1973, Miller 1984, Kerans and Zahm 1998, Kerans and Loucks 2002, Scott 2002b), oysters (Kerans and Loucks 2002), corals (Kerans and Zahm 1998, Johnson 2001) and miliolid benthic forams (Kerans and Zahm 1998, Johnson 2001, Scott 2002b). Coogan (1973) reports on the rudist genera *Kimbleia, Eoradiolites, Mexicaprina,* and *Texicaprina* from the Pecos River crossing with route 90. The faunal composition of the Devils River Limestone varies up section as sediment deposition changed from mud-dominated to grain-dominated environments (Kerans and Zahm 1998). Sequence stratigraphic analyses reveal differences in substrate, oxygen, light, and nutrients allowed for development of unique communities on this carbonate platform (Kerans and Zahm 1998, Scott 2002b).

The most interesting fossils are rudistid reef-builders quite distinct from the coral reefs of our modern oceans and in fact paleoecological research questioning the role of rudists and scleractinian corals in shallow warm-water reefs of the Mesozoic considers fossils from the Devils River Limestone (Johnson 2001). Rudists are an extinct group of anomalously large bivalves that existed exclusively during the Late Jurassic and Cretaceous. Though the mass extinction at the K-T boundary is renowned for the fall of the dinosaurs, reefs composed of these odd-shaped bivalves also disappeared.

Lower Cretaceous units encompassed by Amistad National Recreation Area contain abundant and diverse rudist bivalves. Exposures of the Devils River Limestone along the Pecos River exhibit a range of reef development from hydrodynamic accumulations to isolated mounds that can reach up to 15 ft. in height (Kerans 2002). Four genera of rudists from the upper Albian of North America include *Caprinuloidea, Kimbleia, Mexicaprina,* and *Texicaprina* (Scott 1990), of which some specimens are observed at the mouth of Painted Canyon and Lewis Canyon along the Pecos River (Scott 2002a). Though the Devils River Limestone is undivided and restricted to the Maverick Basin (Lozo and Smith 1964), other units such as the Salmon Peak Limestone are in part laterally equivalent and contain an array of these peculiar rudists as well (Barnes 1977).

Salmon Peak Limestone (Lower Cretaceous)
The Lower Cretaceous Salmon Peak Limestone is the most accessible fossiliferous unit at Amistad National Recreation Area. Exposures along the Devils River and encircling the main reservoir area are almost entirely composed of this variably shelly lime mudstone (Barnes 1977). The Salmon Peak appears to be a poorly cyclic, fairly homogenous unit (Hovorka 1996a, 1996b); however, sequence stratigraphic analyses of a core retrieved near Del Rio by the International Boundary and Water Commission indicate that these hemipelagic intrashelf basin deposits can be subdivided into five lithofacies (Zahm et al. 1995a, 1995b, Zahm 1997).

Though it may seem that few publications comment on Salmon Peak fossils, previous names for this unit are numerous. Spearing (1991) informally categorized Lower Cretaceous rocks in the vicinity of Del Rio

as the Santa Elena Limestone based upon lithological similarities to canyons at Big Bend National Park. Most early publications, however, regard these same Lower Cretaceous units as the Georgetown Limestone instead (e.g., Freeman 1964ab). Though Lozo and Smith (1964) replaced this name in southwestern Texas, rocks of this age in other parts of the state are still referred to as the Georgetown Limestone.

The most commonly reported fossils are caprinid rudists, forams, and ichnofossils. Planktonic forams comprise *Hedbergella delrioensis, Hedbergella planispira,* and *Favusella wachitensis* (Zahm et al. 1995b). Benthic genera primarily consist of *Lagena, Haplophragmoides, Gavelinella, Lenticulina, Ammodiscus,* and *Sprioplectamina,* whereby changes in faunal composition reflect fluctuations in bottom water oxygen. Ichnofossils likely created by worms include *Skolithos* and *Planolites; Thalassinoides* encompasses crustacean-derived burrows (Zahm et al. 1995b). Rudist bivalves are also mentioned by Zahm et al. (1995b) in descriptions of the Stuart City Reef, a high energy shelf-margin facies that is in part equivalent to the Devils River and Salmon Peak. Fossils described from the Salmon Peak Limestone exposed at Amistad Dam comprise forams, calcispheres, echinoids, brachiopods, and burrows (Humphreys 1984a, 1984b, Smith and Brown 1983). Caprinid rudists, shell fragments, and *Globigerina* forams are noted in the vicinity of Amistad National Recreation Area by Barnes (1977). Though it may seem that few publications comment on Salmon Peak fossils, previous names for this unit are numerous and include the Georgetown Limestone as replaced by Lozo and Smith (1964).

Del Rio Clay (Upper Cretaceous)
The Del Rio Clay of the Upper Cretaceous is easily recognized by the abundance of *Ilymatogyra arietina* (Roemer 1849, Offeman et al. 1982). This oyster, previously classified in the genus *Exogyra* by Boese (1919) and many others, is commonly referred to as the "Devil's Toenail" due to its characteristic curled shell. Though this occasionally pyritiferous unit is mapped in a number of areas at AMIS including the southern edge of Spur 406, northeast of the Rt. 277 bridge, Windmill Canyon, San Pedro Campground, and Castle Canyon, exposures are not common as are scattered rock fragments along the shoreline. This calcareous and gypsiferous deposit may also outcrop along the Rio Grande northwest of Cow Creek as well as around the Zuberbueler Bend, since much of the area is mapped as undivided Del Rio Clay and Buda Limestone (Barnes 1977).

Other than the prevalent *Ilymatogyra arietina*, ammonites (Kennedy et al. 2005), gastropods (Maddocks 1988), ostracodes (Maddocks 1988), decapods (Richardson 1955), and echinoids (Richardson 1955) are documented in the Del Rio Clay throughout Texas. Microfossils include coccolithophores (Hill 1975) and foraminifera (Loeblich and Tappan 1946, Bullard 1951, Maudlin 1985); ichnofossils are additionally reported (Udden 1908). Prior to the naming of the Del Rio Clay in southwest Texas, stratigraphers classified this unit as the Grayson Formation from north-central Texas. The Grayson does not correlate unequivocally to the Del Rio, however, as part of the overlying Buda Limestone is likely incorporated (Stephenson 1944). Nonetheless, fossils of the Grayson merit acknowledgement in their relation to the Del Rio Clay. Macrofauna encompass sponges, corals, bryozoans, bivalves, gastropods, nautiloids, ammonoids, belemnoids, asteroids, echinoids, crinoids, annelids, and an assortment of fish as summarized by Mancini (1982a). One particularly interesting note about bryozoans in the Grayson is the appearance of avicularia cheliostome structures, a major change in morphology from ordinary feeding zooids (Cheetham et al. 2006).

Other microfossils consist of ostracodes and an array of forams (Mancini 1978a, 1978b) that change in composition throughout the formation. Deposits in north-central Texas produced 27 different cephalopods (Mancini 1982a) and exposures extending into Oklahoma generated 90 foraminifera species (Tappan 1939). Previous analyses by Tappan (1940) suggest that these forams are Albian in age; however, both the Del Rio and Grayson are now considered Cenomanian. Forams of the Grayson are additionally described by Loeblich and Tappan (1946) and Albritton et al. (1954). Further information on biostratigraphic zonation and paleoecology of the Grayson Formation can be found in Mancini (1979a) and Aepli (1989).

The Grayson Formation is most renowned for its "dwarfed" fauna exhibited in oysters, ammonites, and crinoids among several other taxonomic groups (e.g., Pampe 1979). Early descriptions by Scott (1924) noted the presence of small ammonoids in the Grayson. He initially thought individuals were stunted due to anaerobic conditions, but later regarded shells as merely small species or the preserved inner whorls of larger specimens (Scott 1940a). Kummel (1948) advocated that excessive amounts of iron might be the cause of stunted growth, but Mancini (1978b) disputes this notion as foraminiferal evidence suggests the presence of a normal marine paleoenvironment instead. Mancini (1977) comments that the ubiquitous oyster of the Del Rio Clay, *Ilymatogyra arietina*, is paedomorphic in the Grayson, in that they develop mature ornamentation at an earlier stage in life. He postulates that reduced size is a modification for softer substrates as individuals recovered from southwestern Texas are of normal size having lived upon firmer substrates in a nearshore environment (Mancini 1975, 1977). More on the adaptation of such fauna on soft sediments is described at length by Mancini (1978c). This substrate hypothesis is in part supported by Willis (1997) based on echinoderms of normal size, diminutive cephalopods, gastropods, scaphopods, and bivalves, as well as the presence of *Chondrites* ichnofossils in McLennan County.

Buda Limestone (Upper Cretaceous)
This Upper Cretaceous fine-grained limestone is commonly glauconitic and pyritiferous in the vicinity of Amistad National Recreation Area (Barnes 1977). The Buda is mapped on the western shore of the Devils River outlet, along the water past Langtry, southwest of Cow Creek, and at Long Point among other localities around San Pedro Canyon. Other park areas that may contain outcrops of this highly fossiliferous unit include the Zuberbueler Bend and northwest of Cow Creek on the Rio Grande since shorelines are mapped as undivided Del Rio Clay and Buda Limestone.

Though the Buda is paleontologically significant in and around Amistad NRA, reports of fossils from this unit are largely based on deposits in northeastern and central Texas. Faunal assemblages consist of calcareous algae, corals, bryozoans, bivalves, gastropods, ammonites, echinoids, and Thalassinoidean burrows (Stephenson 1944, Reaser and Dawson 1995a, 1995b). Diverse cephalopods are noted by Archer (1936), Hook and Cobban (1983), Young (1962), and Kennedy et al. (2005) throughout Texas and Mexico. Stromatoporoids (Schmidt Murphy 1991), calcisponges (Wells 1934), and *Microsolena* corals (Wells 1944) are additionally documented. *Gastrochaena* bivalve borings and hexacoral encrustations indicate an ephemeral presence of hard substrates in an otherwise shallow shelf environment (Reaser and Dawson 1995b). Elsewhere Buda Limestone is described as a biomicrite that varies from a mollusk-echinoderm bearing unit to a deposit dominated largely by corals and bryozoans (Reaser and Dawson 1995a, 1995b). Sections near Del Rio (Trevino 1988, Trevino and Smith 2002) are more often composed of benthic communities in a bioturbated wackestone. Future paleontological finds in the Buda at Amistad National Recreation Area are most expected in exposures off the old road leading up to the Rt. 277 S bridge that now serves as a boat launch to the reservoir.

Boquillas Formation (Upper Cretaceous)
The flaggy structure of the Boquillas Formation makes it the most recognizable rock unit of the Cretaceous in southwestern Texas. The deposit is prominently exposed at higher cliff faces along the reservoir near the Zuberbueler Bend, but these sections are inaccessible and in all likelihood extend beyond park boundaries (Barnes 1977). Small pockets of Boquillas flagstone may be found inside the park in other areas such as the southern highway crossing of Evans Creek, northwest of the fork at Cow Creek, and slightly inland of shorelines surrounding Langtry; however, outcrops in these locations are doubtful and likely not accessible if exposed (Barnes 1977). Nonetheless, rocks of the Boquillas Formation are described below as they are geologically and paleontologically significant in the vicinity of Amistad National Recreation Area.

Local stratigraphically important fossils comprise ammonites and Inoceramids as documented by Freeman (1961) in Terrell and Val Verde counties. Sections near Del Rio examined by Trevino (1988) and Trevino and Smith (2002) contain burrows, forams, calcispheres, echinoids, ammonites, and Inoceramids useful for paleoenvironmental interpretation. The contact of the Boquillas and the underlying Buda Formation at these exposures are additionally useful for sequence stratigraphic studies (Trevino 1988,

Trevino and Smith 2002). Numerous publications comment on fossils of the Boquillas in areas surrounding Big Bend National Park including a unique morphological analysis of Inoceramid clusters by Ashmore et al. (1997) and research involving transatlantic ammonite migration by Young (1984). Other reports of fauna from this formation encompass vertebrates (Cicimurri and Bell 1996, Bell 2002, Bell and Von Loh 1998), cephalopods (Young 1958, Freeman 1961, Powell 1967, Hook and Cobban 1983, Young 1984, Cobban 1988, Kennedy and Cobban 1993), bivalves (Cobban and Hook 1980, Kennedy and Cobban 1993), and various microfossils (Huffman 1960, Frush and Eicher 1975, Graham 1995, Graham 1997).

One final note about the Boquillas Formation is the presence of tepee structures observed in outcrops near Del Rio (Lock and Choh 1997, Lock et al. 2001). These sharp anticlines have been historically interpreted as tidal flat features; however, modern studies indicate that these angular structures are related to Quaternary surface caliche deposits instead. They reflect an upward displacement of laterally confined rock that expands in response to the formation of secondary calcium carbonate called caliche (Lock and Choh 1997, Lock et al. 2001). Road cuts of the Boquillas located a few miles south of the intersection of Spur 406 exhibit such structures and are the most accessible exposures for paleontological observations of this flagstone unit proximal to Amistad NRA.

Eagle Ford Group (Upper Cretaceous)
Facies of the Boquillas gradually change to that of the Eagle Ford Group moving east across the Devils River (Barnes 1977). Only small patches of this unit are mapped around San Pedro Canyon limiting the possibility for exposures inside park boundaries. However, much of the shale, siltstone, and limestone that comprise the numerous members of the Eagle Ford Group are regarded as extremely fossiliferous elsewhere in Texas and Mexico.

Microfossils consist mostly of pollen (Brown and Pierce 1962, Stone 1967, Christopher 1982), forams (Schell 1952, Jones 1960, Loeblich and Tappan 1961, McNulty 1964, Longoria 1973, Steinman 1974) and ostracodes (Crane 1965, Hazel 1969). Stratigraphic analyses that utilize microfauna include publications by Moreman (1927, 1942), Bostik (1960), and Pessago (1969). Other marine invertebrates recorded from this unit comprise coral (Perkins 1951) and crabs (Bishop 1989). Mollusks such as cephalopods (Moreman 1927, Scott 1940b, Moreman 1942, Stephenson 1955, Clark 1960, Powell 1963, Kennedy 1988), gastropods (Stephenson 1955), and bivalves (Moreman 1942, Stephenson 1955, Kauffman 1965, Cobban and Hook 1980, Friedman and Hunt 2004) are often recorded.

More evidence of mollusks in the Eagle Ford comes from the occurrence of fossil pearls (Friedman and Hunt 2004). Pearls are rarely preserved in the fossil record; however, abundant Inoceramid oysters during this part of the Cretaceous contributed to an increased availability of pearls for fossilization. Specimens vary in size from a diameter of 1 mm to 3 cm and range from perfect to irregularly shaped spheres of dark color and no luster (Friedman and Hunt 2004). The oldest pearls are documented as far back as the Triassic and pearls created by Inoceramids are not present after the late Cretaceous extinction of these large epifaunal bivalves. Fossil pearls discovered in the Eagle Ford are commonly associated or still attached to their oyster shells (Friedman and Hunt 2004). Though dominance of these bivalves already indicates benthic dysoxic conditions in the paleoenvironment, pearls can be utilized for paleoecological analyses instead. Marine vertebrates are reported by numerous authors including Bilelo (1969), Meyer (1988), and Friedman (2001b). Fish are most commonly documented (McNulty 1970, Gilette 1972, Fielitz and Bardack 1992, Grande and Bardack 1996, Friedman 2001a, Stewart and Friedman 2001, Fielitz and Cornett 2002, Friedman 2004), but sharks (Friedman 2001a, Hamm 2003), mosasaurs (Bell and Polcyn 1995, Polcyn and Bell 1996), plesiosaurs (Welles and Slaughter 1963, Friedman 2001a, Friedman 2004), elasmosaurs (Welles 1949, Shuler 1950), lizards (Bell et al. 1982, Friedman 2004), and turtles (Friedman 2001a, Friedman 2004) are additionally recorded. Vertebrates are also known in the form of abundant bone-bearing coprolites potentially useful for paleoecological and biostratigraphic analyses (Friedman 2001a, Friedman 2004). More unique finds include pterosaurs and crocodiles among other marine fauna noted by Schneider and Ruez (2001). Although the Eagle Ford Group is highly fossiliferous, future paleontological discoveries from this unit at Amistad National Recreation Area are improbable.

Austin Chalk (Upper Cretaceous)
The Austin Chalk is the uppermost Cretaceous section mapped in the vicinity of AMIS. Though exposures of this grayish-white unit are not likely found inside park boundaries, areas near Langtry and a small patch of land adjacent to the southern highway crossing of Evans Creek indicate potential for local fossil discoveries (Barnes 1977). Deposition of this unit occurred during maximum flooding on the craton (Hovorka 1996b) allowing for more offshore species to be preserved than in lower stratigraphic layers. Austin Chalk fauna documented by Freeman (1961) from Terrell and Val Verde counties near the junction of the Rio Grande and the Pecos River encompass ammonites and Inoceramids useful for biostratigraphic correlation. Macrofossils reported elsewhere in Texas include sharks (Bilelo 1969, Bowman 1971), protostegid turtles (McNulty and Slaughter 1964), a variety of fish (Price 1931, Springer 1957, Bardack 1965, Bardack 1968, Willimon 1973, Fielitz and Cornett 2002), ophiuroids (Clark 1959), free-floating crinoids (Marks 1952), brachiopods (Marks 1952, Young and Marks 1952), ammonites (Young and Marks 1952, Clark 1960, Young 1963), and large bivalves (Stephenson 1929, Marks 1952, Young and Marks 1952). Microfauna encompass ostracodes (Crane 1965), isopods (Bowman 1971), and forams (Grice 1948, Young and Marks 1952, Gimbrede 1962, McNulty 1964, Clark and Bird 1966) occasionally preserved in algal reefs (Johnson 1944). Ostracodes described by Maddocks (1988) additionally contain signs of gastropod predation. Though the probability of finding microfossils in the Austin at Amistad NRA is minimal, Bostik (1960) documented countless specimens from this unit in Big Bend National Park. The most accessible exposures of this deposit in Val Verde County are highway road-cuts several miles west of Langtry on Rt. 90.

Quaternary (Pleistocene/Holocene)
Paleontological resources found in rock shelters of the Pleistocene and Holocene are abundant in the vicinity of Amistad National Recreation Area. Caves carved out of Cretaceous limestone contain not only marine fossils, but sometimes additionally preserve Quaternary fauna and flora. Most of these specimens are catalogued in the archaeological collections at Amistad NRA as recovered during operations conducted by the Texas Archaeological Salvage Project prior to construction of the Amistad Dam. Since reservoir completion might endanger or completely inundate valuable archaeological sites, actions to extensively document resources at risk for flooding were put into effect.

Santucci and others (2001) review of paleontological resources associated with National Park Service caves included sites in Amistad National Recreation Area. Vertebrate remains have also been reported from archeological sites within Amistad NRA (Raun and Eck 1967). Cueva Quebrada and Conejo Shelter are two caves located outside of Amistad National Recreation Area; however, fossils from these localities are managed by the NPS. Cueva Quebrada is a small cave measuring approximately 30 feet (9 meters) by 15 feet (5 meters) located on the north side of a small tributary canyon of the Rio Grande. Cueva Quebrada is immediately east of the larger Conejo Shelter, which has been the focus of archeological excavations (Alexander 1974). A number of stratigraphic layers have been identified within Cueva Quebrada. Layer I, the surface of the cave, consists of a white limestone dust with no bones or archeological artifacts. Layers II through IV are made up of brown and gray limestone dust, receiving its coloration from the varying amounts of charcoal in the dust. Layer V is similar to the above layers, but has a light yellow color. Faunal remains are found in layers II through IV.

A wide variety of taxa have been described from within Cueva Quebrada. The described taxa include an unidentifiable chiropteran, *Spilogale* sp. (spotted skunk), *Mephitis mephitis* (striped skunk), *Canis* sp. (dog), *Urocyon cinereoargenteus* (gray fox), *Bassariscus* cf. *astutus* (ringtail cat), *Arctodus simus* (short-faced bear), *Ammospermophilus interpres* (Texas antelope squirrel), *Thomomys bottae* (Botta's pocket gopher), *Pappogeomys castanops* (Mexican pocket gopher), *Perognathus* sp. (pocket mice), *Baiomys taylori* (northern pygmy mouse), *Onychomys leucogaster* (northern grasshopper mouse), *Peromyscus* sp. (deer mice), *Neotoma* sp. (packrats), *Sylvilagus* sp. (cottontails), *Lepus* cf. *californicus* (black-tailed jackrabbit), *Equus* cf. *scotti* (horse), *Equus francisci* (horse), cf. *Camelops* (camel), *Navajoceros fricki* (American mountain deer), *Stockoceros* sp. (antelope), and *Bison* sp (bison). (Lundelius 1984). Lundelius (1984) reports three radiocarbon dates (one from charcoal and two from wood) from layers yielding bone

fragments. The dates yielded from the samples were 12,280 years B.P., 13,920 years B.P. and 14,300 years B.P., indicating a Late Pleistocene assemblage. The fauna exhibits an interesting taphonomy. Much of the bone is burned, often to such a degree as to remove all organic material and in some cases plastically distorting the bone (Lundelius 1984). This burning of the material seems to indicate human activity in the cave, although evidence of butchering and fire pits is not prevalent (Lundelius 1984).

One of the most renowned caves in the vicinity of AMIS is Bonfire Shelter (41VV218) located approximately 15 miles upstream from the confluence of the Pecos River and the Rio Grande in Mile Canyon. This significant archeological site contains several layers of faunal and floral material that has implications for how people of the lower Pecos hunted for bison. Bone deposits containing fragments of hundreds of bison individuals suggest that hunting at this site benefited from the "jump" method, whereby humans drove bison herds off of the overhanging cliff above Bonfire Shelter (Dibble and Lorrain 1968). Charred bone, projectile points, and other cultural remains indicate how lower Pecos people repeatedly utilized this cave for bison kills. Samples of pollen analyzed from this site by Bryant (1977) signify changes in climate throughout the Quaternary that may be useful in understanding the availability of bison in the region. Bison species considered from Bonfire Shelter include *Bison bison, Bison antiquus*, and *Bison occidentalis*, although some controversy exists regarding this interpretation (Dibble and Lorrain 1968). Other fauna recovered include: horse, camel, proboscidean, deer, rabbit, squirrel, fox, gopher, mouse, rat, bat, snake, and fish (Dibble and Lorrain 1968). Pollen from the site supports the early presence of pine woodland that eventually progressed into an increasingly arid Chihuahuan Desert (Bryant 1977).

Arenosa Shelter (41VV99) is another locality excavated in part by the National Park Service. The site is now inundated by the Amistad Reservoir. Jurgens (2005) analyzed faunal remains unearthed in the 1960s including an assemblage of fish, frog, turtle, snake, bird, rabbit, squirrel, coyote, deer, bovine, and horse species. The NPS fossils are held in the TARL collections at the University of Texas at Austin. Additional rock shelters in the vicinity of AMIS have been surveyed by Raun and Eck (1967) for TASP include: Mosquito Cave (41VV215), Zopilote Cave (41VV216), Eagle Cave (41VV167), Devil's Mouth (41VV188), Devil's Rockshelter (41VV264), Coontail Spin (41VV82), and Castle Canyon (41VV7). Mosquito Cave, Devil's Rockshelter, and Castle Canyon were not analyzed in depth due to lack of bones or uncertain provenience, but Cheatum reports numerous molluscan species from Devil's Rockshelter (Story and Bryant 1966). The other four localities contained mostly varying concentrations of fish, turtle, rabbit, and deer remains. Small rodents likely persisted in these areas during the Holocene as well; however, large sieves often utilized at these sites did not retain their remains. Nonetheless, Cheatam documents abundant mollusks at Eagle Cave and Devil's Mouth (Story and Bryant 1966). Fauna recovered from Coontail Spin had the highest density and included some additional taxa: muskrat, beaver, porcupine, dog, coyote, and fox. Other interesting specimens such as the Mexican Ground Squirrel, pocket gopher, skunk, and bison are noted from Eagle Cave. Devil's Mouth also preserved evidence of gopher occupation. Most taxa observed at these rock shelters are still locally extant; however, slight faunal differences suggest increased aridity and erosion throughout the Quaternary (Raun and Eck 1967).

Changes in the environment are moreover supported by pollen analyses initiated by Johnson (1959, 1963) from Centipede Cave (41VV191) and Damp Cave (41VV189) at Amistad National Recreation Area. Palynological specimens indicate the presence of *Agave, Ephedra, Quercus, Prosopis, Pinus,* and *Celtis* among other flora in the region represented by families including: Cactaceae, Chenopodiaceae, Compositae, Cupresaceae, Gramineae, Liliaceae, and Malvaceae (Johnson 1959, 1963). Animal bones, shells, fragmentary plants, and cultural artifacts are also documented from these localities. Vegetation changes in the Late Quaternary are later observed b Bryant and Larson (1968) based on a similar collection of pollen samples from Devil's Mouth. Although many of these early studies focused on understanding regional floral composition, subsequent analyses examined pollen from human coprolites for dietary reasons. Coprolites from Hinds (41VV456) inspected by William-Dean (1978) contained zoophilous pollen (dispersed by insects, birds, and bats) and anemophilous pollen (dispersed by wind). Fruit, seeds, and bone comprised macrofossils found in coprolites. Supplemental investigations of older coprolites at Hinds Cave by Stock (1983) report similar floral and faunal dietary components. Research

conducted by Sobolik (1989) at Baker Cave (41VV213) found common plants to belong to the mustard family, sotol, sunflowers, sagebrush, and grass. Bryant (1968) presents further discussion on Late Quaternary changes in vegetation revealed in part through palynological analysis.

Other paleontological resources found in Quaternary settings include fire-cracked rock (FCR). These colorful red rocks thermally altered are often uncovered in archeological localities referred to as burned rock middens (BRM). Most FCR contains abundant molluscan remains from local Cretaceous deposits; it seems that fossiliferous rocks were preferentially used in hearth features. Labadie (2004) reports the reason for this selection (as postulated by Dr. Don Lewis in 1995) might be that fossil-bearing rocks are less explosive at high temperatures compared to non-fossiliferous limestone based on composition. Since the majority of fire-cracked rock is a result of exposure to extreme heat conditions necessary for cooking activities, it would no doubt be advantageous for people of the Lower Pecos to utilize the less explosive fossiliferous rock at the hearth instead.

Paleontological resources are plentiful in Quaternary deposits surrounding Amistad NRA. Fire-cracked rock, mammalian bones, and plant fragments are the most common finds. Though construction of the Amistad Dam caused complete inundation of some localities (e.g., Arenosa Shelter and Devil's Mouth), paleontological specimens recovered during salvage operations are now protected by the National Park Service. More information on the hundreds of archeological sites in the AMIS vicinity is documented in an assessment completed by Anderson (1974). This publication may not focus on fossils uncovered at these localities; however, it does provide brief summaries of research involving both archeological and paleontological resources.

Finally, a number of additional Quaternary deposits may yield fossils in the future. These include the Uvalde Gravel, a Tertiary fluviate terrace deposits, and other alluvium which are mapped within the park boundaries.

REFERENCES CITED

Aepli, D.B. 1989. Biostratigraphy and paleoecology of the Grayson Formation, McLennan County, central Texas. Baylor University, Waco, TX. Bachelor's Thesis.

Albritton, C.C., Jr., J.R. Puryear, and W.W. Schell. 1954. Foraminiferal populations in the Grayson marl [Texas]. Geological Society of America Bulletin 65(4):327-336.

Alexander, R.K. 1974. The archeology of Conejo Shelter: A study of cultural stability at an achaic rockshelter site in southwestern Texas. Ph.D. Dissertation, University of Texas, Austin.

Anderson, B.A. 1974. An archeological assessment of Amistad Recreation Area Texas. Division of Archeology, National Park Service, Southwest Region, 59 p.

Archer, K. 1936. Some Cephalopoda from the Buda Limestone. University of Texas at Austin, Austin, TX. Master's Thesis.

Ashmore, R.A., J.B. Stevens, D.A. Reed, and M.S. Stevens. 1997. Possible-different uses of giant inoceramid clustering, middle to upper Boquillas Formation, Big Bend region, Trans-Pecos, Texas. Geological Society of America Abstracts with Programs 29(2):2.

Bardack, D. 1965. New Upper Cretaceous teleost fish from Texas. Kansas University Paleontological Contributions Paper 1. 9 pages.

Bardack, D. 1968. *Belonostomus sp.,* the first holostean from the Austin Chalk (Cretaceous) of Texas. Journal of Paleontology 42(5):1307-1309.

Barnes, V.E. 1977. Del Rio Sheet. Geologic Atlas of Texas. University of Texas Bureau of Economic Geology, Austin, TX. 1:250,000 scale map.

Bell, B.A., P.A. Murray, and L. W. Osten. 1982. *Coniasaurus* Owen 1850, from North America. Journal of Paleontology 56(2):520-524.

Bell, G.L., Jr. 2002. The questionable monophyly of Mosasauridae. Society of Vertebrate Paleontology Abstracts 22(3):35A.

Bell, G.L., Jr. and M.J. Polcyn. 1995. A new basal mosasauroid from the Arcadia Park Member of the Eagle Ford Shale (late middle Turonian) near Dallas, Texas.

Bell, G.L., Jr. and J.P. Von Loh 1998. New records of Turonian mosasauroids from the western United States. In Martin, J.E., J.W. Hoganson and R.C. Benton (eds.), Partners Preserving Our Past, Planning our Future: Proceedings for the Fifth Conference on Fossil Resources, Dakoterra 5: 15-28.

Bilelo, M.A.M. 1969. The fossil shark genus *Squalicorax* in north-central Texas. The Texas Journal of Science 20(4):339-348.

Bishop, G.A. 1989. Cretaceous-Tertiary decapod faunas of the Southwest. Geological Society of America Abstracts with Programs 21(1):3-4.

Boese, E. 1919. On a new *Exogyra* from the Del Rio Clay and some observations on the evolution of *Exogyra* in the Texas Cretaceous. University of Texas Bulletin 1902. 22 pages.

Bostik, W.C. 1960. Micropaleontology of the upper Eagle Ford and lower Austin groups, Big Bend National Park, Texas. Texas Tech University, Lubbock, TX. Master's Thesis. 131 pages.

Bowman, T.E. 1971. *Palaega lamnae*, new species (Crustacea; Isopoda) from the upper Cretaceous of Texas. Journal of Paleontology 45(3):540-541.

Brown, C.W. and R.L. Pierce. 1962. Palynologic correlations in Cretaceous Eagle Ford Group, northeast Texas. Bulletin of the American Association of Petroleum Geologists 41(12):2133-2147.

Bryant, V.M., Jr. 1968. Late Quaternary vegetation and climate in the Amistad Reservoir area of southwest Texas. Geological Society of America Special Paper 115:366-367.

Bryant, V.M., Jr. 1977. Late Quaternary pollen records from the east-central periphery of the Chihuahuan Desert. Pages 3-21 *in* R. H. Wauer and D. H. Riskind, editors. Transactions of the Symposium on the biological resources of the Chihuahuan Desert region, United States and Mexico. U.S. National Park Service, Washington, DC. Transactions and Proceedings Series 3.

Bryant, V.M., Jr., and D.A. Larson. 1968. Pollen analysis of the Devil's Mouth site, Val Verde County, TX. Papers of the Texas Archeological Salvage Project 14:57-70.

Bullard, F.J. 1951. Microfauna of the Del Rio Formation (Lower Cretaceous) of central Texas. University of Texas at Austin, Austin, TX. Master's Thesis.

Cheetham, A.H., J. Sanner, P.D. Taylor, A.N. Ostrovsky. 2006. Morphological differentiation of avicularia and the proliferation of species in Mid-Cretaceous *Wilbertopora* Cheetham, 1954 (Bryozoa, Cheilostomata). Journal of Paleontology 80(1):49-71.

Christopher, R.A. 1982. The occurrence of the *Complexiopollis-Atlantopollis* Zone (palynomorphs) in the Eagle Ford Group (Upper Cretaceous) of Texas. Journal of Paleontology 52(2):525-541.

Cicimurri, D.J. and G.L. Bell, Jr. 1996. Vertebrate fauna of the Boquillas Formation of Brewster County, Texas; a preliminary report. Society of Vertebrate Paleontology Abstracts 16(3):28.

Clark, D.L. 1959. Texas Cretaceous ophiuroids. Journal of Paleontology 33(6):1126-1127.

Clark, D.L. 1960. *Parapuzosia* in the north Texas Cretaceous. Journal of Paleontology 34(2):233-236.

Clark, D.L. and K.J. Bird. 1966. Foraminifera and paleoecology of the upper Austin and lower Taylor (Cretaceous) strata in north Texas. Journal of Paleontology 40(2):315-327.

Cobban, W.A. 1988. *Tarrantoceras* Stephenson and related ammonoid genera from Cenomanian (Upper Cretaceous) rocks in Texas and the Western Interior of the United States, U. S. Geological Survey, Reston, VA. Professional Paper. 51 pages.

Cobban, W.A. and Hook, S.C. 1980. Occurrence of *Ostrea beloiti* Logan in Cenomanian rocks of Trans-Pecos Texas; southeastern New Mexico and West Texas. Pages 169-172 *in* P. W. Dickerson, J. M. Hoffer, and J. F. Callender, editors. New Mexico Geological Society Guidebook 31.

Coogan, A.H., 1973. New rudists from Albian and Cenomanian of Mexico and south Texas. Revista del Instituto Mexicano del Petroleo 5(2): 51-83.

Crane, M.J. 1965. Upper Cretaceous ostracodes of the Gulf Coast area. Micropaleontology 11(2):191-254.

Dibble, D.S. and D. Lorrain. 1968. Bonfire Shelter: a stratified bison kill site, Val Verde County, Texas. Texas Memorial Museum, University of Texas, Austin, TX. Miscellaneous Paper 1.

Fielitz, C. and D. Bardack. 1992. *Deltaichthys albuloides*, a new and unusually preserved albulid (Teleostei). Journal of Vertebrate Paleontology 12(2):133-141.

Fielitz, C. and B. Cornett. 2002. A new elopomorph fish from the Austin Chalk Formation of Fannin County, Texas. Society of Vertebrate Paleontology Abstracts 22(3):23.

Freeman, V.L. 1961. Contact of Boquillas Flags and Austin Chalk in Val Verde and Terrell counties, Texas. Bulletin of the American Association of Petroleum Geologists 45(1):105-107.

Freeman, V.L. 1964a. Geologic map of the Langtry Quadrangle, Val Verde County, Texas. U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-422, scale 1:62500.

Freeman, V.L. 1964b. Geologic map of the Shumla Quadrangle, Val Verde County, Texas. U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-424, scale 1:62500.

Friedman, V. 2001a. A new Upper Cretaceous (Cenomanian) fossiliferous locality in north central Texas. Geological Society of America Abstracts with Programs 33(5):54.

Friedman, V. 2001b. A new Upper Cretaceous (Cenomanian) fossiliferous locality in north central Texas. Proceedings of the North American Paleontological Convention 21(2):55.

Friedman, V. 2004. Paleontology, paleoecology and depositional environment of the lower Eagle Ford Group in north central Texas. University of Texas at Dallas, Richardson, Texas, 176 p.

Friedman, V. and A.P. Hunt. 2004. Fossil pearls from the Upper Cretaceous of Texas. Geological Society of America Abstracts with Programs 36(5):62.

Frush, M.P. and D.L. Eicher. 1975. Cenomanian and Turonian foraminifera and palaeoenvironments in the Big Bend region of Texas and Mexico. Geological Association of Canada Special Paper 13. Pages 277-301.

Gilette, D.D. 1972. Coelomic cavity casts of Upper Cretaceous fishes in Texas. Journal of Paleontology 46(1):50-54.

Gimbrede, L. de A. 1962. Evolution of the Cretaceous foraminifer *Kyphopyxa christneri* (Carsey). Journal of Paleontology 36(5):1121-1123.

Graham, J.M. 1995. Lithostratigraphy, microfacies and foraminiferal biostratigraphy of the Santonian-lower Campanian strata in the Trans-Pecos region, West Texas. University of Texas at Dallas, Richardson, TX. PhD Dissertation. 432 pages.

Graham, J.M. 1997. Planktonic foraminiferal biostratigraphy and depositional setting of the Santonian-lower Campanian (Upper Cretaceous) of the Trans-Pecos region, West Texas. Geological Society of America Abstracts with Programs 29(6):53.

Grande, T. and D. Bardack. 1996. A new elopomorph from the Eagle Ford Formation near Arlington, Texas. Society of Vertebrate Paleontology Abstracts 16(3):39.

Grice, C.R. 1948. *Manorella*, a new genus of foraminifera from Austin Chalk of Texas. Journal of Paleontology 22(2):222-224.

Hamm, S.A. 2003. Ptychodontid sharks in the Upper Cretaceous Eagleford Group of northern Texas. Society of Vertebrate Paleontology Abstracts 23(3):58-59.

Hazel, J.E. 1969. *Cythereis eaglefordensis* Alexander, 1929; a guide fossil for deposits of latest Cenomanian age in the Western Interior and Gulf Coast regions of the United States. U. S. Geological Survey, Reston, VA. Professional Paper 650. Pages D155-D158.

Hill, M.E. III. 1975. Selective dissolution of mid-Cretaceous (Cenomanian) calcareous nannofossils. Micropaleontology 21(2):227-235.

Hook, S.C. and Cobban, W.A. 1983. Mid-Cretaceous molluscan sequence at Gold Hill, Jeff Davis County, Texas, with comparison to New Mexico. Contributions to Mid-Cretaceous paleontology and stratigraphy of New Mexico Part II. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM. Circular 185:48-54.

Hovorka, S.D. 1996a. High-frequency cyclicity during eustatic sea-level rise; Edwards Group of the Balcones fault zone. Bulletin of the American Association of Petroleum Geologists 80(9):1504.

Hovorka, S.D. 1996b. High-frequency cyclicity during eustatic sea-level rise; Edwards Group of the Balcones fault zone. Gulf Coast Association of Geological Societies Transactions 46:179-184.

Huffman, M.E. 1960. Micropaleontology of lower portion of Boquillas Formation near Hot Springs, Big Bend National Park, Brewster County, Texas. Texas Tech University, Lubbock, TX. Master's Thesis. 54 pages.

Humphreys, C.H. 1984a. Stratigraphy and petrography of the Lower Cretaceous (Albian) Salmon Peak Formation of the Maverick Basin, South Texas. University of Texas at Arlington, Arlington, TX. Master's Thesis. 138 pages.

Humphreys, C.H. 1984b. Stratigraphy of the Lower Cretaceous (Albian) Salmon Peak Formation of the Maverick Basin, South Texas. Pages 34-59 *in* C. I. Smith, editor. Stratigraphy and structure of the Maverick Basin and Devils River Trend, Lower Cretaceous, Southwest Texas; a field guide and related papers. San Antonio Geological Society, San Antonio, TX.

Johnson, C.C. 2001. Taxonomic and morphologic changes in corals and rudists from Aptian and Albian strata, Texas and Puerto Rico. Geological Society of America Abstracts with Programs 33(6):13.

Johnson, J.H. 1944. Algal reefs in Cretaceous Austin Chalk of Terlingua District, Brewster County, Texas. Bulletin of the American Association of Petroleum Geologists 28(1):123-124.

Johnson, L., Jr. 1959. Palynology at Diablo Reservoir, Part I: Analysis of Sites 41VV189 and 41VV191. Report submitted to the National Park Service by the Division of Research in Anthropology. University of Texas at Austin, Austin, TX.

Johnson, L., Jr. 1963. Pollen analysis of two archeological sites at Amistad Reservoir, Texas. The Texas Journal of Science 15(2):225-230.

Jones, J.I. 1960. The significance of variability in *Praeglobotruncana gautierensis* (Broenniman), 1952, from the Cretaceous Eagle Ford group of Texas. Contributions to the Cushman Foundation for Foraminiferal Research 11:89-103.

Jones, J.O. 1993. Amistad National Recreation Area: Stratigraphy and Paleontology. In V.L. Santucci (ed.), National Park Service Paleontological Research Abstract Volume 1; National Park Service Technical Report NPS/NRPEFO/NRTR-93-11, p. 3.

Jurgens, C.J. 2005. Zooarcheology and bone technology from Arenosa Shelter (41VV99), Lower Pecos region, Texas. University of Texas at Austin, Austin, TX. PhD Dissertation, 688 p.

Kauffman, E.G. 1965. Middle and Late Turonian oysters of the *Lopha lugubris* group. Smithsonian Miscellaneous Collections 148(6):1-92.

Kennedy, W.J. 1988. Late Cenomanian and Turonian ammonite faunas from North-east and central Texas. Special Papers in Paleontology 39. 131 pages.

Kennedy, W.J. and W.A. Cobban. 1993. Lower Cenomanian *Forbesiceras brundrettei* zone ammonite fauna in Texas, U.S.A. Neues Jahrbuch fuer Geologie und Palaeontologie. Abhandlungen 188(3):327-344.

Kennedy, W.J., W.A. Cobban, J.M. Hancock, and A.S. Gale, 2005. Upper Albian and Lower Cenomanian ammonites from the Main Street Limestone and Del Rio Clay in northeast Texas. Cretaceous Research 26(3): 349-428.

Kerans, C. 2002. Styles of rudist buildup development along the northern margin of the Maverick Basin, Pecos River canyon, Southwest Texas. Gulf Coast Association of Geological Societies Transactions 52:501-506.

Kerans, C.,. W. Fitchen, L. Zahm, and K. Kempter. 1995. High-frequency sequence framework of Cretaceous (Albian) carbonate ramp reservoir analog outcrops, Pecos River Canyon, northwestern

Gulf f Mexico Basin. University of Texas at Austin, Bureau of Economic Geology. Field Trip Guidebook, 105 pages.

Kerans, C. and R.G. Loucks. 2002. Stratigraphic setting and controls on occurrence of high-energy carbonate beach deposits; Lower Cretaceous of the Gulf of Mexico. Gulf Coast Association of Geological Societies Transactions 52:517-526.

Kerans, C. and L.C. Zahm. 1998. Facies partitioning at the high-frequency sequence scale in carbonate ramp systems. American Association of Petroleum Geologists Annual Meeting Abstracts.

Kummel, B. 1948. Environmental significance of dwarfed cephalopods. Journal of Sedimentary Petrology 18: 61-64.

Labadie, J.H. 2004. Cultural Resources Management at Amistad National Recreation Area, Del Rio, Texas. in Proceedings: Speaker Series Faces and Places of the Chihuahuan Desert 2003-2004, El Paso, Texas, p. 70-82.

Lock, B.E. and S.-J. Choh. 1997. Tepee structures in Boquillas Formation near Del Rio, Texas, resulting from sub-Recent calichification. Bulletin of the American Association of Petroleum Geologists 81(5):868.

Lock, B.E., S.-J. Choh, and J.J. Willis. 2001. Tepees and other surficial deformation features of Cretaceous rocks in central and West Texas, resulting from late Cenozoic caliche formation Gulf Coast Association of Geological Societies Transactions 51:173-185.

Loeblich, A.R., Jr. and H.N. Tappan. 1946. New Washita foraminifera [Oklahoma, Texas]. Journal of Paleontology 20(3):238-258.

Loeblich, A.R., Jr. and H.N. Tappan. 1961. Cretaceous planktonic foraminifera; Part 1, Cenomanian. Micropaleontology 7(3):257-304.

Longoria, J.F. 1973. *Pseudoticinella*, a new genus of planktonic foraminifera from the Early Turonian of Texas. Revista Espanola de Micropaleontologia 5(3):417-423.

Lozo, F.E. and C.I. Smith. 1964. Revision of Comanche Cretaceous stratigraphic nomenclature, southern Edwards Plateau, southwest Texas. Gulf Coast Association of Geological Societies Transactions 4:285-306.

Lundelius, E.L., Jr. 1984. A late Pleistocene mammalian fauna from Cueva Quebrada, Val Verde County, TX. Pages 456-481 *in* H. H. Genoways and M. R. Dawson, editors. Contributions in Quaternary Vertebrate Paleontology: A Volume in Memorial to John E. Guilday. Special Publication of the Carnegie Museum of Natural History Number 8, p. 456-481.

Maddocks, R.F. 1988. One hundred million years of predation on ostracods; the fossil record in Texas. Pages 637-657 *in* T. Hanai, N. Ikeya, and K. Ishizaki, editors. Evolutionary biology of Ostracoda; its fundamentals and applications. Elsevier, Netherlands.

Mancini, E.A. 1975. Grayson micromorph fauna (late Cretaceous). Geological Society of America Abstracts with Programs 7(2):212.

Mancini, E.A. 1977. Paedomorphism in upper Cretaceous oyster populations of Texas. Geological Society of America Abstracts with Programs 9(2):163.

Mancini, E.A. 1978a. Foraminiferal paleoecology of Grayson Formation (Upper Cretaceous) of North-central Texas. Bulletin of the American Association of Petroleum Geologists 62(9):1761.

Mancini, E.A. 1978b. Foraminiferal paleoecology of the Grayson Formation (Upper Cretaceous) of North-central Texas. Gulf Coast Association of Geological Societies Transactions 28:295-311.

Mancini, E.A. 1978c. Origin of the Grayson micromorph fauna (Upper Cretaceous) of North-central Texas. Journal of Paleontology 52(6):1294-1314.

Mancini, E.A. 1979a. Late Albian and early Cenomanian Grayson ammonite biostratigraphy in North-central Texas. Journal of Paleontology 53(4):1013-1022.

Mancini, E.A. 1982a. Early Cenomanian cephalopods from the Grayson Formation of north-central Texas. Cretaceous Research 3(3):241-259.

Marks, E. 1952. Occurrence of Santonian crinoid in western Gulf region. American Journal of Science 250(3):226-227.

Maudlin, R.A. 1985. Foraminiferal biostratigraphy, paleoecology, and correlation of the Del Rio Clay (Cenomanian) from Big Bend National Park, Brewster County, and Dona Ana County, New Mexico. Master's Thesis, University of Texas at El Paso, El Paso, Texas, 89 p.

McNulty, C.L. 1964. Foraminifers from the Eagle Ford - Austin contact, northeast Texas. Bulletin of the American Association of Petroleum Geologists 48(4):537-538.

McNulty, C.L., Jr. 1970. A new cylindracanthid rostrum from the Eagle Ford Shale (Turonian), Dallas County, Texas. The Texas Journal of Science 21(3):337.

McNulty, C.L., Jr. and B. H. Slaughter. 1964. A protostegid turtle ramus from the Upper Cretaceous of Texas. Copeia 2:454.

Meyer, J.P. 1988. Shark's Tooth Hill. Lapidary Journal 42(4):65-66.

Miller, B.C. 1984. Physical stratigraphy and facies analysis, Lower Cretaceous, Maverick Basin and Devils River Trend, Uvalde and Real counties, Texas. Bulletin of the American Association of Petroleum Geologists 68(4):508.

Moreman, W.L. 1927. Fossil zones of the Eagle Ford of north Texas. Journal of Paleontology 1(1):89-101.

Moreman, W.L. 1942. Paleontology of the Eagle Ford of north and central Texas. Journal of Paleontology 16(2):192-220.

Offeman, I.D., P.C. Lewis, S.W. Arnette, T.J. Akers, R.H. Ganshirt, M.Martin, R.E., Akers, and R.M. Landry. 1982. Texas Cretaceous bivalves and localities. Houston Gem and Mineral Society, Texas Paleontology Series 2, 155p.

Pampe, W.R. 1979. A dwarfed fauna from the Grayson Formation near Lake Waco, Texas. Earth Science Bulletin 12(3):18-32.

Perkins, B.F. 1951. *Hindeastraea discoidea* White from the Eagle Ford shale, Dallas County, Texas. Fondren Science Series 2. 11 pages.

Pessagno, E.A., Jr. 1969. Cenomanian-Turonian (Eaglefordian) stratigraphy in the western Gulf Coastal Plain area. Proceedings of the International Conference on Planktonic Microfossils 2:509-525.

Polcyn, M.J. and G.L. Bell, Jr. 1996. A complete skull of a new mosasauroid from the Arcadia Park Member of the Eagle Ford Shale (late middle Turonian) near Dallas, Texas. Society of Vertebrate Paleontology Abstracts 16(3):58.

Powell, J.D. 1963. Turonian (Cretaceous) ammonites from northeastern Chihuahua, Mexico. Journal of Paleontology 37(6):1217-1232.

Powell, J.D. 1967. Mammitine ammonites in Trans-Pecos Texas. The Texas Journal of Science 19(3):311-322.

Price, L.L. 1931. Fishing in the Austin Chalk [*Xiphactinus audax*]. Compass of Sigma Gamma Epsilon 12(1):11-12.

Raun, G.G. and L.J. Eck. 1967. Vertebrate remains from four archeological sites in the Amistad Reservoir area, Val Verde County, Texas. The Texas Journal of Science 19(2):138-150.

Reaser, D.F. and W.C. Dawson. 1995a. Geologic study of Upper Cretaceous (Cenomanian) Buda Limestone in Northeast Texas with analysis of some regional implications. Gulf Coast Association of Geological Societies Transactions 45:495-502.

Reaser, D.F. and W.C. Dawson. 1995b. Geologic study of Upper Cretaceous (Cenomanian) Buda Limestone outliers in Northeast Texas. Bulletin of the American Association of Petroleum Geologists 79(10):1566.

Richardson, E.S., Jr. 1955. A new variety of Cretaceous decapod from Texas. Fieldana Zoology 37:445-448.

Roemer, F. 1849. Texas, Mit besonderer Rucksicht auf deutsche Auswanderung and die physischen Verhaltnisse des Landes nach eigener Beobachtung geschildert. Adoph Marcus, Bonn, 464 p., 1 map.

Santucci, V.L., J. Kenworthy, and R. Kerbo, 2001. An inventory of paleontological resources associated with National Park Service Caves. National Park Service Geologic Resources Division Technical Report, NPS/NRGRD/GRDTR-01/02, 50 pp.

Schell, W.W. 1952. Foraminifera of the Eagle Ford shale in the type area, Dallas and Tarrant counties. Southern Methodist University, Dallas, TX. Master's Thesis. 86 pages.

Schmidt Murphy, S.M. 1991. Microstructure and systematic paleontology of Cenomanian stromatoporoids of the Buda Limestone, Trans-Pecos Texas. University of Texas at Arlington, Arlington, TX. Master's Thesis. 94 pages.

Schneider, C.L. and D.R. Ruez, Jr. 2001. A paleoenvironmental conundrum; vertebrates versus invertebrates in the Late Cretaceous Eagle Ford Formation. Society of Vertebrate Paleontology Abstracts 21(3):98.

Scott, G. 1924. Some gerontic ammonites of the Duck Creek Formation. Texas Christian University Quarterly 1: 5-31.

Scott, G. 1940a. Paleoecological factors controlling distribution and mode of life of Cretaceous ammonoids in the Texas area. Journal of Paleontology 14: 229-323.

Scott, G. 1940b. Pyrite faunas of Washita and Eagle Ford groups of Texas Cretaceous and the paleoecological significance. Geological Society of America Bulletin 51(12):1977.

Scott, R.W. 1990. Models and stratigraphy of mid-Cretaceous reef communities, Gulf of Mexico. SEPM Concepts in Sedimentology and Paleontology 2, 102 p.

Scott, R.W. 2002a. Albian caprinid rudists from Texas re-evaluated. Journal of Paleontology 76(3):408-423.

Scott, R.W. 2002b. Upper Albian benthic foraminifers new in West Texas. Journal of Foraminiferal Research 32(1):43-50.

Shuler, E.W. 1950. A new elasmosaur from the Eagle Ford shale of Texas; the elasmosaur and its environment. Fondren Science Series 1. 32 pages.

Smith, C.I. and J.B. Brown. 1983. First day road log. Pages 6-26 *in* E. C. Kettenbrink Jr., editor. Structure and stratigraphy of the Val Verde Basin-Devils River Uplift, Texas. West Texas Geological Society, Midland, TX. Publication 83-77.

Smith, C.I., B.C. Miller, and P.R. Rose. 1984a. First day road log; San Antonio to Uvalde. Pages 101-106 *in* C. I. Smith, editor. Stratigraphy and structure of the Maverick Basin and Devils River Trend, Lower Cretaceous, Southwest Texas; a field guide and related papers. San Antonio Geological Society, San Antonio, TX.

Smith, C.I., J.B. Brown, and F.R. Lozo. 2000. Regional stratigraphic cross sections, Comanche Cretaceous (Fredericksburg-Washita Division), Edwards and Stockton plateaus, West Texas; interpretation of sedimentary facies, depositional cycles, and tectonics. University of Texas Bureau of Economic Geology, Austin, TX. 39 pages.

Sobolik, K.D. 1989. The identification and quantification of pollen recovered from coprolites. American Association of Stratigraphic Palynologists Abstracts 13: 286.

Spearing, D., 1991. Roadside geology of Texas. Mountain Press Publishing Company, Missoula, Montana, 418 p.

Springer, V.G. 1957. A new genus and species of elopid fish (*Laminospondylus transverses*) from the Upper Cretaceous of Texas. Copeia 2:135-140.

Steinman, D.M. P. 1974. Cretaceous benthonic foraminifera of the Eagle Ford Formation [Texas]. University of Idaho, Moscow, ID. Master's Thesis.

Stephenson, L.W. 1929. Two new mollusks of the genera *Ostrea* and *Exogyra* from the Austin Chalk, Texas. Proceedings of the United States National Museum 76:1-6.

Stephenson, L.W. 1944. Fossils from limestone of Buda age in Denton County, Texas. Bulletin of the American Association of Petroleum Geologists 28(10):1538-1541.

Stephenson, L.W. 1955. Basal Eagle Ford fauna (Cenomanian) in Johnson and Tarrant counties, Texas. U. S. Geological Society, Reston, VA. Professional Paper 274. Pages 53-67.

Stewart, J.D. and V. Friedman. 2001. Oldest North American record of Saurodontidae (Teleostei, Ichthyodectiformes). Society of Vertebrate Paleontology Abstracts 21(3):104.

Stock, J.A. 1983. The prehistoric diet of Hinds Cave (41VV456), Val Verde County, Texas: the coprolite evidence. Master's Thesis, Texas A&M University, College Station, Texas, 246 p.

Stone, J.F. 1967. Quantitative palynology of a Cretaceous Eagle Ford exposure. Compass of Sigma Gamma Epsilon 45(1):17-25.

Story, D.A. and V.M. Bryant, Jr. 1966. A preliminary study of the paleoecology of the Amistad Reservoir area. Final report of research sent to the National Science Foundation, 255 pages.

Tappan, H.N. 1939. Foraminifera from the Grayson Formation of northern Texas. Proceedings of the Oklahoma Academy of Science 19(93):113.

Tappan, H.N. 1940. Foraminifera from the Grayson Formation of northern Texas. Journal of Paleontology 14(2):93-126.

Trevino, R.H., III. 1988. Facies and depositional environments on the Boquillas Formation, Upper Cretaceous of Southwest Texas. University of Texas at Arlington, Arlington, TX. Master's Thesis. 120 pages.

Trevino, R.H. and C.I. Smith. 2002. Facies and depositional environments of the Boquillas Formation. American Association of Petroleum Geologists Annual Meeting Abstracts. Pages 177-178.

Udden, J.A. 1908. Fossil tracks in the Del Rio clay. Transactions and Proceedings of the Texas Academy of Science 10:51-52.

Visaggi, C.C. 2006. Investigation of paleontological resources at Amistad National Recreation Area. Geological Society of America, Abstracts with Programs 38(7): 35.

Webster, R.E. and G.P. Bolden. 1983. Second day road log. Pages 27-47 *in* E. C. Kettenbrink Jr., editor. Structure and stratigraphy of the Val Verde Basin-Devils River Uplift, Texas. West Texas Geological Society, Midland, TX. Publication 83-77.

Webster, R.E. and G.P. Bolden. 1984. Third day road log; Del Rio to San Antonio. Pages 115-128 *in* C. I. Smith, editor. Stratigraphy and structure of the Maverick Basin and Devils River Trend, Lower Cretaceous, Southwest Texas; a field guide and related papers. San Antonio Geological Society, San Antonio, TX.

Welles, S.P. 1949. A new elasmosaur from the Eagle Ford shale of Texas; systematic description. Fondren Science Series 1. 28 pages.

Welles, S.P. and B.H. Slaughter. 1963. The first record of the plesiosaurian genus Polyptychodon (Pliosauridae) from the New World. Journal of Paleontology 37(1):131-133.

Wells, J.W. 1934. A new species of calcisponge from the Buda limestone of central Texas. Journal of Paleontology 8(2):167-170.

Wells, J.W. 1944. A new coral from the Buda limestone (Cenomanian) of Texas. Journal of Paleontology 18(1):100.

Williams-Dean, G.J. 1978. Ethnobotany and cultural ecology of prehistoric man in southwest Texas. Ph.D. Dissertation, Texas A&M University, College Station, Texas, 287 p.

Willimon, E.L. 1973. An enchodontid skull from the Austin Chalk (upper Cretaceous) of Dallas, Texas. The Southwestern Naturalist 18(2):201-210.

Willis, M.J. 1997. Paleoecology and distribution of echinoderms in the Grayson Formation, McLennan County, Texas. Baylor University, Waco, TX. Bachelor's Thesis.

Young, K.P. 1958. Cenomanian (Cretaceous) ammonites from Trans-Pecos Texas. Journal of Paleontology 32(2):286-294.

Young, K.P. 1961. Edwards Plateau ammonite localities. Pages A3-A5 *in* Southern Edwards Plateau. Gulf Coast Association of Geological Societies. Annual Meeting Guidebook.

Young, K.P. 1962. Ammonites of the Buda Limestone (Cretaceous), Texas and Mexico. The Texas Journal of Science 14(4):420-421.

Young, K.P. 1963. Upper Cretaceous ammonites from the Gulf Coast of the United States. University of Texas Bureau of Economic Geology, Austin, TX. Publication 6304. 373 pages.

Young, K.P. 1979. Edwards Plateau ammonites. Pages 59-75 *in* P. R. Rose, editor. Stratigraphy of the Edwards Group and equivalents, eastern Edwards Plateau, Texas. South Texas Geological Society, San Antonio, TX. Edition 2.

Young, K.P. 1984. *Hysteroceras* Hyatt [Cretaceous (Albian) ammonoid] in Texas and the Angola connection. The Texas Journal of Science 36:185-195.

Young, K.P. and E. Marks. 1952. Zonation of Upper Cretaceous Austin Chalk and Burditt Marl, Williamson County, Texas. Bulletin of the American Association of Petroleum Geologists 36(3):477-488.

Zahm, L.C. 1997. Depositional model and sequence stratigraphic framework for upper Albian/lowerCenomanian carbonate ramp, western Comanche Shelf, Texas. University of Texas at Austin, Austin, TX. Master's Thesis. 134 pages.

Zahm, L.C., C. Kerans, and J.L. Wilson. 1995a. Cyclostratigraphic and ichnofacies analysis of the upper Albian Salmon Peak Formation, Maverick Basin, Texas. Bulletin of the American Association of Petroleum Geologists 79(10):1569.

Zahm, L.C., C. Kerans, and J.L. Wilson. 1995b. Cyclostratigraphic and ichnofacies analysis of the upper Albian Salmon Peak Formation, Maverick Basin, Texas. Gulf Coast Association of Geological Societies Transactions 45:595-604.

ADDITIONAL REFERENCES

Adams, C.S. 1988. The nature, distribution, and significance of very hard limestones in the Comanchean Series, central Texas. Baylor University, Waco, TX. Bachelor's Thesis. 160 pages.

Alexander, R.K. 1970. Archeological investigations at Parida Cave, Val Verde County, Texas. Papers of the Texas Archeological Salvage Project, no. 19, Austin, Texas.

Armstrong, A.W. 1995. The use of stable isotope ratios to investigate the relative importance of Amistad Reservoir to recharge of the McKnight and associated limestones, southwestern Val Verde County, Texas. University of Texas at San Antonio, San Antonio, TX. Master's Thesis. 105 pages.

Barnes, V.E., 1981. Geologic atlas of Texas, Sonora sheet. University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas, 1:250000 scale.

Bender, R.A. and T.W. McTern, 1968. Analysis of human skeletal remains from Coontail Spin. Bulletin of the Texas Archeological Society 38: 66-75.

Bryant, V.M., Jr. 1966. Pollen analysis: its environmental and cultural implications in the Amistad Reservoir Area. Master's Thesis, University of Texas at Austin.

Bryant, V.M., Jr. 1969. Late full-glacial and post-glacial pollen analysis of Texas sediments. Ph.D. Dissertation, University of Texas at Austin.

Chatterton, M.F., 1984. Baker Cave, Val Verde County, Texas: The 1976 excavations. Center for Archeological Research, Special Report 13, University of Texas, San Antonio.

Collins, E.W., 1972a. Rough Canyon SE Quadrangle, University of Texas at Austin, Bureau of Economic Geology. STATEMAP Project Geologic Maps, 1:24000 scale.

Collins, E.W., 1972b. Del Rio NE Quadrangle, University of Texas at Austin, Bureau of Economic Geology. STATEMAP Project Geologic Maps, 1:24000 scale.

Collins, E.W., 1972c. Del Rio NW Quadrangle, University of Texas at Austin, Bureau of Economic Geology. STATEMAP Project Geologic Maps, 1:24000 scale.

Dawson, W.C. 1986. Austin Chalk and Buda Limestone (Cretaceous) petroleum reservoirs in Caldwell County, Texas; a case history. Energy Exploration and Exploitation 4(5):377-389.

Dering, J.P., 1979. Pollen and plant macrofossil vegetation record recovered from Hinds Cave, Val Verde County, Texas. Master's Thesis, Texas A&M University, College Station, Texas.

Dibble, D.S., 1967. Excavations at Arenosa Shelter, 1965-1966. Report submitted to the National Park Service by the Texas Archeological Salvage Project, University of Texas, Austin, Texas.

Dibble, D.S. and R.K. Alexander, 1972. The archeology of Texas caves. In Natural History of Texas Caves, p. 133-148.

Douglas, C.L., 1969. Catfish spines from archeological sites in Texas. Bulletin of the Texas Archeological Society 40: 263-265.

Edwards, S.K., 1990. Investigations of Late Archaic Coprolites: pollen and macrofossil remains from Hinds Cave, Val Verde County, Texas. Master's Thesis, Texas A&M University, College Station, Texas.

Erdogan, S.Z. 1969. Cenomanian Buda limestone (Comanche Cretaceous), of west and Trans-Pecos, Texas. Louisiana State University, Baton Rouge, LA. Master's Thesis.

Ewing, T. 1996. Summary of the geology of the San Antonio area. Pages 7-54 *in* Rocks, landscapes and man; urban geology of the San Antonio area. South Texas Geological Society, San Antonio, TX. Guidebook.

Freeman, V.L., 1965. Geologic Map of the Baker's Crossing Quadrangle, Val Verde County, Texas. U.S. Geological Survey, I-434, 1:62500 scale.

Freeman, V.L., 1968. Geology of the Comstock-Indian Wells area, Val Verde, Terrell, and Brewster Counties, Texas. U.S. Geological Survey, PP 594-K, 1:250000 scale.

Hoadley, C.R. 1986. Paleoecology of encrusting epifauna of echinoids and oysters of the Mid-Cretaceous. Baylor University, Waco, TX. Master's Thesis. 86 pages.

Hixon, S.B. 1959. Facies and petrography of the Cretaceous Buda Limestone of Texas and northern Mexico. University of Texas at Austin, Austin, TX. Master's Thesis.

Hudson, R.M. 1986. Progradation of a secondary shelf margin, upper Salmon Peak Formation, Maverick Basin, Southwest Texas. University of Texas at Arlington, Arlington, TX. Master's Thesis. 120 pages.

Jacobs, L.L. and D.A. Winkler. 1998. Mammals, archosaurs, and the Early to Late Cretaceous transition in north-central Texas. Pages 253-280 *in* Y. Tomida, L. J. Flynn, and L. L. Jacobs. Advances in Vertebrate Paleontology and Geochronology. Natural Science Museum Monographs **14**.

Jaroska, R.S. 1955. Population analysis of the Del Rio Formation in central and Southwest Texas. University Texas at Austin, Austin, TX. Master's Thesis.

Johnston, C. 1962. Stop no. 1; The Del Rio clay. Pages 22-23 *in* Southwestern McLennan County and eastern Coryell County. Baylor Geological Society, Waco, TX. Popular Geology of Central Texas 7.

Lehman, T.M. 1985. Stratigraphy, sedimentology, and paleontology of Upper Cretaceous (Campanian-Maastrichtian) sedimentary rocks in Trans-Pecos Texas. Ph.D. Dissertation, University of Texas at Austin, Austin, Texas, 299 p.

Lehman, T.M. 1986. Late Cretaceous sedimentation in Trans-Pecos Texas. Bulletin of the West Texas Geological Society 25(7):4-9.

Lehmann, C.T. 1997. Sequence stratigraphy and platform evolution of Lower Cretaceous (Barremian-Albian) carbonates of northeastern Mexico. University of California at Riverside, Riverside, CA. PhD Dissertation. 261 pages.

Lock, B.E. 1996. Stratigraphic significance of diastemic surfaces; examples from the Cretaceous of west-central Texas. Geological Society of America Abstracts with Programs 28(7):124.

Lord, K.J., 1984. The zooarcheology of Hinds Cave (41VV456). Ph.D. Dissertation, Texas A&M University, College Station, Texas, 296 p.

Mancini, E.A. 1979b. Models for interpretation of micromorph faunas in Washita Group. Bulletin of the American Association of Petroleum Geologists 63(3):490.

Mancini, E.A. 1982b. Foraminiferal population changes in a shallow epicontinental marine carbonate-claystone sequence; Main Street-Grayson interval (Cretaceous), North-central Texas. Proceedings of the North American Paleontological Convention 3:353-358.

McCormick, C.L., C.L. Smith, and C.D. Henry. 1996. Cretaceous stratigraphy. Pages 30-46 *in* C.D. Henry, W.R. Muehlberger, C.L. McCormick, L.L. Davis, R.J. Erdlac, Jr., M.J. Kunk, and C.I. Smith, editors. Geology of the Solitario Dome, Trans-Pecos Texas; Paleozoic, Mesozoic, and Cenozoic sedimentation, tectonism, and magmatism. University of Texas Bureau of Economic Geology, Austin, TX. Report of Investigations 240.

Meyer, J.P. 1991. Harvesting Cretaceous crabs. Lapidary Journal 45(6):61-62, 64, 66, 68.

Moreman, W.L. 1925. Micrology of the Woodbine, Eagle Ford, and Austin Chalk. Bulletin of the University of Texas 2544. Pages 74-78.

Moreman, W.L. 1931. Stratigraphy and paleontology of the Eagle Ford Formation of north and central Texas. University of Kansas, Lawrence, KS. PhD Dissertation. 75 pages.

Neck, R.W. 1990. Geological substrate and human impact as influences on bivalves of Lake Lewisville, Trinity River, Texas. The Nautilus 104(1):16-25.

Nunley, J.P., L.F. Duffield, and E.B. Jelks, 1972. Excavations at Amistad Reservoir, 1962 Season. Texas Archeological Salvage Project, No. 3, Austin, Texas.

Patton, J.L. 1932. The paleontology of the Austin Chalk in Travis and Williamson counties, Texas. University of Texas at Austin, Austin, TX. Master's Thesis.

Peterson, J.D. 1985. A petrologic and depositional study of the Lower Cretaceous Buda Limestone, central Texas. Baylor University, Waco, TX. Bachelor's Thesis. 76 pages.

Powell, J.D. 1968. Woodbine-Eagle Ford transition, Tarrant Member. Pages 27-43 *in* Stratigraphy of the Woodbine Formation. Geological Society of America South-Central Section Field Trip Guidebook.

Prewitt, E.R. and D.A. Lawson, 1972. An assessment of the archeological and paleontological resources of Lake Texoma, Texas – Oklahoma. Texas Archeological Salvage Project Survey Reports, No. 10, Austin, Texas.

Redfield, R.C. 1940. A study of the lower portion of the Boquillas Formation, Brewster County, Texas. University of Texas at Austin, Austin TX. Master's Thesis.

Rodda, P.U., W.L. Fisher, W.R. Payne, and D.A. Schofield. 1966. Limestone and dolomite resources, Lower Cretaceous rocks, Texas. University of Texas Bureau of Economic Geology, Austin, TX. Report of Investigations 56. 286 pages.

Ross, R.E., 1965. The archeology of Eagle Cave. Texas Archeological Salvage Project, No. 7, Austin Texas.

Sanders, R.B. and T.M. Lehman. 1989. Sedimentology and stable isotope geochemistry of the Ernst Member of the Boquillas Formation (Late Cretaceous) Trans-Pecos Texas. Geological Society of America Abstracts with Programs 21(1):39.

Schuetz, M.K., 1956. An analysis of Val Verde County Cave materials. Bulletin of the Texas Archeological Society 27: 129-160.

Schuetz, M.K., 1961. An analysis of Val Verde County Cave materials. Part II. Bulletin of the Texas Archeological Society 31: 167-205.

Schuetz, M.K., 1963. An analysis of Val Verde County Cave materials. Part III. Bulletin of the Texas Archeological Society 33: 131-165.

Scott, R.W. and E.J. Kidson. 1977. Lower Cretaceous depositional systems, West Texas. Pages 169-181 *in* D. G. Bebout and R. G. Loucks, editors. Cretaceous carbonates of Texas and Mexico; applications to subsurface exploration. University of Texas Bureau of Economic Geology, Austin, TX. Report of Investigations 89.

Sharps, J.A., 1963. Geologic Map of the Malvado Quadrangle, Terrell and Val Verde Counties, Texas. U.S. Geological Survey, I-382, 1:62500 scale.

Sharps, J.A. and V.L. Freeman, 1965. Geologic Map of the Mouth of Pecos and Feely Quadrangles. Val Verde County, Texas. U.S. Geological Survey, I440, 1:62500 scale.

Smith, C.I., B.C. Miller, and P.R. Rose. 1984b. Second day road log; Uvalde to Del Rio. Pages 107-114 *in* C.I. Smith, editor. Stratigraphy and structure of the Maverick Basin and Devils River Trend, Lower Cretaceous, Southwest Texas; a field guide and related papers. San Antonio Geological Society, San Antonio, TX.

Stanford, J.W. 1958. The Del Rio Clay. Pages 64-68 *in* Guide to the mid-Cretaceous geology of central Texas. Baylor Geological Society, Waco, TX.

Stevens, J.B., R.A. Ashmore, L.C. Doornbos, D.A. Reed, and M.S. Stevens. 1995. Faunal change in cyclic deposits of the late Coniacian-early Santonian, Terlingua Group, Big Bend National Park, Trans-Pecos Texas. Geological Society of America Abstracts with Programs **27**(6):176.

Taylor, D.R. 1960. The Buda limestone. Pages 98-99 *in* Cretaceous stratigraphy of the Grand and Black Prairies, east-central Texas. Baylor Geological Society, Waco, TX. Field Conference Guidebook.

Taylor, W.W. and F.G. Rul, 1961. An archeological reconnaissance behind the Diablo Dam, Coahuila, Mexico. Bulletin of the Texas Archeological Society 31: 153-165.

Thomas, R.G., 1971. The geomorphic evolution of the Pecos River System. Master's Thesis, Baylor University, Waco, Texas.

Webster, R.E., C.F. Miller, and D.F. Reaser. 1978. Structural geology of Southwest Edwards Plateau region, Texas. Bulletin of the American Association of Petroleum Geologists 62(3):571.

Whitney, F.L. 1911. Fauna of the Buda Limestone (Lower Cretaceous, Texas). Cornell University, Ithaca, NY. Master's Thesis.

Word, J.H. and C.L. Douglas, 1970. Excavations of Baker Cave, Val Verde County, Texas. Bulletin of the Texas Memorial Museum, No. 16, Austin, Texas.

Yates, R.G. and G.A. Thompson. 1959. Geology and quicksilver deposits of the Terlingua District, Texas. U. S. Geological Survey, Reston, VA. Professional Paper 312. 114 pages.

Young, K. 1977. Middle Cretaceous rocks of Mexico and Texas. Pages 325-332 *in* D. G. Bebout and R. G. Loucks, editors. Cretaceous carbonates of Texas and Mexico; applications to subsurface exploration. University of Texas Bureau of Economic Geology, Austin, TX. Report of Investigations 89.

DATA SETS

DS-AMIS-XXX Amistad National Recreation Area Paleontological Archives. 5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

DS-AMIS-XXX Amistad National Recreation Area Files and Archives. 8/1937–present. (letters, notes, exhibit text, etc.). Originated by AMIS staff; status: Inactive.

BIG BEND NATIONAL PARK

Big Bend National Park (BIBE) was originally authorized by Congress on June 20, 1935 "*…for the use of the public for recreational park purposes…within the boundaries to be determined ….. within the area of approximately one million five hundred thousand acres...*" The park was later established in 1944 to protect over 800,000 acres of the Chihuahuan Desert. The southern boundary of Big Bend defined by the Rio Grande River, which represents the international boundary between the United States and Mexico. The name Big Bend is derived from the fact that the Rio Grande River makes rather large bends in its course southeast in west Texas.

The park was designated in 1976 as a U.S. Biosphere Reserve. Big Bend also includes 533,900 acres of recommended wilderness, and administers the 190-mile Rio Grande Wild and Scenic River. Species diversity is increased due to inclusion of the Rio Grande and the Chisos Mountains, a 50-square mile range that is home to numerous relict and isolated populations. Major threats to the largest park unit in the Chihuahuan Desert Network include groundwater mining, water quality degradation, significant reduction in air quality, expansion of nonnative plants distribution and border issues involving Mexico.

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

The NPS Geologic Resources Division conducted a geologic scoping session for Big Bend National Park, including the Rio Grande Wild and Scenic River, during January 2002. The purpose of this meeting was to inventory the park's geologic resources and geologic issues, review the status of geologic maps, and to assess resource management issues and needs. A paleontological resource scoping session was held for Big Bend National Park, including Rio Grande Wild and Scenic River, in April 2000.

Hill (1887) provides the earliest published geologic information for Texas including the Big Bend area. Between 1898 and 1903 Dr. J.A. Udden conducted geologic field work in the Big Bend region. From his work Udden developed a topographic map and a geologic report on the Chisos Mountains area which were never officially published. In 1907, Udden finally published "A brief sketch of the geology of the Chisos Country" (Udden 1907).

During the Paleozoic the Big Bend area was situated within a northeasterly trending trough called the Ouachita Trough. The trough was submerged by marine water and was a center for deposition of continental sediments from the north. Marine invertebrates including sponges, brachiopods and trilobites were preserved in these Paleozoic rocks now exposed between Persimmon Gap and Marathon. Maxwell (1968) refers to the Paleozoic sequences at Persimmon Gap as undifferentiated limestone, chert, novaculite, and shale from the Maravillas, Caballos and Tesnus formations. Regional tectonics during the late Paleozoic resulted in folding and regional uplift. Between the late Paleozoic and the Cretaceous, a great unconformity exists in the Big Bend area.

Geologically, the park is dominated by marine and terrestrial deposits from the Cretaceous. The thick Cretaceous sequence extends into the Tertiary representing a K/T boundary transition. The Cretaceous sequence in stratigraphic order includes: Glen Rose Limestone, Telephone Canyon Formation, Del Carmen Limestone, Sue Peaks Formation, Santa Elena Limestone, Devils River Limestone, Del Rio Clay, Buda Limestone, Boquillas Formation, Pen Formation, Aguja Formation and Javelina Formation.

The Cenozoic history of BIBE has resulted in flow covered anticlinal and laccolithic mountains, including the Chisos Mountains. Volcanic flows, talus slopes, pediments and graded plains extend out from these mountain highlands. Mesas, plateaus, cuestas, and hogbacks are common surface features within Big Bend. The Chisos Mountains are surrounded by huge fan-like aprons of sediments. Dikes and sills traverse and dissect the pediment fill.

West of the Chisos Mountains is a southeast – northwest trending plateau referred to as Mesa de Anguila. This plateau is composed of Cretaceous marine limestone. The Rio Grande cut through the Mesa de Anguila plateau as an antecedent stream forming a canyon. The Sierra de Caballo Muerta Mountains occur in the eastern part of the park and consist of a plateau and isolated mesas broken by faults.

Significant Cretaceous and Early Tertiary fossil plant and vertebrate localities are preserved at Big Bend National Park. Fossils have been known from the Big Bend region since the end of the 1800s. Paleontological research at Big Bend has been continuous and active since the 1930s. The largest collections of fossils from the park are maintained in the collections of the University of Texas at Austin (Texas Memorial Museum), with more than 7700 specimens curated in the collections. Field parties from the American Museum of Natural History led many expeditions into Big Bend prior to the 1960s. The Dallas Museum of Natural History, Field Museum in Chicago, Texas Tech University, University of Texas at El Paso, Yale Peabody Museum, and the University of California at Berkeley, Museum of Paleontology all have collections of Big Bend fossils.

Consistent with the concept of "Texas Sized", some noteworthy fossil discoveries in Big Bend National Park include the largest known crocodilian, largest complete dinosaur skull, and the largest known flying creature the Earth has ever known. Additionally, the sediments at Big Bend National Park Big Bend span the Cretaceous – Tertiary boundary and enable study of the geology, paleontology and taxonomic diversity across this important period of earth history.

History of Paleontological Field Work

The earliest published report of vertebrate fossils in the Big Bend area was by J.A. Udden in 1907. Bones collected by Udden were sent to Dr. S.W. Williston who identified them as hadrosaur, possible ceratopsian, carnosaur, crocodilian and fresh water turtles. Williston suggested that the fauna was similar to the Laramie or Judith River fauna.

During the 1930s the National Park Service worked with the Civilian Conservation Corps (CCC) to plan and build the Big Bend Museum. An old CCC barracks was dismantled, moved into the basin of the Chisos Mountains, and rebuilt. Part of this structure was used as a temporary museum facility (Maxwell, 1940). When geologist Ross Maxwell reported to Big Bend in May 1936, he found several hundred geological and paleontological specimens already placed in the museum. Some of these were collected by Regional Geologist Charles Gould (Region 3) during 1935. Maxwell (1940) provides a brief history of the Big Bend Museum which contains some of Gould's photos showing the museum and some fossil specimens including: dinosaur bones, mammoth teeth, shark's teeth (Aguja Formation), oysters (Boquillas flagstone and Terlingua Shale), petrified tree stump (Aguja Formation).

Between June and September 1937 R.C. Redfield was employed as a student technician in geology to prepare a report on the paleontology of the Chisos Region of Big Bend National Park (Redfield 1937). Redfield was assigned to identify the invertebrate fossils collection placed in the museum established at the park. The museum collection included fossils from the Devils River Limestone, Del Rio Clay, Buda Limestone, Boquillas Formation and Aguja Formation.

University of Oklahoma conducted field work at BIBE in 1938 just south of the Mariscal – San Vicente road. The university collected a ceratopsian dinosaur from this locality at that time (Langston personal communication 2001).

During 1938 and 1939 three fossil quarries were excavated in the Aguja Formation by W.P.A. field crews working under the supervision of William S. Strain from the Texas College of Mines and Metallurgy in El Paso, Texas. Work crews of eleven men were employed on the W.P.A. payrolls during the paleontological project. Approximately 500 individual fossil bones were collected (Strain 1940).

According to Dr. Wann Langston (written communication, 1968) there is a short film showing the field operations of the Works Progress Administration (W.P.A). at Big Bend during 1938 – 39. In Langston's letter, the film was in his possession at the University of Texas, Austin. However, there was a reference that a copy could be obtained through Bill Strain in El Paso.

The University of Texas at Austin and the Texas Memorial Museum (TMM) have undertaken extensive paleontological field work within Big Bend National Park. Paleontologists from the Texas Memorial Museum prepared field reports documenting activities within BIBE. Below are summaries from these various field reports.

1947 TMM Field Report was prepared by Dr. Wann Langston. The report includes a discussion regarding the *"…apparent stripping of the area of exposed vertebrate remains…"* by an individual specifically named in the report, *"…prior to the time that Big Bend was established as a Federal area."* (Langston 1948). In a letter prepared by Superintendent Ross A. Maxwell, dated August 15, 1947, the following information was written, *"His (Dr. Langston) failure to find many specimens supports my past suspicions that Dr. Barnum Brown, from the American Museum, and Dr. Bill Strain from the Texas School of Mines, pretty well stripped the park area of vertebrate fossils during the year prior to the establishment of the park. I was willing for Dr. Langston to make this study and now that we know his results I believe that our service should be reluctant to grant similar permits in the future."* (R. Maxwell, written correspondence in park files, 1947).

Langston reported that field activities took place between July 18 and August 25, 1947. Cretaceous dinosaur, crocodile and turtle remains were collected and were curated at the West Texas Museum of the Texas Technology College. Langston made specific reference to the collection of sauropod dinosaur remains including a hind limb and foot. Hadrosaur, ceratopsian, crocodilian and turtle remains were also collected according to Langston's report.

1948 TMM Field Report was prepared by Dr. Wann Langston. Dr. Langston indicated that the following institutions have made paleontological collections from the area now administered by BIBE. These institutions include: American Museum of Natural History, Texas College of Mines (El Paso), Texas Technological College (Lubbock), and the University of Oklahoma.

1951 TMM Field Report was prepared by J.A. Wilson. During this field season Wilson discovered the lower jaw of *Coryphodon* in the Tornillo Flat area of BIBE. This discovery helped to confirm the early Tertiary age of this sedimentary unit (Wilson et al. 1952). Additional field work in February of 1952 yielded additional mammalian remains confirming new Paleocene and Lower Eocene strata in the park. This discovery led to the development of the *in situ* fossil mammal exhibit at Tornillo Flat.

1965 – 1966 TMM Field Report was prepared by Dr. J.A. Wilson. Field activities were conducted in the area of Castolon between June and August 1965, and between May and August 1966. Only Miocene vertebrates, including the remains of titanotheres, were collected during these two years.

1968 – 1969 TMM Field Report was prepared by Dr. J.A. Wilson. Field activity during July and August 1968 and the summer of 1969 was confined to a detailed study of exposures in the Black Peaks Formation at Tornillo Flat. During September 1969 Judith Schiebout and Dr. Wilson collected sediments from the foot of the Rosillos Mountains in order to screen wash for microvertebrate teeth and bones. Dr. James and Margaret Stevens undertook two collecting trips to localities in the Miocene Delaho Formation in the park. A large collection of fossils obtained by the then Texas College of Mines at El Paso during 1938-1939 were transferred to the Texas Memorial Museum (Wilson 1969).

1970 field season activities were documented in a letter prepared by Dr. Wann Langston in 1971. Doug Lawson and Langston continued reconnaissance of the Javelina Formation. Lignite deposits with fossil leaf impressions were located in the Javelina near Dawson Creek. They also located a small bonebed containing the remains of gar scales and teeth, two types of turtles, and a mammal tooth. Lawson (1976) collected tyrannosaur and torosaur material during 1970 (R. Hunt personal communication 2007).

1971 TMM Field Report was prepared by Dr. Wann Langston. Judith Schiebout continued her graduate fieldwork in the Black Peaks Formation and made collections of mammal fossils including a primate not previously known form this unit. Margaret Stevens continued field studies and collecting of mammals from the Miocene Delaho Formation. Dr. Langston worked with graduate student Douglas Lawson to collect vertebrates from the Javelina Formation. The remains of the sauropod *Alamosaurus*, hadrosaur dinosaurs, pterosaur, turtle, and a Cretaceous mammal tooth were collected.

1972 TMM Field Report was prepared by Dr. Wann Langston. Langston and Doug Lawson worked in the park between March 30 and April 1, 1972 and discovered the first invertebrate fossils known from the Javelina Formation. The invertebrates included several gastropods and an internal mold of a pelecypod. A few fragments of egg shell were also located during this fieldwork. Langston indicated that these appear to be associated with dinosaurs based on surface morphology. On north side of Tornillo Flat Langston and Lawson located a very large (5 feet long), intensively weathered sauropod femur. The paleontologists suspected that this may be the same femur that appears in a photograph taken in 1940 which features American Museum of Natural History paleontologist Barnum Brown during the excavation of a very large dinosaur vertebra. Additionally, an articulated specimen of *Alamosaurus* was located.

1973 TMM Field Report was prepared by Dr. Wann Langston. The highlights from 1973 include: the discovery and collection of an incomplete skeleton of a titanosaurid dinosaur *Alamosaurus* from the Javelina Formation; the discovery of a new pterosaur locality; and, collection of fossil mammal remains in the Miocene Delaho Formation (Langston 1973).

1974 TMM Field Report was prepared by Dr. Wann Langston. A new pterosaur locality was discovered in the Tornillo Flats area of the park. In addition to the collection of pterosaur post-cranial elements, a lower jaw was discovered. Miocene mammals and a lizard jaw were recovered from the Delaho Formation several miles south of Castolon Peak. The Fossil Bone Exhibit sustained some extensive damage due to vandalism. A restoration of the exhibit began in 1973. A mural depicting the Paleocene landscape was painted inside the exhibit by Mrs. Margaret Colbert, wife of Dr. Ned Colbert. Dr. Wilson and his wife donated time to help restore the exhibit.

1985 – 1987 TMM Field Report prepared by unknown individual. During the time period reported field parties from the TMM visited BIBE sixteen times. Work continued at "Pterodactyl Ridge" with the remains of about 25 individuals assigned to *Quetzalcoatlus* sp. were recovered. Some of the more important discoveries included a near complete axis-atlas complex, two partial skulls, a lower jaw, and articulate cervical vertebrae. Margaret Stevens continued work in the Tertiary localities near Castolon and collected the remains of numerous fossil mammals. Graduate student Anthony Runkel conducted field work at eighteen middle and late Eocene localities collecting a variety of mammal and reptile remains.

BIG BEND STRATIGRAPHY AND PALEONTOLOGY

Glen Rose Limestone (Lower Cretaceous)
The first evidence of an expanding Cretaceous seaway in the Big Bend area is represented by the Lower Cretaceous (Albian) Glen Rose Limestone. The Glen Rose Limestone is exposed near Persimmon Gap near the north entrance to BIBE. The mollusks *Exogyra quitmanensis* and *Orbitolina texana* are preserved in the Glen Rose Limestone (Maxwell and Dietrich 1965).

Telephone Canyon Formation (Lower Cretaceous)
The Lower Cretaceous (Albian) Telephone Canyon Formation is a buff, nodular, marly limestone which overlies the Glen Rose Limestone. One of the best exposures in the park is at the mouth of the Santa Elena Canyon. The type locality for this formation is in Telephone Canyon where Heath Creek crosses the Sierra del Caballo Muerto Range (Maxwell and Dietrick 1965). This unit contains fossil clams,

oysters, gastropods and echinoids. *Exogyra texana* and *Gryphaea mucronata* are common pelecypod taxa of the Telephone Canyon Formation.

Del Carmen Limestone (Lower Cretaceous)
Overlying the Telephone Canyon Formation is the Lower Cretaceous (Albian) Del Carmen Limestone. This unit is a massive, heavy-bedded, cherty limestone unit. The Del Carmen Limestone forms vertical cliffs escarpments in Sierra del Carmen (type locality), Santa Elena Canyon, Mariscal Canyon, and in the Christmas Mountains (Maxwell and Dietrich 1965). This unit contains many rudistids and a few species of pelecypods and gastropods.

Sue Peaks Formation (Lower Cretaceous)
Above the Del Carmen Limestone is the Lower Cretaceous Sue Peaks Formation. This unit is a shaley, marly and nodular limestone which is named for the exposure at Sue Peaks in the Sierra del Carmen. The Sue Peaks Limestone is also exposed in Boquillas and Mariscal Canyons and in the Christmas Mountains (Maxwell and Dietrich 1965). The ammonites *Craginities* sp., *Idiohamites fremonti, Pervinquieria* sp., *Mortoniceras* sp., and *Prohysteroceras* sp. occur within the Sue Peaks Limestone at BIBE.

Santa Elena Limestone (Lower Cretaceous)
Continuing up in the Lower Cretaceous sequence is the Santa Elena Limestone (Albian). This unit is a massive, cherty limestone with a type section defined within the vertical walls of Santa Elena Canyon which are 730 feet thick in BIBE. In addition to the Santa Elena Canyon, this limestone is exposed on the ridge tops of the Sierra del Carmen Range, Mariscal Mountain, Sierra San Vicente, and the Christmas Mountains (Maxwell and Dietrich 1965). Rudists are extremely abundant in this unit along with *Gryphaea* sp.

Devils River Limestone (Lower Cretaceous)
There are some inconsistencies and confusion regarding use of stratigraphic nomenclature for the Lower Cretaceous (Albian) stratigraphy of the Big Bend region. Some authors such as Eley (1938) and Smith and others (2000) recognize the Devils River Limestone as the Lower Cretaceous (Albian) rock unit which is widespread in southern Texas along the Rio Grande (see section on Amistad National Recreation Area). The Devils River Limestone may be interpreted by others such as Maxwell and Dietrich (1965) as the Albian sequence including the Telephone Canyon Formation, Del Carmen Limestone, Sue Peaks Formation, and Santa Elena Limestone. This review is not intended to determine or establish which stratigraphic interpretation is correct. Thus both stratigraphic perspectives are presented.

According to Eley's interpretation the Devils River Limestone (Albian) is best exposed on the eastern escarpment of Mesa de Anguila (western portion of park) and within the Mariscal and San Vicente Mountains in the southeastern portions of the park. The Devils River Limestone is also exposed in the western escarpments of the Sierra del Caballo Muerto Mountains (eastern portion of park) and the Christmas Mountains (mostly outside of north-central boundary of the park). The uppermost beds of the Devils River Limestone are exposed in the Santiago Mountains near Persimmon Gap and Dog Canyon in the most northern part of the park. Fragments of invertebrate shells occur in the unit but tend to be poorly preserved locally (Eley 1938). A few interbedded shale layers occur in the cliffs at Mesa de Anguila contain good specimens of *Gryphea marcoui* and *Exogyra texana* (Eley 1938).

The faunal composition of the Devils River Formation appears to vary throughout the section as sediment deposition changed from mud-dominated to grain-dominated environments (Kerans and Zahm 1998). Fossils groups from within the Devils River Formation include benthic forams (Kerans and Zahm 1998, Johnson 2001, Scott 2002), corals (Kerans and Zahm 1998, Johnson 2001), rudist bivalves (Miller 1984, Kerans and Loucks 2002), oysters (Kerans and Loucks 2002), and ammonites (Young 1961, 1979).

Del Rio Clay (Upper Cretaceous)
The Del Rio Clay was established within an Upper Cretaceous (Cenomanian) marine clay unit in the Rio Grande Valley near Del Rio, Texas (see section on Amistad National Recreation Area). The Del Rio Clay

conformably overlies the Devils River Limestone (or equivalent stratigraphic unit in the Big Bend area) and has often been referred to as the *Exogyra arietina* clay in older literature based upon the abundance of this fossil. This unit is a light gray to buff epicontinental deposit representing near shore sediments. The Del Rio Clay thins northward and eventually the Buda Limestone lies directly on the Devils River Limestone.

The Del Rio Clay is exposed on Mesa de Anguila and in Dog Canyon along the western slopes of Sierra del Carmen (Maxwell and Dietrich 1965). The more common fossil taxa include *Exogyra artietina, E. graysonana, E. cartledgei, Heteraster texanus,* and *Haplostiche texana*. Additionally, midway between the mouth of Santa Elena Canyon and Lajitas are hills and ridges formed by the Del Rio Clay and Buda Limestone.

Buda Limestone (Upper Cretaceous)
The Buda Limestone at Big Bend National Park is an Upper Cretaceous (Cenomanian) unit which is subdivided into three members: 1) basal limestone member; 2) middle marly nodular limestone member; and 3) upper limestone member (Maxwell and Dietrich 1965). All three members are exposed along the west side of the Sierra del Carmen. Most of the fossils are concentrated in the middle marly limestone member and some of the more common taxa include: *Budaiceras* sp., *Exogyra clarki, Gryphaea graysonana, Lima wacoensis, Pecten romeri, Heteraster* sp., *Trigonia* sp., and *Turritella* sp.

Boquillas Formation (Upper Cretaceous)
The Upper Cretaceous Boquillas Formation unconformably overlies the Buda Limestone in the Big Bend area. The Boquillas Formation is divided into two members; the lower Ernst Member and upper San Vicente Member (Maxwell and Dietrich 1965). The Ernst Member (Late Cenomanian and Turonian) is a gray, buff, and yellow-brown flaggy limestone interbedded with gray and buff marl. The San Vicente Member (Coniacian) is a gray and blue-gray chalk and gray to buff argillaceous flaggy limestone. The contact between the two members is well represented in the San Vicente – Hot Springs area of the park. Maxwell and Dietrich (1965) present a biostratigraphic zonation of ammonites in the Boquillas Formation. The "*Coilopoceras* Zone" marks the top of the Ernst Member. The top of the San Vicente Member of the Boquillas Formation is identified by the presence of *Inoceramus undulatoplicatus*.

The Cenomanian – Turonian boundary has been established within the Boquillas Formation in Big Bend National Park (Powell 1963, Frush 1973). Foraminifera were collected from a locality on the bluffs along the Rio Grande between points 50 meters downstream to 150 meters upstream of Hot Springs. Frush and Eicher (1975) reported that the Cenomanian – Turonian boundary occurred at this location 37 meters above the base of the Boquillas Formation based on the last occurrence of the foram genus *Rotalipora*. Powell (1963, 1965) established the base of the Turonian at approximately 22.5 meters above the base of the Boquillas Formation from a locality just east of BIBE based upon molluscan fauna (*Tragodesmoceroides* and *Inoceramus labiatus*).

During March 1967, the Department of Geology, Colorado School of Mines conducted a field trip to Big Bend National Park. During the field trip a collection of marine invertebrates and a few shark's teeth were obtained from the Boquillas Formation. Other reports of fauna from this formation encompass vertebrates (Cicimurri and Bell 1996, Bell 2002, Bell and Von Loh 1998), cephalopods (Young 1958, Freeman 1961, Powell 1967, Hook and Cobban 1983, Young 1984, Cobban 1988, Kennedy and Cobban 1993), bivalves (Cobban and Hook 1980, Kennedy and Cobban 1993), and various microfossils (Huffman 1960, Frush and Eicher 1975, Graham 1995, Graham 1997).

The remains of marine reptiles known as mosasaurs have been reported from at least two localities in the Ernst Member of the Cretaceous Boquillas Formation in the eastern portion of Big Bend National Park (Bell 1991, 1995). Bell has proposed that two taxa of mosasaurs are represented in the collection of isolated remains recovered. The mosasaur remains are associated with the ammonite *Collignoniceras woollgari* indicating a Middle Turonian age. Bell and Von Loh (1998) reported 3 additional taxa of small primitive amphibious mosasauroids from these localities. They also amended the previous ammonite

identification to late Middle Turonian. A partial specimen of a large tylosaurine mosasaur was collected by Jim and Margaret Stevens from the San Vicente Member in the western part of the park (G.L. Bell, Jr., personal communication, 2007). Teeth of sharks, pycnodonts, and teleost fish also occur within the Ernst Member of the Boquillas Formation at BIBE (Bell 1991, 1995). Maxwell and others (1967) also report the remains of fish bones and sharks teeth from the Boquillas Formation in BIBE.

Pen Formation (Upper Cretaceous)
The Upper Cretaceous Pen Formation (Coniacian – Campanian) is a dark grayish-blue gypsiferous marl and clay that weathers yellow. The unit contains of concretionary limestone and layers of calcareous sandstone. Many of the concretions are disk-shaped, large (up to 4 feet in diameter), and sometimes contain fossils. One of the most fossiliferous concretionary beds is within a yellow clay generally about 300 feet above the base of the formation. This zone contains very large ammonites, pelecypods, and gastropods. Some of the more common fossil taxa include: *Exogyra ponderosa, Veniella conradi, Cyprimeria* sp., *Placenticeras* sp., *Delawarella delawarensis, Texanites* sp., *Eutrephoceras* sp., *Durania terlinguae, Trigonia* sp., and *Turritella* sp. (Maxwell and Dietrich 1965). Udden (1907) referred to this unit as the Terlingua Beds.

Mosley (1993) assessed the McKinney Springs tongue of the Pen Formation and determined the unit to contain four lithologic facies. According to Mosley, these integrading facies are, ascending order: the calcareous shale facies; interbedded sandstone and shale facies; the phosphate nodule facies; and, the silty shale facies. This series of lithofacies records deposition in a muddy shelf or prodeltic setting during the marine transgression, high water still stand, and subsequent deltaic progradation. The fauna in this unit is not abundant and exhibits a low species diversity (Mosley 1993).

The calcareous shale facies contains two different types of trace fossils. These include the ichnogenera *Fodichnia* and *Gyrolithes* (Mosley 1993). *Fodichnia* are horizontal and randomly directed feeding burrows. *Gyrolithes* traces are vertically oriented and spiral burrows. Macrofauna consists of large oysters (*Exogyra ponderosa*) and other bivalves including *Inoceramus vanuxemi* and *Durania* sp. Many of the bivalves exhibit evidence of epibionts which have encrusted or bored into the valves. Fragments of turtle shell and dinosaur bones are also present in this unit.

The interbedded sandstone and shale facies contains alternating thin beds of sandstone and shale. The sandstone beds contain poorly preserved specimens of *Inoceramus* sp. The shale beds contain Exogyra ponderosa ranging in size from 15 to 20 centimeters in diameter, oriented in life position, and contain clionid sponge and lithophagid borings in the shell material (Mosley 1993).

The phosphate nodule facies is a lag deposit which contains rounded and abraided skeletal material. Shark teeth from three species are common including: *Scapanorhynchus texanus, Squalicorax kaupi*, and *Cretolamna* sp. (Mosley 1993). Small inoceramid bivalves, small mactrid bivalves, small gastropods, and an occasional crab are also known from this unit (Mosley 1993). Adjacent to this phosphatic lag in the westernmost parts of the park and just outside the park boundary are plates from a large undescribed floating crinoid (G.L. Bell, Jr., personal communication, 2007)

Within the silty shale facies, there are several thin sandstone beds which contain well developed trace fossils (*Fodichnia*). Macrofauna consists of occasional shark teeth and fish vertebrae. Two types of ammonites (*Placenticeras* sp. and *Baculites* sp.) are present in the upper portion of the facies (Mosley 1993). Small clusters of *Inoceramus biconstrictus* bivalves also occur in this facies.

The lower part of the Pen Formation west of the park has produced several vertebrate taxa including the sharks *Squalicorax kaupi, Cretolamna appendiculata, Scapanorhynchus* sp., and *Ptychodus mortoni*. Several species of fish including articulated specimens of the bonefish *Albula*, a toxocheliid turtle, and the mosasaurs *Clidastes liodontus* and *Tylosaurus* sp. (G.L. Bell, Jr., personal communication, 2007).

The remains of the giant teleost fish *Xiphactinus* and the ray *Ptychotrygon,* along with gar, are noted from the Campanian portion of the Pen Formation (Standhardt 1986; Wick, personal communication, 2006; Hunt, et al. 2006). Sharks are well known from both the Pen and the Aguja Formation, with known species including *Lissodus selachos, Squalicorax kaupi*, *Cretorectolobus olsoni, Ischyrhiza mira, Scapanorhynchus texanus*, *S. raphidon*, *Cretolamna appendiculata*, *Odontaspis*, *Anomotodon angustidens* and *Lamna appendiculata* (Standhardt 1986; Lehman 1985).

Aguja Formation (Upper Cretaceous)
The Upper Cretaceous Aguja Formation (Campanian) represents two progradational cycles of marine and non-marine sedimentary rocks. In the late 1800s the Aguja Formation was originally referred to as the "Rattlesnake Beds" and was first studied by Udden (1907). The unit was later formally described and named the Aguja Formation by W.S. Adkins (1933). The base of the Aguja Formation consists of a yellow, yellow-brown marine sandstone which lies unconformably on an eroded surface of the Pen Formation. Above the basal sandstone are fossiliferous clays which contain the fossil taxa: *Flemingostrea* sp., *Exogyra ponderosa, Inoceramus cummingsi* and *Texanites* sp. (Maxwell and Dietrich 1965).

The non-marine Aguja Formation consists of continental, lacustrine, and lagoonal deposits. The lithologies include: 1) yellow to yellow brown, argillaceous, cross-bedded sandstones with ripple-marks; 2) a variegated clay with calcareous nodules; 3) calcareous clay; 4) fresh water limestones; 5) dark carbonaceous clay with coal seams (Maxwell and Dietrich 1965).

The upper portions of the Aguja Formation contain a rich vertebrate fauna including gar scales, shark teeth, turtles, crocodiles, and dinosaurs. Dinosaur remains were first recognized from Cretaceous (Campanian / Maastrichtian) strata in the Big Bend region since the late 1800s. Over a century of paleontological field work has yielded an important assemblage of Cretaceous dinosaurs and other vertebrates from areas now administered as Big Bend National Park. The vertebrate fauna is equivalent to the Judith River (Judithian) fauna from Montana and Alberta, Canada.

Petrified wood is abundant in the upper Aguja Formation in BIBE. Silicified logs are documented up to 40 feet in length and 5 feet in diameter. Most of the petrified wood is believed to be gymnosperm, however, some angiosperm and palm wood has been identified. Wheeler (1993) reports on the occurrence of dicot wood from the Aguja Formation in BIBE. Fossil dicots from the park include woods of the platnoid (sycamore-like) and phyllanthoid types. Cretaceous dicots are relatively rare in the fossil record with fewer than 100 localities worldwide. In addition, Wheeler (1993) documented at least five other wood types, which represent new taxa of tropical trees.

An important Upper Cretaceous megafossil plant locality was discovered in an upper shale unit of the Aguja Formation in BIBE (Baghai 1998). Impressions of leaves, stems, seeds and fruits are well preserved in a tan to dark brown shale. The flora includes a diverse assemblage of both gymnosperms and angiosperms. Dorf (1939) reported on a small collection of plant fossils collected by Barnum Brown. Most notably is a well preserved palm specimen assigned to the genus *Sabalites*.

Hunt and others (2006) report on a diversity of fossil fish and shark remains from the Aguja Formation of Big Bend National Park. Sharks are well known from both the Pen and the Aguja Formation, with known species including *Lissodus selachos, Squalicorax kaupi*, *Cretorectolobus olsoni, Ischyrhiza mira, Scapanorhynchus texanus*, *S. raphidon*, *Cretolamna appendiculata*, *Odontaspis*, *Anomotodon angustidens* and *Lamna appendiculata* (Standhardt 1986; Lehman 1985). The sawfish *Ochopristis*, the rays *Squatirhina americana, Myledaphus bipartitus, Ptychotrygon agujaensis,* along with the bowfin *Melvius thomasi* and the gars *Lepisosteus* and *Atractosteus* are also known from the Aguja Formation (Late Campanian/Early Maastrichtian; McNulty and Slaughter 1972; Boreske 1974; Davis 1983; Lehman 1985; Standhardt 1986; Mosley 1993; Wick, personal communication, 2006).

A new genus and species of fossil sea turtle was discovered within the Aguja Formation in Big Bend National Park. The marine turtle was described and named *Terlinguachelys fischbecki* by Lehman and Tomlinson (2004).

During 1940 the American Museum of Natural History conducted a paleontological expedition into the Big Bend region of west Texas. During this expedition Barnum Brown discovered fragmentary remains of the skull, jaws, and other bones of a gigantic crocodile which is estimated to be up to 35 - 40 feet in length. The specimen was discovered near Glen Springs in the Cretaceous Aguja Formation within Big Bend National Park (Colbert and Bird 1954). The crocodile specimen, originally named *Phobosuchus riograndensis,* was excavated by Barnum Brown and Roland Bird. Bird later prepared the specimen, which was renamed *Deinosuchus*, and is on display at the American Museum of Natural History in New York.

As a graduate student at the University of Texas at Austin, Thomas Lehman began to research a ceratopsian bone bed from the Aguja Formation in BIBE (Lehman 1982). Lehman (1989b) reports on a new ceratopsian dinosaur from a bone bed in the Aguja Formation of the park. *Chasmosaurus mariscalensis* was identified as a new species from the park based upon 10 – 15 partial skeletons representing adult, subadult, and juvenile specimens.

During March 1991, a large and fairly complete *Chasmosaurus* skull was discovered in the park by University of Chicago undergraduate Tom Evans during a field trip (Forster and Sereno 1993; Forster et al. 1993). The analysis of chasomsaurine characters may shed light on the biogeographic history of northern and southern taxa and their dispersal in North America. The discovery of this specimen in Big Bend National Park resulted in some national media attention.

A microvertebrate locality in the Aguja Formation within BIBE has yielded remains of Cretaceous mammals. The microvertebrate assemblage has been referred to as the Terlingua Local Fauna and includes at least six multituberculate taxa and is tentatively assigned to "Judithian" land mammal age. Sankey (2005) reports on a vertebrate assemblage from the basal sandstone unit of the Aguja Formation.

Javelina Formation (Upper Cretaceous)
The Upper Cretaceous Javelina Formation (Maastrichtian) is predominantly a clay unit with some lenticular masses of yellow to brown, cross-bedded sandstones (Maxwell and Dietrich 1965). The clay is bentonitic and variegated with color bands of gray, green, maroon and brown and forms a badlands topography. Channel sandstones within the Javelina Formation contain petrified wood and vertebrate bones.

Lawson (1976) briefly describes a microflora consisting of thirty-seven species which was collected from a lignite bed in the lower portion of the Javelina Formation in the western portion of BIBE. The flora included twelve ferns, five gymnosperms, and fifteen angiosperms. The angiosperms include: *Alnipollenites trina, Betulaceoipollenites infrequens, Faguspollenites granulatus,* and *Bombacacipites nacimientoensis*.

Wheeler and others (1994) describe a new form of Late Cretaceous dicotyledonous tree from BIBE. The new genus and species *Javelinoxylon multiporosum* is described from the Javelina Formation. The wood structure of this new taxon is different from other known dictoyledenous wood from the Cretaceous. One log approximately 70 cm in diameter contains well-preserved termite galleries (Wheeler et al. 1994).

Gar scales are locally abundant and the rays *Rhombodus* and *Dasyatis* are reported from this unit (Hunt et al. 2006; Hunt 2005; Schmidt, personal communication, 2006).

In 1971 the remains of the largest known flying creature were discovered at Big Bend National Park by a University of Texas, Austin, graduate student named Doug Lawson. Lawson collected some of the bones

found in the Cretaceous Javelina Formation and presented them to Dr. Wann Langston at the Texas Memorial Museum. The men eventually determined that these bones were from a large flying reptile referred to as a pterosaur. In fact, these bones were part of the radius from the largest known flying creature with an estimated wingspan of about 11 meters. The specimen represented a new genus and species. Therefore the type specimen of *Quetzalcoatlus northropi* was originally described and named based upon the specimen discovered in BIBE (Lawson 1975). The pterosaur is named after the Aztec Feathered Serpent god Quetzalcoatl. Similar fossils have been found in the traditional Aztec homeland in northern Mexico and the southwest United States. The bones of this giant pterosaur may have influenced the image of mythic figures such as Quetzalcoatl although there is currently no definitive evidence of such a connection (Kenworthy et al. 2006; Mayor 2005).

During 1970 a small left maxilla with teeth of *Tyrannosaurus rex* was discovered in the Javelina Formation in the northeast portion of BIBE (Lawson 1976). A cast of the T. rex maxilla is on display in the Panther Junction Visitor Center. Additionally, Lawson (1976) reports that a portion of the frill of a ceratopsian dinosaur identified as *Torosaurus utahensis* was found in the same area in 1972. Hunt (2005) has undertaken an assessment of *Torosaurus* from Big Bend National Park.

In 1999, researchers discovered approximately 8 meter (27 feet) long section of cervical vertebrae of a large sauropod dinosaur belonging an enigmatic group referred to as the alamosaurids. The vertebrae were exceptionally well preserved and, at the time, represented the first known occurrence of cervical vertebrae for an adult of the species *Alamosaurus*. The specimen was discovered in an area of the park designated as wilderness. Given the scientific significance and the fact that the specimen was threatened by weathering, erosion, or theft / vandalism, that the park management initiated an environmental assessment (EA) before any decision was made regarding whether to issue a permit to collect the large dinosaur fossil. Based upon the information compiled within the EA and the public comment received, the park selected the "preferred alternative", to issue a scientific research and collecting permit to the Dallas Museum of Natural History (DMNH) for the excavation, collection and study of the rare dinosaur specimen.

Two of only three known Chasmosaurine dinosaur bone beds in the world are located in Big Bend National Park. A taphonomic study of these bone beds was undertaken by Hunt (2006).

Early Tertiary Stratigraphy
The early Tertiary strata at BIBE can be broadly divided into a lower non-volcanic unit and an upper volcanic unit (Maxwell and Dietrich 1965). The non-volcanic strata are primarily conglomerate, sandstone, and clay lithologies of the Blacks Peak Formation (Paleocene) and Hannold Hill Formation (Lower Eocene). The upper volcanic unit includes the Canoe Formation (Eocene), Chisos Formation (Upper Eocene), and South Rim Formation (Oligocene?). In BIBE there is an angular unconformity between the top of the non-volcanic unit (Hannold Hill Formation) and the base of the volcanic unit (Canoe Formation).

Black Peaks Formation (Upper Cretaceous / Paleocene)
The Black Peaks Formation is a yellow-gray and white sandstone deposited on an eroded surface of the Javelina Formation. This contact represents the Cretaceous / Tertiary boundary and is the earliest known Tertiary deposit in West Texas. A juvenile specimen of *Alamosaurus sanjuanensis* was recovered from the Black Peaks Formation immediately at the contact with the underlying Javelina Formation within BIBE (Coulson 1998; Lehman and Coulson 2002). The juveniles sauropod represents the youngest and stratigraphically highest dinosaur-bearing locality in this region.

The Tertiary portion of the sequence is well exposed on the eastern side of Tornillo Flat. An *in situ* fossil exhibit was established in Tornillo Flat approximately ¼ mile north of the Tornillo Creek Bridge. During renovation of the exhibit in the late 1980s, park staff excavated the *in situ* remains and replaced them with replica fossils. Schiebout (1973, 1974) identified thirty-one species of mammals from the Black Peaks Formation in BIBE. This mammalian assemblage represents the southernmost large Paleocene fauna in

North America. Wilson and others (1952) have been able to use mammalian remains found in the Black Peaks Formation to assign this unit to the Paleocene. Some of the mammalian taxa include: *Phenacodus grangeri, Tetraclaenodon puercensis,* and *Psittacotherium multifragum*. Gar scales are locally abundant and the rays *Rhombodus* and *Dasyatis* are reported from this unit (Hunt et al. 2006). Fresh water clams and gastropods, along with abundant petrified wood, also occur within the Black Peaks Formation.

Wheeler (1993) has documented over 30 logs in the Paleocene Black Peaks Formation in BIBE. All of these logs have been identified as a single new species *Paraphyllanthoxylon abbotti.* The species name was assigned to recognize the late Maxine Abbott who collected the material. The wood from this fossil dicot species is a platanoid type and represent the only Paleocene dicot woods described from the United States (Wheeler 1993). Paleocene dicots are relatively rare worldwide with only 40 known localities.

Hannold Hill Formation (Eocene)
The Eocene Hannold Hill Formation is predominantly a clay unit which contains conglomerate and channel sandstone deposits. The lithology is similar in color and texture to the Cretaceous Javelina Formation and is difficult to differentiate. Fossils are the most useful evidence to distinguish these units. The remains of mammals, gar, and the ray *Myliobatis* are reported from the Hannold Hill Formation in BIBE (Hunt et al. 2006). Mammalian fossil taxa include *Coryphodon* sp., *Phenacodus primaevus* (primitive carnivore) and *Hyracotherium* sp. (early horse).

Some authors recognize the Tornillo Group designation which includes the Javelina, Black Peaks, and Hannold Hill formations (Lehman 1988). Schiebout and others (1987, 1988) proposed some changes in the stratigraphic interpretation of the Tornillo Group based upon mammalian biostratigraphy.

Canoe Formation (Eocene)
The Middle Eocene Canoe Formation is the basal volcanic unit and is composed of sandstone, conglomeratic channel sandstone with igneous pebbles, tuffaceous clay and mudstone, vitric tuff and some lava beds (Maxwell and Dietrich 1965). The lower portion of the Canoe Formation is a conglomeratic sandstone with pebbles of chert, novaculite, and igneous rock. Above the sandstone is an interval of clay in which the amount of tuff increases upward in the section. The upper beds of the Canoe Formation are predominantly tuff with some basaltic flows. Mammalian fossil remains in the Tornillo Flat area has helped to date the Canoe Formation to Middle Eocene (Bridgerian). Some of the mammalian fossil taxa include *Hyrachyus* sp. and *Helohyus lentus*.

Chisos Formation (Eocene)
The Upper Eocene Chisos Formation consists of coarse, massive conglomerate, tuffaceous sandstone, tuff, and several lava flows (Maxwell and Dietrich 1965). The Chisos Formation constitutes a thick blanket of sediments and interbedded volcanic flows accumulated on a highly irregular surface eroded on Cretaceous and early Tertiary rocks. The lava flows range in composition from rhyolite to basalt and ash-flow tuff. A unique succession of volcanic flows and sediments accumulated around several centers of volcanic eruption.

Isolated fossiliferous zones or horizons have been discovered during mapping and provided opportunities for relative dating of sequences of rock. At one locality near Cerro Castellan a skull and partial skeleton of a dog-like carnivore identified as *Uintacyon* sp., along with some turtle and other tooth and bone fragments tentatively identified as rhinoceratid, were collected from a brownish mudstone bed above the Alamo Creek Basalt within the Chisos Formation (Maxwell and Dietrich 1965). The small faunal assemblage in the mudstone enabled this bed to be identified as Uintan. The remains of fossil mammals include *Archaeolgus* sp. (rabbit), *Stenomylus crassipes* (camel), *Oxydactylus gibbi* (camel), *Nanotragulus* sp. (small deer) and *Hypsiops luskensis* (sheep-like grazer).

South Rim Formation (Oligocene?)
The South Rim Formation is the youngest of the early Tertiary volcanics in BIBE. This formation consists of thick lavas, flow breccias, tuff, and other pyroclastic rocks, along with conglomerate (Maxwell and

Dietrich 1965). The South Rim Formation has not been precisely dated and fossils have not been found within the formation. An Oligocene age for the formation has been assigned by Maxwell and Dietrich (1965).

Delaho Formation (Miocene)
A small collection of fossil vertebrates have also been made from the Miocene Delaho Formation in Big Bend National Park (Stevens 1971; Stevens 1991; Stevens et al. 1969). Some of the earliest Miocene vertebrate fossils (Late Arikareean) have been discovered in a lower informal member of the Delaho Formation southwest of Castolon in the park. The locality was first discovered by Dr. John A. Wilson (University of Texas, Austin) in 1963. The vertebrates from this locality have been identified as the Castolon Local Fauna (Stevens 1977; Stevens 1991; Stevens et al. 1969; Stevens and Stevens 1989).

Old Gravel Beds (Miocene?)
Approximately one-fourth of the surface deposits at BIBE are alluvium and colluvium. These terrestrial deposits vary widely in lithology, thickness, and age. Maxwell and Dietrich (1965) reference the Old Gravel Beds which are exposed in most of the fault block valleys southwest of the Chisos Mountains. In the valley immediately southeast of Cerro Castellan and east of the ridge that extends southward from that peak is a silty deposit that has yielded a Miocene mammalian fauna (Maxwell and Dietrich 1965). Skulls and teeth have been identified to the following taxa *Archaeolagus* sp., *Stenomylus crassipes, Oxydactylus gibbi, Nannotragulus* sp., and *Hypsiops luskensis*.

Silts and Gravels (Pliocene-Pleistocene)
Deposits of unnamed Pliocene silts and gravels in Estufa Canyon have produced a small vertebrate fauna. Between 1985 – 1987, the field parties from the Texas Memorial Museum, including Margaret Stevens, collected fossil remains of turtles, rodents, lagomorphs, carnivores, artiodactyls, and perissodactyls from these Pliocene deposits of Estufa Canyon (Reeder 1987). Stevens (1993) reports that some very important specimens were collected in 1990 from a locality in the lower Tornillo Creek – Estufa Canyon areas in BIBE. One specimen was the partial skull of the horse *Hipparion forcei* and the other specimen was the lower jaw, rib, and vertebrae from a long-jawed mastodon.

Based on a visitor report in 1987, Margaret Stevens was able to locate a fragmentary tusk of a Pleistocene proboscidean in a wash near Dog Canyon in the northern panhandle of the park (Reeder 1987).

Paleontological Resources in BIBE Caves
Many of the Cretaceous limestones of Big Bend are cavernous, notably the Upper Cretaceous Santa Elena Formation. The caves generally are small in size and somewhat inaccessible.

In the Chisos Mountains there is an important paleontological locality within Mule Ears Peak Cave (Santucci et al. 2001). This cave is formed within a cluster of Tertiary intrusive dikes associated with the Chisos Formation. In 1932, Mule Ears Peak Cave #1 and #2 were excavated by Frank M. Setzler from the U.S. National Museum (D. Corrick, personal communication, 2001). Twenty-seven condor bones, representing three individuals identified as *Gymnogyps californianus* (California condor), were collected during the excavation (Seltzer 1935). Radiocarbon analysis of condor material from Mule Ears Cave yielded a date of 12,580 years B.P. (Emslie 1987).

A cave survey is currently underway at Big Bend National Park. This survey is designed to more fully document both the paleontological and archaeological resources within the caves of Big Bend (D. Corrick, personal communication, 2001).

INTERPRETATION

The Panther Junction Visitor Center at Big Bend is largely devoted to the interpretation of the Late Cretaceous and Early Tertiary paleontology of the park. An *in situ* fossil exhibit called the Fossil Bone

Exhibit is maintained in the Tornillo Flats area of the park. The original *in situ* exhibit was relocated in order to make the trail handicap accessible. This exhibit focuses on the early Tertiary mammals found at Big Bend. The park has also developed a site bulletin on the park fossils titled "Dinosaurs, Pterosaurs, and Crocodiles".

Two paleontology interns were hired at Big Bend National Park through the NPS Geologic Resource Division's Geologists-In-Park (GIP) Program. Jessica Toubman (1999) and Scott Gainer (2000) worked closely with BIBE Park Geologist Don Corrick and GRD Paleontologist Vincent Santucci to conduct an begin compiling information regarding paleontological research and resource management at Big Bend.

The park archives contain a collection of important reports and photos which relate to paleontological field activities and research spanning from the late 1930's through the recent.

REFERENCES CITED

Baghai, N.I. 1998. Reconstructing paleoecology and paleoclimatology from Campanian plant megafossils and dispersed cuticles, Big Bend National Park, Texas. In R.A. Hunter (ed.), Tate Museum Guidebook #3: 35-45.

Bell, G.L., Jr. 1991. Middle Turonian Mosasauroids from the Cretaceous Boquillas Formation, in Big Bend National Park, Texas. Geological Society of America, Abstracts with Programs, Rocky Mountain Section Meeting, Abstract No. 2050, p. 3.

Bell, G.L., Jr. 1995. Middle Turonian (Cretaceous) Mosasauroids from Big Bend National Park, Texas. In V.L. Santucci and L. McClelland (eds.), National Park Service Paleontological Research, Volume 2, NPS/NRPO/NRTR-95-16, p. 55-64.

Bell, G.L., Jr. 2002. The questionable monophyly of Mosasauridae. Society of Vertebrate Paleontology Abstracts 22(3):35A.

Bell, G.L., Jr. and J.P. Von Loh 1998. New records of Turonian mosasauroids from the western United States. In Martin, J.E., J.W. Hoganson and R.C. Benton (eds.), Partners Preserving Our Past, Planning our Future: Proceedings for the Fifth Conference on Fossil Resources, Dakoterra 5: 15-28.

Boreske, J. 1974. A review of the North American fossil Amiid fishes Museum of Comparative Zoology Bulletin, v. 146, p. 1-87.

Cicimurri, D.J. and G.L. Bell, Jr. 1996. Vertebrate fauna of the Boquillas Formation of Brewster County, Texas; a preliminary report. Society of Vertebrate Paleontology Abstracts 16(3):28.

Cobban, W.A. 1988. *Tarrantoceras* Stephenson and related ammonoid genera from Cenomanian (Upper Cretaceous) rocks in Texas and the Western Interior of the United States, U. S. Geological Survey, Reston, VA. Professional Paper. 51 pages.

Cobban, W.A. and Hook, S.C. 1980. Occurrence of *Ostrea beloiti* Logan in Cenomanian rocks of Trans-Pecos Texas; southeastern New Mexico and West Texas. Pages 169-172 *in* P. W. Dickerson, J. M. Hoffer, and J. F. Callender, editors. New Mexico Geological Society Guidebook 31.

Colbert, E.H., and R.T. Bird. 1954. A Gigantic Crocodile from the Upper Cretaceous beds of Texas. American Museum of Natural History Novitates 1688, 22 pp.

Coulson, A.B. 1998. Sedimentology and taphonomy of a juvenile *Alamosaurus* site in the Javelina Formation (Upper Cretaceous), Big Bend National Park, Texas. Unpublished M.S. Thesis, Texas Tech University, Lubbock, 103 p.

Davies, K.L. 1983. Hadrosaurian dinosaurs of Big Bend National Park, Brewster County, Texas [M.S. Thesis]: Austin, University of Texas, 235 p.

Dorf, E., 1939. Fossil plants from the Upper Cretaceous Aguja Formation of Texas. American Museum Novitates, No. 1015, 9p.

Forster, C.A. and P.C. Sereno. 1993. *Chasmosaurus mariscalensis* skull from Big Bend National Park. In V.L. Santucci (ed.), National Park Service Paleontological Research Abstract Volume 1; National Park Service Technical Report NPS/NRPEFO/NRTR-93-11, p. 14.

Forster, C.A., P.C. Sereno, T.W. Evans, and T. Rowe 1993. A complete skull of *Chasmosaurus mariscalensis* (Dinosauria: Ceratopsidae) from the Aguja Formation (Late Campanian) of West Texas. Journal of Vertebrate Paleontology 13(2): 161-170.

Freeman, V.L. 1961. Contact of Boquillas Flags and Austin Chalk in Val Verde and Terrell counties, Texas. Bulletin of the American Association of Petroleum Geologists 45(1):105-107.

Frush, M.P. 1973. Cenomanian and Turonian foraminfera, Big Bend region of Texas and Mexico. Unpublished M.S. Thesis, University of Colorado, Boulder.

Frush, M.P. and D.L. Eicher 1975. Cenomanian and Turonian foraminifera and paleoenvironments in the Big Bend Region of Texas and Mexico. Geological Association of Canada Special Paper No. 13: 277-301.

Graham, J.M. 1995. Lithostratigraphy, microfacies and foraminiferal biostratigraphy of the Santonian-lower Campanian strata in the Trans-Pecos region, West Texas. University of Texas at Dallas, Richardson, TX. PhD Dissertation. 432 pages.

Graham, J.M. 1997. Planktonic foraminiferal biostratigraphy and depositional setting of the Santonian-lower Campanian (Upper Cretaceous) of the Trans-Pecos region, West Texas. Geological Society of America Abstracts with Programs 29(6):53.

Hook, S.C. and Cobban, W.A. 1983. Mid-Cretaceous molluscan sequence at Gold Hill, Jeff Davis County, Texas, with comparison to New Mexico. Contributions to Mid-Cretaceous paleontology and stratigraphy of New Mexico Part II. New Mexico Bureau of Mines and Mineral Resources, Socorro, NM. Circular 185:48-54.

Huffman, M.E. 1960. Micropaleontology of lower portion of Boquillas Formation near Hot Springs, Big Bend National Park, Brewster County, Texas. Texas Tech University, Lubbock, TX. Master's Thesis. 54 pages.

Hunt, R.K. 2005. Ceratopsid Dinosaurs from the Javelina Formation (Maastrichtian) of Big Bend National Park, Texas [M.S. thesis]: Lubbock, Texas Tech University, 104 p.

Hunt, R.K. 2006. The taphonomy of a chasmosaurine dinosaur bone bed from the Javelina Formation (Maastrichtian) of Big Bend National Park, Texas. Geological Society of America Abstracts with Programs 38(4): 62.

Hunt, R.K., V.L. Santucci, and J. Kenworthy. 2006. A preliminary inventory of fossil fish from National Park Service units. In Lucas, S.G., Speilman, J.A., Hester, P.M., Kenworthy, J.P., and Santucci, V.L.

(eds.), Fossils from Federal Lands, New Mexico Museum of Natural History and Science Bulletin, 14, p. 63-69.

Johnson, C.C. 2001. Taxonomic and morphologic changes in corals and rudists from Aptian and Albian strata, Texas and Puerto Rico. Geological Society of America Abstracts with Programs 33(6):13.

Kennedy, W.J. and W.A. Cobban. 1993. Lower Cenomanian *Forbesiceras brundrettei* zone ammonite fauna in Texas, U.S.A. Neues Jahrbuch fuer Geologie und Palaeontologie. Abhandlungen 188(3):327-344.

Kenworthy, J. and V.L. Santucci. 2006. A preliminary inventory of National Park Service paleontological resources in cultural resource contexts, Part 1: General Overview. In Lucas, S.G., Speilman, J.A., Hester, P.M., Kenworthy, J.P., and Santucci, V.L. (eds.), Fossils from Federal Lands, New Mexico Museum of Natural History and Science Bulletin, 14, p. 70-76.

Kerans, C. and R.G. Loucks. 2002. Stratigraphic setting and controls on occurrence of high-energy carbonate beach deposits; Lower Cretaceous of the Gulf of Mexico. Gulf Coast Association of Geological Societies Transactions 52:517-526.

Kerans, C. and L.C. Zahm. 1998. Facies partitioning at the high-frequency sequence scale in carbonate ramp systems. American Association of Petroleum Geologists Annual Meeting Abstracts.

Langston, W. 1948. Report of Paleontologic Field Operations conducted in the Big Bend National Park by the West Texas Museum of Texas Technological College (July and August 1947). Typewritten Report in the Big Bend National Park Archives, 8 p.

Langston, W. 1973. Report of Vertebrate Paleontological Investigations, Big Bend National Park, Texas. Typewritten Report, The University of Texas at Austin, Texas, 7 p.

Lawson, D.A. 1975. Pterosaur from the Latest Cretaceous of West Texas: Discovery of the largest flying creature: Science, v. 187, p. 947-948.

Lawson, D.A. 1976. *Tyrannosaurus* and *Torosaurus*, Maastrichtian dinosaurs from Trans-Pecos Texas. Journal of Paleontology 50(1):158-164

Lehman, T.M. 1982. A ceratopsian bone bed from the Aguja Formation (Upper Cretaceous), Big Bend National Park, Texas. M.A. thesis, University of Texas at Austin, 209 pp.

Lehman, T.M. 1985. Stratigraphy, sedimentology, and paleontology of Upper Cretaceous (Campanian-Maastrichtian) sedimentary rocks in Trans-Pecos Texas [Ph.D. dissertation]: Austin, University of Texas at Austin.

Lehman, T.M. 1988. Stratigraphy of the Cretaceous-Tertiary and Paleocene-Eocene transition rocks of Big Bend National Park, Texas: a discussion: Journal of Geology, v. 96, 627-631.

Lehman, T.M. 1989b. *Chasmosaurus mariscalensis*, sp. nov., a new ceratopsian dinosaur from Texas. Journal of Vertebrate Paleontology 9(2): 137-162.

Lehman, T.M. and A.B. Coulson 2002. A juvenile specimen of the sauropod dinosaur *Alamosaurus sanjuanensis* from the Upper Cretaceous of Big Bend National Park, Texas. Journal of Paleontology 76(1): 156-172.

Lehman, T.M. and S.L. Tomlinson 2004. *Terlinguachelys fischbecki,* a new genus and species of sea turtle (Chelonioidea, Protostegidae) from the Upper Cretaceous of Texas. Journal of Paleontology 78(6): 1163-1178.

Maxwell, R.A. 1940. A brief history of the Big Bend Museum with list of species. Unpublished National Park Service Report, 25 pp.

Maxwell, R.A., Lonsdale, J.T., Hazzard, R.T. and Wilson J.A. 1967. Geology of Big Bend National Park, Brewster County, Texas: University of Texas Bureau of Economic Geology Publication 6711, 320 p.

Mayor, A. 2005. Fossil legends of the first Americans: Princeton, Princeton University Press, 446 p.

McNulty, C.L., Jr. and B.H. Slaughter. 1972. The Cretaceous Selachian genus, *Ptychotrygon* Jaekel, 1894: Eclogae Geologicae Helvetiaev, v. 65, p. 647–656.

Miller, B.C. 1984. Physical stratigraphy and facies analysis, Lower Cretaceous, Maverick Basin and Devils River Trend, Uvalde and Real counties, Texas. Bulletin of the American Association of Petroleum Geologists 68(4):508.

Mosley, J.L. 1993. Distribution of fossil material in the McKinney Springs Tongue of the Pen Formation (Late Cretaceous) Big Bend National Park, Texas, *in* Santucci, V.L., ed., National Park Service Paleontological Research Abstract Volume, National Park Service Petrified Forest National Park Technical Report NPS/NRPEFO/NRTR-93/11, p. 15.

Powell, J.D. 1963. Cenomanian – Turonian (Cretaceous) ammonites from Trans-Pecos Texas and northeastern Chihuahua, Mexico. Journal of Paleontology 37(2): 309-322.

Powell, J.D. 1965. Late Cretaceous platform – basin facies, northern Mexico and adjacent Texas. American Association of Petroleum Geologists Bulletin 49(5): 511-525.

Powell, J.D. 1967. Mammitine ammonites in Trans-Pecos Texas. The Texas Journal of Science 19(3):311-322.

Redfield, R.C. 1937. Paleontological report on the Chisos Region (Big Bend National Park). Report to the National Park Service, 21 p.

Sankey, J.T. 2005. Late Cretaceous vertebrate paleoecology Big Bend National Park, Texas; pp. 98-106 In: Dinosaur Park Symposium, Short Papers, Abstracts, and Program, D.R. Braman, F. Therrien, E.B. Koppelhus, and W. Taylor (eds.). Special Publication of the Royal Tyrrell Museum, September 24-25, 2005, Drumheller, Alberta, Canada.

Santucci, V.L. A.P. Hunt, and M.G. Lockley, 1998. Fossil vertebrate tracks in National Park Service areas. Dakoterra, vol. 5, p.107-114.

Santucci, V.L., J. Kenworthy, and R. Kerbo, 2001. An inventory of paleontological resources associated with National Park Service Caves. National Park Service Geologic Resources Division Technical Report, NPS/NRGRD/GRDTR-01/02, 50 pp.

Schiebout, J.A. 1973. Vertebrate paleontology and paleoecology of Paleocene Black Peaks Formation, Big Bend National Park, Texas. Ph.D. dissertation, University of Texas, Austin, 246 pp.

Schiebout, J.A. 1974. Vertebrate paleontology and paleoecology of Paleocene Black Peaks Formation, Big Bend National Park, Texas. Texas Memorial Museum Bulletin 24, 88 pp.

Schiebout, J.A., C.A. Rigsby, S.D. Rapp, J.A. Hartnell, and B.R. Standhardt. 1987. Stratigraphy of the Cretaceous-Tertiary and Paleocene-Eocene transition rocks of Big Bend National Park, Texas: Journal of Geology, v. 95, 359-375.

Schiebout, J.A., C.A. Rigsby, B.R. Standhardt, S.D. Rapp, and J.A. Hartnell. 1988. Stratigraphy of the Cretaceous-Tertiary and Paleocene-Eocene transition rocks of Big Bend National Park, Texas: a reply: Journal of Geology, v. 96, 631-634.

Scott, R.W. 2002. Upper Albian benthic foraminifers new in West Texas. Journal of Foraminiferal Research 32(1):43-50.

Seltzer, F.M. 1935. A prehistoric cave culture in southwestern Texas. American Anthropologist 37(1): 104-110.

Smith, C.I., J.B. Brown, and F.R. Lozo. 2000. Regional stratigraphic cross sections, Comanche Cretaceous (Fredericksburg-Washita Division), Edwards and Stockton plateaus, West Texas; interpretation of sedimentary facies, depositional cycles, and tectonics. University of Texas Bureau of Economic Geology, Austin, TX. 39 pages.

Standhardt, B.R. 1986. Vertebrate paleontology of the Cretaceous/Tertiary Transition of Big Bend National Park [Ph.D. dissertation]: Baton Rouge, Louisiana State University and Agricultural and Mechanical College, 229 p.

Stevens, M. 1993. Stratigraphy and vertebrate paleontology of the Late Tertiary sediments, lower Tornillo Creek – Estufa Canyon areas, Big Bend National Park. In V.L. Santucci (ed.), National Park Service Paleontological Research Abstract Volume 1; National Park Service Technical Report NPS/NRPEFO/NRTR-93-11, p. 16.

Wheeler, E. 1993. Fossil dicotyledonous wood of Big Bend National Park, Texas. In V.L. Santucci (ed.), National Park Service Paleontological Research Abstract Volume 1; National Park Service Technical Report NPS/NRPEFO/NRTR-93-11, p. 17.

Wheeler, E. A., T. M. Lehman, and P. E. Gasson. 1994. *Javelinoxylon*, an Upper Cretaceous dicotyledonous tree from Big Bend National Park, Texas, with presumed malvalean affinities. American Journal of Botany 81(6): 703-710.

Wilson, J.A. 1967. Report of vertebrate paleontological and geological investigations, Big Bend National Park, 1965 - 1966. Typewritten Report, The University of Texas at Austin, Texas, 3 p.

Wilson, J.A. 1969. Report of vertebrate paleontological investigations, 1968 – 1969, Big Bend National Park, Texas. Typewritten Report, The University of Texas at Austin, Texas, 4 p.

Wilson, J.A., R.A. Maxwell, J.T. Lonsdale, and J.H. Quinn. 1952. New Paleocene and Lower Eocene vertebrate localities, Big Bend National Park, Texas: Univ. Texas Bureau Econ. Geol., Report Inv. no. 14, p. 7.

Works Progress Administration. 1939. Report on Works Progress Administration Paleontological Project sponsored by the Texas College of Mines and Metallurgy. National Park Service Report for Big Bend National Park, 21 p.

Young, K.P. 1958. Cenomanian (Cretaceous) ammonites from Trans-Pecos Texas. Journal of Paleontology 32(2):286-294.

Young, K.P. 1961. Edwards Plateau ammonite localities. Pages A3-A5 *in* Southern Edwards Plateau. Gulf Coast Association of Geological Societies. Annual Meeting Guidebook.

Young, K.P. 1979. Edwards Plateau ammonites. Pages 59-75 *in* P. R. Rose, editor. Stratigraphy of the Edwards Group and equivalents, eastern Edwards Plateau, Texas. South Texas Geological Society, San Antonio, TX. Edition 2.

Young, K.P. 1984. *Hysteroceras* Hyatt [Cretaceous (Albian) ammonoid] in Texas and the Angola connection. The Texas Journal of Science 36:185-195.

ADDITIONAL REFERENCES

Abbott, M.L. 1985. Petrified wood from the Paleocene, Black Peaks Formation, Big Bend National Park, Texas. In Pause, P.H. and R.G. Spears (eds.), Geology of the Big Bend area and Solitario Dome, Texas. West Texas Geological Society, p. 141-142.

Adkins, W.S. 1933. Mesozoic System in Texas. In The Geology of Texas, vol. 1, Sellards, E.H., Adkins, W.S., and Plummer, F. (eds.), University of Texas Bulletin 3232: 240-518.

Ager, D.V., J.R. Underwood, and R.K. DeFord. 1963. New Cretaceous brachiopod from Trans-Pecos Texas. Journal of Paleontology, 37(2): 371-378.

Baghai, N. 1993. Plant and dinosaur interactions. In V.L. Santucci (ed.), National Park Service Paleontological Research Abstract Volume 1; National Park Service Technical Report NPS/NRPEFO/NRTR-93-11, p. 13.

Baghai, N. and J. DiBenedetto, 2001. An unusual dinosaur coprolite from the Campanian Aguja Formation, Texas. Transactions Gulf Coast Association of Geological Societies 51: 9-20.

Baker, C.L. 1927. Exploratory geology of a part of south-western Trans-Pecos Texas: Austin, The University of Texas Bulletin 2746, 70 p.

Baker, C.L. 1928. Desert range tectonics of Trans-Pecos Texas: Pan-American Geologist, v. 50, p. 341-373.

Baker, C.L. 1934. The geologic story of the Chisos Mountains. Unpublished Manuscript – Big Bend National Park Archives.

Baker, C.L. 1935. Major structural features of Trans-Pecos Texas: *in* Sellards, E.H., and Baker, C.L., The geology of Texas, Volume II, Structural and economic geology: The University of Texas at Austin, Bulletin 3401, p. 137-214.

Barker, D.S. 1980. Cenozoic igneous rocks, Sierra Blanca area, Texas, *in* Dickerson, P.W., and Hoffer, J. M., eds., Trans-Pecos region: New Mexico Geological Society 31st Annual Field Conference Guidebook, south-eastern New Mexico and West Texas, 314 p., p. 219-223.

Barker, D.S., C.D. Henry, and F.W. McDowell. 1986. Pine Canyon caldera, Big Bend National Park: a mildly peralkaline magmatic systems, in Price, J.G., Henry, C.D., Parker, D.F., and Barker, D.S. eds., Igneous geology of Trans-Pecos Texas, field trip guidebook and research articles: The University of Texas at Austin, Mining and Mineral Resources research Institute, Bureau of Economic Geology Guidebook No. 23, prepared from the 99th Annual Meeting, Geological Society of America, 360 p., p. 266-285.

Bell, G.L. 1993. A reevaluation of the systematic position of "*Mosasaurus*" *embeensis* Antunes (Mosasauroides: Squamata). Journal of Vertebrate Paleontology, Abstracts with Programs, 13(3): 26A.

Berry, E.W. 1919. An Eocene flora from Trans-Pecos Texas. U.S. Geological Survey Professional Paper P-125A, pp. 1-9.

Bohanan, J.P. 1987. Sedimentology and petrography of deltaic facies in the Aguja Formation, Brewster County, Texas. M.S. Thesis, Texas Tech University, Lubbock, Texas.

Bostik, W.C. 1960. Micropaleontology of the upper Eagle Ford and lower Austin groups, Big Bend National Park, Texas. Unpublished M.S. Thesis, Texas Tech University, Lubbock, Texas, 131 pp.

Brawley, T.R. 1961. Micropaleontology of the Del Rio Formation of Brewster County, Texas. Unpublished M.S. Thesis, Texas Tech University, Lubbock, Texas, 142 pp.

Busby, A.B. and T.M. Lehman. 1989. Vertebrate paleontology, biostratigraphy and depositional environments, latest Cretaceous and Tertiary, Big Bend area, Texas. Guidebook, Field Trip Numbers 1A, B, and C, 49th Annual Meeting of the Society of Vertebrate Paleontology, Austin, Texas.

Chang, S.W. 1973. Petrified Wood from the Paleocene, Black Peaks Formation, Big Bend National Park, Texas. M.S. Thesis. Sul Ross State University, Alpine, Texas.

Cifelli, R.L. 1994. Therian mammals of the Terlingua local fauna (Judithian), Aguja Formation, Big Bend of the Rio Grande, Texas. University of Wyoming, Contributions to Geology 30: 117-136.

Cobban, W.A. 1984. Mid-Cretaceous ammonite zones, Western Interior, United States. Geological Society of Denmark Bulletin 33: 71-89.

Cochran, R.A. and J.L. Rives. 1985. Soil survey of Big Bend National Park, part of Brewster County, Texas. Soil Conservation Service, Alpine, Texas, 117 p.

Dasch, E.J., R.L. Armstrong, and S.E. Clabaugh. 1969. Age of Rim Rock dike swarm, Trans-Pecos Texas: Geological Society of America Bulletin, v. 80, p. 1819-1824.

Dasch, E.J., C.D. Henry, J.G. Price, P.D. Kempton, and L.W. Snee. 1987. Rim Rock dike swarm, Trans-Pecos Texas: South-Central Section, Geological Society of American Abstracts with Programs, v. 19. p. 150.

Davies, K.L. 1983. Hadrosaurian dinosaurs of Big Bend National Park, Brewster County, Texas. MA. thesis, University of Texas, Austin, 235 pp. (E)

Deal, D.E. 1979. Evolution of the Rio Conchos-Rio Grande drainage system, in Walton, A.W., and Henry, C.D., eds., Cenozoic Geology of the Trans-Pecos Volcanic Field of Texas: The University of Texas at Austin, Bureau of Economic Geology, Guidebook 19, 193 p., p. 137-146.

DeCamp, D.W. 1985. Structural geology of Mesa de Anguila, Big Bend National Park, Texas, *in* Dickerson, P.W., and Muehlberger, W.R., eds., Structure and Tectonics of Trans-Pecos Texas: Field Conference Guidebook, West Texas Geological Society Publication 85-81, 278p., p. 127-135.

DeFord, R.K., and L.W. Bridges. 1959. Tarantula gravel, northern Rim Rock country, Trans-Pecos Texas: Texas Journal of Science, v. 11, p. 286-295.

Dickerson, E.J. 1966. Bolson fill, pediment, and terrace deposits of Hot Springs area, Presidio County, Trans-Pecos Texas [MA thesis}: Austin, Texas, The University of Texas at Austin, 100 p.

Dickerson, P.W. 1980. Structural zones transecting the southern Rio Grande Rift-preliminary observations, in Dickerson, P.W., and Hoffer, J.M., eds., Trans-Pecos region: New Mexico Geological Society 31st Annual Field Conference Guidebook, southeastern New Mexico and West Texas, 314 p., p. 63-70.

Dietrich, J.W. 1966. Geology of Presidio area, Presidio County, Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Quadrangle Map 28, with text, 45 p.

Echols, W.H. 1860. Camel expedition through the Big Bend country. U.S. 36th Congress, 2nd Session, Congressional Documents, vol. 2, Report of October 10, 1860.

Eley, H.M. 1938. The invertebrate paleontology of the Big Bend Park, Marathon, Texas. M.S. thesis, School of Geology, the University of Oklahoma, 118 pp.

Eley, H.M. 1938. Paleontology (invertebrate) of Big Bend region of Brewster County, Texas. Abstract – Oil and Gas Journal.

Ellison, S.P. 1962. Conodonts from Trans Pecos Paleozoic of Texas. Bulletin of the American Association of Petroleum Geologists 46(2): 266.

Emory, W.H. 1857. United States and Mexican boundary survey. U.S. 34th Congress, 1st Session, Executive Documents No. 135, vol. 1, pt. 1, p. 74-92; pt. 2, p. 49-61.

Emslie, S.D. 1987. Age and Diet of Fossil California Condors in Grand Canyon, Arizona. *Science* 237:768-770.

Farke, A. 2002. A review of *Torosaurus* (Dinosauria: Ceratopsidae) specimens from Texas and New Mexico. Journal of Vertebrate Paleontology, 22(3):52A.

Ferguson, K. M., T. M. Lehman, and R. T. Gregory. 1991. C- and O-isotopes of pedogenic soil nodules from two sections spanning the K/T transition in west Texas. Geological Society of America Abstract with Program.

Fiorillo, A.R. 1998. Preliminary report on a new sauropod locality in the Javelina Formation (Late Cretaceous), Big Bend National Park, Texas. In Santucci (ed.), National Park Service Paleontological Research Volume, NPS Geologic Resources Division Technical Report, NPS/NRGRD/GRDTR-98/01, p. 29-31.

Gingerich, P.D. 1979. *Lambertocyon eximius*, a new arctocyonid (Mammalia, Condylarthra) from the Late Paleocene of Western North America. Journal of Paleontology 53(3): 524-529.

Gustafson, E.P. 1986. Carnivorous mammals of the Late Eocene and Early Oligocene of Trans-Pecos Texas. Bulletin of the Texas Memorial Museum No. 33.

Harris, J.M. 1967a. Oligocene vertebrates from western Jeff Davis County, Trans-Pecos Texas [MA thesis]: The University of Texas at Austin, 1967, 164 p.

Harris, J.M. 1967b. *Toxotherium* (Mammalia: Rhinocerotoidea) from Western Jeff Davis County, Texas: The University of Texas at Austin, Texas Memorial Museum, The Pearce-Sellards Series, no. 9, 7p.

Harris, J.M., and A.E. Wood. 1969. A new genus of Eomyid Rodent from the Oligocene Ash Spring Local Fauna of Trans-Pecos Texas: The University of Texas at Austin, Texas Memorial Museum, The Pearce-Sellards Series, no. 14, 7 p.

Hartnell, J.A. 1980. The vertebrate paleontology, depositional environment and sandstone provenance of early Eocene rocks on Tornillo Flat, Big Bend National Park, Brewster County, Texas. M.S. thesis, Louisiana State University, 174 pp.

Henry, C.D. 1998. Geology of Big Bend Ranch State Park, Texas. University of Texas at Austin, Bureau of Economic Geology, Guidebook #27, 1:50,000 scale.

Henry, C.D. and F.W., McDowell. 1986. Geochronology of magmatism in the Tertiary volcanic field, Trans-Pecos Texas: in Igneous Geology of Trans-Pecos Texas, Field Trip Guide and Research Articles, eds. J.G. Price, C.D. Henry, D.F. Parker, D.S. Barker, Bureau of Economic Geology, University of Texas Guidebook 23: 99-122,

Henry, C.D., J.G. Price, and F.W. McDowell. 1983. Presence of the Rio Grande Rift in west Texas and Chihuahua, *in* Clark, K.F., and Goodell, P.C., Geology and mineral resources of north-central Chihuahua: El Paso Geological Society, Guidebook for the 1983 Field Conference, 455p., p. 108-118.

Hill, R.T. 1887. Present condition of knowledge of the geology of Texas. U.S. Geological Survey Bulletin No. 45: 9-89.

Hill, R.T. 1901. Running the canyons of the Rio Grande. Century Magazine 61: 371-387.

Hopkins, E.M.H. 1965. Sedimentology of the Aguja Formation, Big Bend National Park, Brewster County, Texas. M.A. Thesis, University of Texas, Austin, Texas.

Horgan, P. 1954. Great river – the Rio Grande in North American history. Rinehart and Company, Inc., New York, vol. 1 and 2, 1020 p.

Jacobs-L. 1995. Lone Star dinosaurs. Texas A&M University Press. College Station, TX, United States. Pages: 160.

Johnson, J.H. 1944. Algal reefs in Cretaceous Austin chalk of Terlingua District, Brewster County, Texas. Bulletin of American Association of Petroleum Geologists 28(1): 123-124.

Kalb, J. 1990. Reconnaissance survey of Albert Fay Ranch, Brewster County, Texas. Open File Report, University of Texas, Austin, Texas.

Klein, J.J. 1986. Paleoecology of the Aguja Formation, Brewster County, Texas. M.S. Thesis, Stephen F. Austin State University, Nacogdoches, Texas.

Kiver, E.P. and D.V. Harris. 1999. Geology of U.S. Parklands. John Wiley & Sons, Inc., New York, 902 pp.

Kues, B.S., T.M. Lehman, and J.K. Rigby, Jr. 1980. The teeth of *Alamosaurus sanjuanensis*, a Late Cretaceous sauropod. Journal of Paleontology 54(4): 864-869.

Langston, W.L. 1970. Unpublished field notes, University of Texas at Austin.

Langston, W.L. 1971. Vertebrate paleontology in Big Bend National Park. Open File Report, Texas Memorial Museum, Austin, Texas.

Langston, W.L. 1978. Summary of Paleontological Investigations, Big Bend National Park, Texas. The University of Texas at Austin, Texas.

Langston, W.L. 1986. Rebuilding the world's biggest flying creature: the second coming of *Quetzalcoatlus northropi*. In Pause, P.H. and R.G. Spears (eds.), Geology of the Big Bend area and Solitario Dome, Texas. West Texas Geological Society Publication 86—82, p. 125-128.

Lawson, D.A. 1972. Paleoecology of the Tornillo Formation, Big Bend National Park, Brewster County, Texas. Unpublished M.A. Thesis, University of Texas, Austin, 182 pp.

Lawson, D.A. 1975. Pterosaur from the latest Cretaceous of West Texas: discovery of the largest flying creature; Science 187:947-948.

Lehman, T.M. 1981. The Alamo Wash local fauna: A new look at the old Ojo Alamo fauna. In S. Lucas, K. Rigby and B. Kues (eds.), Advances in San Juan Basin Paleontology, pp. 189-221. Albuquerque: University of New Mexico Press.

Lehman, T.M. 1985a. Stratigraphy, sedimentology, and paleontology of Upper Cretaceous (Campanian-Maastrichtian) sedimentary rocks in Tran-Pecos Texas. Ph.D. dissertation, University of Texas, Austin. 299.pp

Lehman, T.M. 1985b. Transgressive-regressive cycles and environments of coal deposition in Upper Cretaceous strata of Trans-Pecos Texas. Transactions of the Gulf Coast Association of Geological Societies, 35: 431-438.

Lehman, T.M. 1986. Late Cretaceous sedimentation in Trans-Pecos Texas, in Pause', P.H., and Spears, R.G., eds., Geology of the Big Bend area and the Solitario Dome: West Texas Geological Society 1986 Field Trip Guidebook, publication 86-82, 279 p., p. 105-110.

Lehman, T.M. 1987. Late Maastrichtian paleoenvironments and dinosaur biogeography in the western interior of North America. Palaeogeography, Palaeoclimatology, Palaeoecology 60: 189-217.

Lehman, T.M. 1989a. Upper Cretaceous (Masstrich) paleosols in Trans-Pecos Texas: Geological Society of America Bulletin, v. 101, p. 188-203.

Lehman, T.M. 1990a. Upper Cretaceous (Maastrichtian) paleosols in Trans-Pecos Texas. Bulletin of the Geological Society of America 101: 188-203.

Lehman, T.M. 1990b. Paleosols and the Cretaceous / Tertiary transition in the Big Bend region of Texas. Geology, vol. 18: 362-364.

Lehman, T.M. 1996. A horned dinosaur from the El Picacho Formation of West Texas, and review of ceratopsian dinosaurs from the American southwest. Journal of Paleontology 70(3): 494-508. f

Lehman, T.M. 2002. Revisions to the Tornillo Group (Upper Cretaceous – Eocene), Big Bend National Park. Geological Society of America Abstracts with Programs 34(3): 10.

Lehman, T.M. in press. Growth and population age structure in the horned dinosaur Chasmosaurus. In, K. Carpenter (ed.), Horns and Beaks. Indiana University Press, Life of the Past Series.

Lehman, T.M. and A.B. Coulson. 2002. A juvenile specimen of the sauropod dinosaur *Alamosaurus sanjuanensis* from the Upper Cretaceous of Big Bend National Park, Texas. Journal of Paleontology 76(1): 156-172.

Lehman, T.M., F.W. McDowell, and J.N. Connelly 2006. First isotopic (U-PB) age for the Late Cretaceous *Alamosaurus* vertebrate fauna of west Texas, and its significance as a link between two faunal provinces. Journal of Vertebrate Paleontology 26(4): 922-928.

Lonsdale, J.T., R.A. Maxwell, J.A. Wilson, and R.T. Hazzard 1955. Geology of Big Bend National Park. West Texas Geological Society Guidebook, 1955 Spring Field Trip, Midland, Texas, 142 p.

Lucas, S.G. 1989. *Coryphodon* (Mammalia, Pantodonta) from the Hannold Hill Formation, Eocene of Trans-Pecos Texas: Pearce-Sellards Series No. 46, Texas Memorial Museum, The University of Texas at Austin: 1-16.

Lucas, S.G. and R.M. Schoch, 1987. Paleopathology of early Cenozoic *Coryphodon* (Mammalia: Pantodonta). Journal of Vertebrate Paleontology 7(2): 145-154.

Main, D.J. and A.R. Fiorillo. 2002. Results of the ground penetrating radar mapping technique at a dinosaur quarry in Big Bend National Park. Abstracts with Programs - Geological Society of America. 34; 6, Pages 539-540.

Main, D.J. and H. Montgomery. 2000. Paleoecology of a titanosaurid sauropod dinosaur locality within the Javelina Formation of Big Bend National Park. Geological Society of America. 32; 3, Pages 34.

Matthews, W.H. 1960. Texas fossils: An amateur collector's handbook. University of Texas Bureau of Economic Geology Guidebook No. 2, 123 p.

Mauldin, R.A. 1985. Foraminiferal biostratigraphy, paleoecology, and correlation of the Del Rio Clay (Cenomanian) from Big Bend National Park, Brewster County, Texas, to the Cerro de Muleros Area, Dona Ana County, New Mexico. M.S. Thesis, University of Texas, El Paso.

Maxwell, R.A. 1940. A brief history of the Big Bend Museum with list of specimens, U.S. Department of Interior National Park Service, unpublished report, 181 pp.

Maxwell, R.A. 1968. The big bend of the Rio Grande: A guide to the rocks, landscape, geologic history, and settlers of the area of Big Bend National Park. University of Texas at Austin, Bureau of Economic Geology, Guidebook #7, 1:62500 scale.

Maxwell, R.A. and J.W. Dietrich. 1965. Geologic summary of the Big Bend region. West Texas Geological Society Publication 65-51: 11-33.

Maxwell, R.A. and J.W. Dietrich. 1972. Geology of the Big Bend area, Texas: Field Trip Guidebook, West Texas Geological Society Publication 72-59, reprint, with additions, of Publication 65-51, 248 p.

Maxwell, R.A., J.T. Lonsdale, R.T. Hazzard, and J.A. Wilson. 1967. Geology of Big Bend National Park, Brewster County, Texas. University of Texas, Bureau of Economic Geology Publication 6711, 320 pp.

McDowell, F. W., T. M. Lehman, and J. N. Connelly. 2004. A U-Pb age for the Late Cretaceous Alamosaurus fauna of West Texas. Geological Society of America, Abstracts with Programs, 36(4):6.

McGrew, P. 1953. A new and primitive early Oligocene horse from Trans-Pecos, Texas. Fieldiana Geology 10(15): 167-171.

McNulty, C.L. and B.H. Slaughter. 1972. The Cretaceous selachian genus *Ptychotrygon* Jaekel 1894. Ecologae Geologicae Helvetiae 65(3): 647-655

Miller, H.T. 1978. Sedimentology and Petrology of the Javelina Formation, Big Bend National Park, Brewster County, Texas. M.S. Thesis. West Texas State University, Canyon, Texas.

Moon, C.G. 1953. Geology of the Agua Fria Quadrangle, Brewster County, Texas: Geological Society of American Bulletin, v. 61, p. 151-196.

Rapp, S.D. 1983. Sedimentology and magnetic polarity stratigraphy of the Black Peaks Formation, Big Bend National Park, Brewster County, Texas. M.S. thesis, Louisiana State University, Baton Rouge, 135 pp.

Rapp, S.D., B.J. MacFadden, and J.A. Schiebout. 1983. Magnetic polarity stratigraphy of the early Tertiary Black Peaks Formation, Big Bend National Park, Texas, J. Geol. 91:555-572.

Record, R.S. 1988. Paleoenvironmental analysis of coastal marsh deposits in the Aguja Formation, Late Cretaceous, Trans-Pecos Texas. M.S. Thesis, Texas Tech University, Lubbock, Texas.

Reeder, W.G. 1987. Summary of vertebrate paleontological investigations, 1985 – 1987, Big Bend National Park, Texas. Open File Report, Texas Memorial Museum, Austin, Texas.

Rigsby, C.A. 1982. Provenance and depositional environments of the middle Eocene Canoe Formation, Big Bend National Park Texas: MA thesis, Louisiana State University. Baton Rouge, 1-111.

Rigsby, C.A. 1982. Provenance and depositional environments of the middle Eocene Canoe Formation, Big Bend National Park Texas: MS thesis, Louisiana State University Baton Rouge, 112 pp.

Rigsby, C.A. 1986. The Big Yellow Sandstone: a sandy braided stream, *in* Pause, P.H., and Spears, R.G., eds., Geology of the Big Bend Area and Solitario Dome, Texas: West Texas Geological Soc. Publ. 86-82, p. 111-116.

Romer, A.S. 1940. Fossil collecting in the Texas Redbeds. Harvard Alumni Bulletin, 42: 1045-1049.

Rowe, T. 1990. Summary of vertebrate paleontological investigations, 1998-1990, Big Bend National Park, Texas. Open File Report – Office of Science and Resources Management, Big Bend National Park.

Rowe, T., R.L. Cifelli, T.H. Lehman, and A. Weil. 1992. The Campanian Terlingua Local Fauna, with a summary of other vertebrates from the Aguja Formation, Trans-Pecos Texas. Journal of Vertebrate Paleontology, 12(4): 472-493.

Runkel, A.C. 1988. Stratigraphy, sedimentology, and vertebrate paleontology of Eocene rocks, Big Bend region, Texas. Dissertation, University of Texas at Austin, 310 pp.

Runkel, A.C. 1989. Stratigraphy and depositional history of Cretaceous and Paleogene rocks, Trans-Pecos Texas, *in* Dickerson, P.W., Stevens, M.S., and Stevens, J.B., eds., Geology of the Big Bend and Trans-Pecos Texas: South Texas Geological Society Guidebook, prepared for the 74th Annual Convention, American Association of Petroleum Geologists.

Sanders, R.B. 1988. Sedimentology and isotope geochemistry of the Upper Cretaceous Ernst Member of the Boquillas Formation, Big Bend National Park, Texas. M.S. Thesis, Texas Tech University, Lubbock, Texas, 170 p.

Sankey, J.T. 2001. Late Campanian southern dinosaurs, Aguja Formation, Big Bend, Texas. Journal of Paleontology 75(1): 208-215.

Sankey, J.T. and W. Gose, 2001. Late Cretaceous mammals and magnetostratigraphy, Big Bend, Texas. Louisiana State University, Occasional Papers of the Museum of Natural Science 77: 1-16.

Sankey, J.T. and J.A. Schiebout, 2001. Late Cretaceous dinosaurs and other vertebrates in microvertebrate sites, Big Bend National Park, Texas. Proceedings of the 6th Conference on Fossil Resources, Grand Junction, Colorado.

Schiebout, J.A. 1970. Sedimentology of Paleocene Black Peaks Formation, western Tornillo Flat, Big Bend National Park, Texas. M.A. thesis, University of Texas, Austin, 114 pp.

Schiebout, J.A. 1977. *Schizotheroides* (Mammalia: Perissodactyla) from the Oligocene of Trans-Pecos, Texas. Journal of Paleontology, 5) : 455-458.

Schiebout, J.A. 1981. Effects of Sea Level Changes on the Distribution and Evolution of Early Tertiary Mammals. Transactions, Gulf Coast Association of Geological Societies. 31st. Annual Meeting.

Schiebout, J.A. 1982. A crossroads in the Beginning of the Age of Mammals. The Explorer, vol. 24, (2): 4-9.

Schiebout, J.A. 1995. The Paleocene / Eocene transition on Tornillo Flat in Big Bend National Park, Texas. In V.L. Santucci and L. McClelland (eds.), National Park Service Paleontological Research, Volume 2, NPS/NRPO/NRTR-95-16, p. 65-76.

Schiebout, J.A., J.T. Sankey, B.R. Standhardt, and J. Ramcharan. 1998. Louisiana State University Museum of Natural Science Collections from Late Cretaceous through Early Eocene microvertebrate sites, Big Bend National Park, Texas. In V.L. Santucci and L. McClelland (eds.), National Park Service Paleontological Research, Volume 3, NPS/NRGRD/GRDTR-98-01, p. 32-35.

Schiebout, J.A., and S.Y. Ting. 1981. Factors Governing Early Tertiary Fossil Mammal Distribution. Proceedings, International Symposium on Concepts and Methods in Paleontology. Barcelona, Spain.

Schroeder, M.R. 1988. Sedimentology and petrography of a distributary channel complex in the Aguja Formation (Late Campanian), Big Bend National Park, Texas. M.S. Thesis, Texas Tech University, Texas.

Sloan, R.E. 1969. Cretaceous and Paleocene terrestrial communities of western North America: Proc. N. Amer. Paleo. Convention, Part E, p. 427-453

Small, T.A. 1949. Cretaceous guide to fossils of the Rio Grande Valley, Big Bend District, Upper Dams and Reservoir Investigations. International Boundary and Water Commission, El Paso, Texas.

Smiser, J.S. 1936. Cretaceous echinoids from Trans-Pecos Texas. Journal of Paleontology 10(6): 449-480.

Standhardt, B.R. 1986. Vertebrate paleontology of Cretaceous/Tertiary transition of Big Bend National Park, Texas. Ph.D. dissertation, Louisiana State University, Baton Rouge, 298 pp. (B)

Standhardt, B.R. 1995. Early Paleocene (Puercan) vertebrates of the Dogie Locality, Big Bend National Park, Texas. In V.L. Santucci and L. McClelland (eds.), National Park Service Paleontological Research, Volume 2, NPS/NRPO/NRTR-95-16, p. 77-82.

Stenzel, H.B. 1944. Decapod crustceans from the Cretaceous of Texas. University of Texas Bulletin No. 4401: 401-476.

Stevens, J.B. 1969. Geology of the Castolon area, Big Bend National Park, Brewster County, Texas [PhD dissertation]: Austin, The University of Texas, 129 p.

Stevens, J.B. 1988. Mid-Tertiary and Pleistocene Sections, Sotol Vista to Cerro Castellan, Big Bend National Park, Trans-Pecos Texas, *in* Hayward, O.T., ed., Geological Society of America, Centennial Field Guide, V. 4, South Central Section: 468p., p. 429-434.

Stevens, J.B., and M.S. Stevens. 1986, An outline of the Cenozoic geologic history of the area around Big Bend National Park, *in* Stevens, J.B., Roberts, D.C.., and Stevens M.S., eds, Field seminar on the Big Bend, Trans-Pecos region, Texas: Houston Geological Society Spring Field trip Guidebook, 120 p., p. 45-73.

Stevens, M.S. 1969. New early Miocene formation and vertebrate local fauna, Big Bend National Park, Brewster County, Texas. Texas Memorial Museum, Austin, Texas, Pearce Sellards Series, no. 15, 53 pp.

Stevens, M.S. 1971. Second report on preliminary paleontological investigations of the Early Miocene Diablo Formation in the Castolon Area, Big Bend National Park, for the year 1971. Open File Report – Texas Memorial Museum, Austin, Texas.

Stevens, M.S. 1977. Further study of Castolon Local Fauna (early Miocene) Big Bend National Park, Texas. Texas Memorial Museum, Pearce-Sellards Series 28, 70 pp.

Steves, M.S. 1991. Osteology, systematics, and relationships of earliest Miocene *Mesocyon venator* (Carnivora: Canidae). Journal of Vertebrate Paleontology 11(1): 45-66.

Stevens-M.S and J.B. Stevens. 1994. Equidae (Perissodactyla) indicate later Miocene age for the Screw-Bean local fauna, youngest known Miocene fossil vertebrates, Trans-Pecos Texas. Abstracts with Programs - Geological Society of America. 26; 7, Pages 61..

Stevens, M.S., J.B. Stevens, and M.R. Dawson. 1969. New early Miocene formation and vertebrate local fauna, Big Bend National Park, Brewster County, Texas, Texas Memorial Museum Pearce-Sellards Series 15, 53 pp. (H)

Stevens, M.S., J.B. Stevens, and J.A. Wilson. 1984. Devil's Graveyard Formation (new) Eocene and Oligocene age Trans-Pecos Texas, Texas Memorial Museum Bulletin 32, 21 pp.

Stovall, J.W. 1984. Chadron vertebrate fossils from below the Rim Rock of Presidio County, Texas. Amer. J. Sci. 246: 78-95.

Straight, W.H. 1996. Stratigraphy and paleontology of the Cretaceous – Tertiary boundary, Big Bend National Park, Texas. Unpublished M.S. Thesis, Texas Tech University, Lubbock, 102 p.

Strain, W.S. 1939. Three quarries for dinosaur bones. Work Progress Administration. Texas College of Mines and Metallurgy, El Paso, Texas.

Strain, W.S. 1940. Report on Works Progress Administration Paleontological project sponsored by the Texas College of Mines and Metallurgy. Unpublished report submitted to the Works Progress Administration upon completion of Projects W.P. 10106, O.P. 465-66-3-374, 20 pp.

Strain, W.S. 1959. Blancan mammalian fauna from Rio Grande Valley, Hudspeth County, Texas: Geological Society of America Bulletin, v. 70. p. 375-377.

Strain, W.S. 1966. Blancan mammalian fauna and Pleistocene formations, Hudspeth County , Texas: The University of Texas at Austin, Texas Memorial Museum, Bulletin 10.,55 p.

Tomlinson, S. 1997. Late Cretaceous and Early Tertiary Turtles from the Big Bend Region, Brewster County, Texas. Unpublished PhD Dissertation, Texas Tech University. x + 194 p.

Udden, J.A. 1907. A sketch of the Geology of the Chisos country, Brewster County, Texas, University of Texas Bulletin, 93: 101.pp.

VanBrackle, M.C. 1978. Observations on some fossil turtles from the state of Texas, M.S. thesis, Auburn University, 115 pp.

Wagner, J. 2001. The Hadrosaurian Dinosaurs (Ornithischia: Hadrosaur) of Big Bend National Park, Brewster County, Texas, with Implications for Late Cretaceous Paleozoogeography. Unpublished Masters Thesis, Texas Tech University. xvi + 417.

Walton, A.H. 1986. Magnetostratigraphy and the ages of Bridgerian and Uintan faunas in the Lower and Middle members of the Devil's Graveyard Formation, Trans-Pecos Texas [MA thesis]: Austin, Texas, The University of Texas at Austin, 135 p.

West, R.M. 1970. *Tetraclaenodon puercensis* (Mammalia: Phenacodontidae), Goler Formation, Paleocene of California, and distribution of the genus. Journal of Paleontology, vol. 44, no. 5, p. 851-857.

Wheeler, E. 1991. Paleocene dicotyledous trees from Big Bend National Park, Texas: Variability in wood types common in the Late Cretaceous and Early Tertiary, and ecological inference. American Journal of Botany, vol. 78(5): 658-671.

Wheeler, E. 1995. Systematic and ecologic significance of fossil hardwoods: examples from Big Bend National Park, Yellowstone National Park, and Florissant Fossil Beds National Monument. In V.L. Santucci and L. McClelland (eds.), National Park Service Paleontological Research, Volume 2, NPS/NRPO/NRTR-95-16, p.191-200.

Wheeler, E. A. and T. M. Lehman. 2000. Late Cretaceous woody dicots from the Aguja and Javelina Formations, Big Bend National Park, Texas, USA. IAWA Journal 21(1): 83-120.

Wheeler, E.A. and T.M. Lehman. 2005. Upper Cretaceous- Paleocene conifer woods from Big Bend National Park, Texas. Paleogeography, Paleoclimatology, Paleoecology 226: 233-258,

Wheeler, E.A., T.M. Lehman, and P.E. Gasson 1994. *Javelinoxylon*, an Upper Cretaceous dicotyledonous tree from Big Bend National Park, Texas, with presumed malvalean affinities. American Journal of Botany 81: 703-710.

White, J.C. 2002. The geology of Big Bend National Park: What have we learned since Maxwell et al., 1967? Field Trip Guide, Geological Society of America, South-Central Section Meeting, Alpine, Texas, 67 pp.

White, P. and J.A. Schiebout, 2001. Paleogene paleosols of Big Bend National Park, Texas. Geological Society of America Special Paper 369: 537-550.

Williams, E., G. Howe, G. Matzko, R. White, and W. Starke. 1993. Investigation of petrified wood samples from Big Bend National Park. In V.L. Santucci (ed.), National Park Service Paleontological Research Abstract Volume 1; National Park Service Technical Report NPS/NRPEFO/NRTR-93-11, p. 18.

Wilson, J.A. 1965. Cenozoic history of the Big Bend area, West Texas. Geology of the Big Bend Area, Texas – Field Trip Guide Book, West Texas Geological Society, Midland, Texas, pp. 34-36.

Wilson, J.A. 1967a. Early Tertiary mammals. *in* Maxwell, R.A., J.T. Lonsdale, R.T. Hazzard, and J.A. Wilson, Geology of Big Bend National Park, Brewster County, Texas. University of Texas Bureau of Economic geology Publication 6711:157-169.

Wilson, J.A. 1967b. Report on vertebrate paleontological and geological investigations, Big Bend National Park, Texas. Open File Report – University of Texas, Austin, Texas.

Wilson, J.A. 1971. Early Tertiary vertebrate faunas, Vieja Group, Trans-Pecos Texas: Agriochoeridae and Merycoidodontidae. Texas Memorial Museum Pearce-Sellards Series 18:1-83.

Wilson, J.A. 1972. Vertebrate biostratigraphy of Trans-Pecos Texas and northern Mexico, *in* Seewald, K., and Sundeen, D., eds., The geological framework of the Chihuahua Tectonic Belt: symposium honoring R.K. DeFord, West Texas Geological Society Publication 71-59, 205 p., p. 159-66

Wilson, J.A. 1974. Early Tertiary vertebrate faunas, Vieja Group and Buck Hill Group, Trans-Pecos Texas: Protoceratidae, Camelidae, Hypertragulidae. Texas Memorial Museum Pearce-Sellards Series 23:1-34.

Wilson, J.A. 1977. Early Tertiary vertebrate faunas, Big Bend Area, Trans-Pecos Texas: Brontotherriidae. Texas Memorial Museum Pearce-Sellards Series 25:1-17.

Wilson, J.A. 1980. Geochronology of the Trans-Pecos Texas volcanic field. New Mexico Geological Society Guidebook, 31st Field Conference, Trans-Pecos Region: 205-211

Wilson, J.A. 1984. Vertebrate faunas 49 to 36 ago and additions to species of *Leptoreodon* (Mammalia: Artiodactyla) found in Texas, J. Vert. Paleo. 4: 199-207.

Wilson, J.A. 1986. Stratigraphic occurrence and correlation of early Tertiary vertebrate faunas, Trans-Pecos Texas: Agua Fria-Green Valley Areas, J. Vert. Paleo. 6:350-373.

Wilson, J.A. and J.A., Schiebout. 1981. Early Tertiary vertebrate faunas Trans-Pecos Texas: Amynodontidae: Pearce-Sellards Series No. 33, Texas Memorial Museum, Austin, 1-62.

Wilson, J.A. and J.A., Schiebout. 1984. Early Tertiary vertebrate faunas Trans-Pecos Texas: Ceratomorpha less Amynodontidae. Texas Memorial Museum Pearce-Sellard Series 39, 47 pp.

Wilson, J.A., and M.S., Stevens. 1986. Fossil vertebrates from the latest Eocene, Skyline channels, Trans-Pecos Texas, University of Wyoming Contributions to Geology, Special paper 3:221-235.

Wilson, J.A., P.C. Twiss, R.K. Deford, and S.E. Clabaugh. 1968. Stratigraphic succession, potassium-argon dates, and vertebrate faunas, Vieja Group, Trans-Pecos Texas: American Journal of Science, v. 266, p. 590-604.

Wolleben, J.A. 1967. Senonian (Cretaceous) mollusca from Trans-Pecos Texas and northeastern Chihuahua, Mexico. Journal of Paleontology 41(5): 1150-1165.

DATA SETS

DS-BIBE-XXX Big Bend National Park Paleontological Archives. 5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

DS-BIBE-XXX Big Bend National Park Files and Archives. 1937–present. (letters, notes, exhibit text, etc.). Originated by BIBE staff; status: Inactive.

DS-BIBE-XXX Texas Memorial Museum – University of Texas at Austin Paleontological Collections from Big Bend National Park. 1937–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Texas Memorial Museum Staff; status: Active.

DS-BIBE-XXX Dallas Museum of Natural History - Big Bend National Park Collections and Archives. 1996–present. (letters, notes, exhibit text, etc.). Originated by Fiorillo, Anthony; status: Active.

DS-BIBE-XXX Texas Tech University (Lubbock) - Big Bend National Park Collections and Archives. 1981–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Lehman, Tom; status: Active.

DS-BIBE-XXX Louisiana State University, Museum of Natural Science - Big Bend National Park Collections and Archives. 1970–present. (hard copy data; reports; electronic data; photographs; maps; publications) Originated by Schiebout, Judith; status: Inactive.

DS-BIBE-XXX American Museum of Natural History Paleontological Collections and Archives. 1947–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Brown, Barnum; status: Inactive.

DS-BIBE-XXX Colorado School of Mines Department of Geology Collections. 1967–present. (field notes, photographs). Originated by Department of Geology; status: Inactive.

DS-BIBE-XXX University of Oklahoma Paleontological Collections. 1938–present. (hard copy data; reports, photographs). Originated by Eley, Hugh; status: Inactive.

CARLSBAD CAVERNS NATIONAL PARK

Carlsbad Caverns National Park (CAVE) was established October 25, 1923 to preserve *"… a limestone cavern … of extraordinary proportions and of unusual beauty and variety of natural decoration … spacious chambers that have been explored, other vast chambers of unknown characters and dimensions exist…"*. CAVE includes 46,766 acres, of which 33,125 acres are designated wilderness. At the surface CAVE elevations range from 3,595 to 6,520 feet and include fossilized reef uplands and diverse incised canyons. The park is best recognized for large cave systems of which, Carlsbad Cavern, contains one of the world's largest underground chambers. The park contains 113 known caves consisting of over 160 miles (257 kilometers) of passages and rooms. In 1986 a discovery in Lechuguilla Cave led to a significant network of passages and rooms At this time Lechuguilla Cave at 120.2 miles long and 1,604 feet deep is the fourth longest and fourth deepest cave in the United States. This cave contains massive gypsum features referred to as chandeliers. Lechuguilla Cave is found totally within Congressionally designated wilderness and recent research has yielded bacteria known only from this cave which may have important pharmacological potential. CAVE was designated a World Heritage Site on December 6, 1995 based upon the remarkable geology exposed both above and below the ground.

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

Geological scoping sessions, sponsored by the Geologic Resources Division, were conducted for Carlsbad Caverns National Park and Guadalupe Mountains National Park in March 2001. In response to a technical assistance request to establish baseline paleontological resource data for CAVE, Jason Kenworthy conducted a site visit to the park in May 2006.

The geology of Carlsbad Caverns is very similar to nearby Guadalupe Mountains National Park (Hayes 1964). Hill (1987) provides an excellent review of the geology of Carlsbad Cavern. Karst features have developed primarily within the Permian Capitan Limestone, with some cavern formation in the Artesia Group limestones. Both Carlsbad Caverns National Park and Guadalupe Mountains National Park are located within the Guadalupe Mountains. The Guadalupe Mountains are a limestone mountain range consisting of an extensive Permian fossil reef developed between 260 and 270 million years ago.

The extensive Permian reef complex is exposed in the cliffs and canyons of the Guadalupe, Apache, and Glass Mountains. The principle reef is referred to as the Capitan Reef and is exposed both above and below the surface at CAVE and at the surface at GUMO. The reef limestone is named the Capitan Limestone and is hundreds of miles long, 2 to 3 miles wide, and reaches up to 1,800 feet in thickness. Capitan Limestone is an enormous reef consisting of a framework of algae, sponge, and bryozoan fossils supporting a matrix of unbedded fine-grained limestone. This barrier reef formed around the perimeter of the Delaware Basin during the Permian, continuing for over 300 miles (483 kilometers). The back-reef limestones of the Permian Artesia Group (including the Tansill, Yates, and Seven Rivers Formations) are prominently bedded and contain a high percentage of locally eroded silt as well as gypsum (Palmer 1995).

Artesia Group—Tansill and Yates formations (Upper Permian)
Rock formations of the reef complex represent the forereef, reef, and backreef environments. The lagoonal backreef facies are preserved in the Tansill and Yates formations. The sediments from the Tansill Formation were the most proximate to the adjacent terrestrial environment. The backreef was subjected to episodic drying resulting in increased salinity of water and sediments. The Yates Formation is composed of dolomite and sandstone deposited in a lagoonal environment. These sedimentary layers reflect shallow and quiet water depositional environment. Dry periods within the backreef are indicated by evidence of mudcracks in this facies. Both the Tansill and Yates formations contain aggregates of round carbonate-coated particles with a concentric structure called pisolites. Pisolites form in calcium carbonate rich waters that are subjected to wave action.

Capitan Formation (Upper Permian)
The Capitan Formation consists of a massive limestone unit formed by the buildup of the skeletal remains of calcareous reef-building organisms over millions of years. The ancient reef contained algae, sponges, bryozoans and other marine organisms. As the Delaware Basin subsided, the reef continued to build upon itself increasing the vertical height of the reef. The skeletal deposits of dead organisms were cemented by calcite and encrusted by epibionts. The forereef of the Capitan Formation is represented by sloping reef debris on the ocean side of the reef. As the reef grew vertically, large blocks of the limestone broke from the reef and dropped into deeper water. Within the boundary of CAVE significant exposures of the deep water facies of the reef are found in Slaughter Canyon and the steep escarpments to the southwest of the canyon.

Capitan Reef Complex
A voluminous literature exists for geology of the Capitan Reef and of the Guadalupe Mountains. Crandall (1929), Lloyd (1929) and Blanchard and Davis (1929) independently recognized the Capitan Limestone as fossil barrier reef in the same year. King (1942, 1948) presented a comprehensive history of investigations focused on the physical stratigraphy and regional geology of the Delaware Basin and the Guadalupe Mountains. Adams and Frenzel (1950) presented a detailed interpretation of the sedimentary history of the Capitan Reef including the review of subsurface data. Hayes (1964) and Hill (1987, 1996) provide excellent overviews on the geology of the Guadalupe Mountains. Newell and others (1953) provides one of the most definitive interpretations of the geology of the Permian Reef Complex of west Texas and New Mexico.

Unlike many other caves that are formed through dissolution of limestone by carbonic acid from surface sources, Carlsbad Caverns was dissolved chiefly by sulfuric acid. This sulfuric acid was created when hydrogen sulfide rising from depth reacted with oxygen near the water table (Palmer 1995). The cave-forming limestones in the park contain a rich assemblage of marine invertebrate fossils. Some of the limestones within the reef contain such an abundance of fossils these zones have been referred to as "fossil hash", or coquina.

The diversity of fossil species is high within the Permian Reef Complex (see Guadalupe Mountains National Park section of this report). Girty (1908) made the extensive collections of fossils from the Guadalupe Mountains in 1901. Invertebrate fossils are present throughout the exposed reef including algae, fusulinids, sponges, corals, bryozoans, brachiopods, trilobites, ostracods, gastropods, cephalopods, scaphopods, pelecypods, crinoids, echinoids, and conodonts. The reef limestone (Capitan Formation) is composed primarily of algae, sponges and bryozoans. Johnson (1942) identified and described ecological zones or facies based upon fossil algae in the reef. Newell and others (1953) identified five growth forms of bryozoans and three growth forms in corals in the Permian Reef Complex. Fusilinids, brachiopods and crinoids are more common in the fore reef and back reef deposits.

Algae, sponges, and bryozoans are abundant throughout the reef. Rocks near the entrance to the park, on White's City property, have yielded the largest fossil sponge yet known from the Permian (Vequist 1997). A specimen of the sponge *Guadalupia cylindrical* can be found in the wall exposed near the elevators in the caverns. Rigby et al. (1998) described a number of new sponges from the park that were not previously known from the Permian of North America. A nice specimen of the bryozoan genus *Domopora* can be found along the shortcut in the Main Corridor of the cavern.

Fusulinids, brachiopods, scaphopods, cephalopods, and crinoids are documented from the Permian limestones in the park (Black 1953). Brachiopods are fairly common in the caverns and a few examples include: a specimen of *Productus guadauplensis* is present near the Lion's Tail; brachiopod specimens of the genera *Martinia* and *Squamularia* can be located near the Top of Cross area; and a *Productus meekanus* specimen showing spines can be located in the shortcut in the Main Corridor of the cavern. A specimen of the scaphopod *Plagioglypta canna* occurs in the wall at the Devil's Den area of the caverns. A

cephalopod of the genus *Foordoceras* can be observed in the Caveman Junction area. A few specimens of gastropods (snails) of the genus *Pleurotomaria* are visible near the first set of stairs in the Main Corridor. Crinoid specimens are exposed at the Lion's Tail and along the switchbacks above Iceberg Rock. Two species of trilobite have been identified at Carlsbad Caverns. A fine specimen of the trilobite *Anisopyge perannulata* is exposed near the elevator lobby at the cavern.

Paleontological Resources in CAVE Caves (Pleistocene/Holocene)
A large diversity of Pleistocene/Holocene vertebrates has been documented from the caves within Carlsbad Caverns National Park (Santucci et al. 2001). Fossil remains are known primarily from Carlsbad Cavern, Lechuguilla Cave, Slaughter Canyon Cave, and Musk Ox Cave. Thirty-six species have been identified from the park caves including 16 species representing now extinct or locally extirpated taxa. Pleistocene shrub oxen, pronghorn, an extinct cheetah-like cat, mountain goat, dire wolf, shrew, marmot, horse, an extinct vulture, and numerous other vertebrates are among the bones found in the caves and identified by Lloyd Logan and other Smithsonian Institution personnel.

Many specimens, representing numerous fossilized bat species, have been discovered in Lower Cave, the scenic rooms, the Big Room and a number of other areas within Carlsbad Cavern (Baker 1963). Carbon 14 dating from guano recovered from an old bat roost within the Big Room showed an average date of 45,830 +/- 1,366 years before present (Jablonsky 1999). The remains of a juvenile ground sloth *Nothrotheriops shastensis* (Shasta ground sloth) were discovered in Lower Devil's Den of Carlsbad Cavern in 1947. Disarticulated ribs, vertebrae, and foot bones were identified by paleontologist C. Gazin (Smithsonian) in 1948. Additional juvenile ground sloth bones were collected from the same location in 1959 and believed to be part of the same individual. Uranium series dating of the bone material provided a date of approximately 111,900 years B.P. (Hill and Gillette 1987). Although the remains of ground sloths are known for nearly two million years in the American southwest, the Carlsbad specimen has provided the oldest absolute date for any sloth material.

Fossil vertebrates are reported from Lechuguilla Cave. During January 1988, members of the Lechuguilla Cave Project expedition discovered an articulated and extensively calcified small mammal skeleton. The skeleton was identified by Pat Jablonsky as *Bassariscus astutus* (ringtail cat) (P. Jablonsky, personal communication, 1993).

Fifty complete bat skulls from an observed approximate 100 specimens of bats were collected from throughout Lechuguilla Cave between 1990 and 1996 (Jablonsky 2004). These bat bones date to less than 10,000 years B.P. Seven species constituting four genera were collected and identified. All of these specimens were members of the family Vespertilionidae. One of the species, *Lasiurus cinereus* (hoary bat) is not commonly found in caves. *Corynorhinus townsendii* (western big-eared bat) prefers shallow gypsum caves or roosts in entrances of caves or mines. *Myotis volans* (long-legged bat) prefers rock crevices or trees. *Myotis ciliolabrum* (Western small-footed myotis) was the most abundant inhabitant of Lechuguilla Cave. Interestingly, *Myotis ciliolabrum* has not been found at Carlsbad Cavern which is three miles southeast of Lechuguilla Cave.

The extinct species of bat *Tadarida constantinei* (Constantine's free-tailed bat) is known only from Slaughter Canyon Cave (New Cave). Much older than originally thought, uranium series dating on a flowstone cap above a trench where guano from this species was removed shows a date of 210.000 years before present (Polyak 2002). Additionally, all bat bones in this same deposit now consist of the mineral apatite (Polyak 1999). Based on the time necessary for the bones to turn to apatite, the guano deposit could be considerably older than this date. The remains of *Navahoceros fricki* (mountain deer) and other vertebrates have also been collected and identified from Slaughter Canyon Cave. Recent excavations by Gary Morgan in Slaughter Canyon Cave have recovered thousands of *Tadarida constantinei* bones and other vertebrates including *Gopherus agassize*, the Desert Tortoise, *Arctodus simus*, the giant Short-faced Bear, and *Capromeryx minor*, a minature pronghorn (Morgan 2002).

An important vertebrate fauna has been reported from Muskox Cave (Logan 1977, 1979). The fossil material represents an assemblage of Late Pleistocene vertebrates that apparently died after being trapped in a large sinkhole. This cave was first discovered and entered in 1954. A small group, led by Park Ranger Patterson, collected a number of bones from within Muskox Cave during this first reported entry. This material was examined by paleontologist Lewis Gazin who identified the remains of a horse, a small artiodactyl, a bovid, a large dog, and a bobcat-like cat. The cave was revisited in February 1969 by a small group led by Park Naturalist Bullington. Bullington prepared a trip report detailing the visit to Muskox Cave and reported "literally thousands of small disassociated bones." A few fossil vertebrates were collected from the cave and forwarded to paleontologist Ernest Lundelius, at the University of Texas, Austin. Dr. Lundelius identified the remains as a shrubox (possibly *Euceratherium*), a horse, and a small antelope (Logan 1979).

In November of 1975, members of the Cave Research Foundation began mapping Muskox Cave. The mapping continued into 1976 with to the discovery of numerous new passages. During this mapping project, a skull and associated skeleton was found in a small pool at the base of a breakdown slope in a virgin passage. A second skull was found embedded in the floor of the cave near the pool (Logan 1977, 1979). These discoveries prompted another trip into Muskox Cave in March 1976, led by NPS Cave Resources Specialist Ronal Kerbo. Kerbo photographed the skulls and skeleton, later identified as *Euceratherium* cf. *sinclairi* (Bush Ox) and dire wolf. Other skeletal remains were observed during this trip including elements identified as *Equus, Bassariscus*, *Spilogale*, and *Neotoma*. A joint field party from the Smithsonian Institution, Texas Tech University, and the National Park Service spent ten days during July 1976 collecting the skeleton in the pool and other vertebrates from the cave (Logan 1979). A follow-up trip collecting trip was undertaken in April 1977. Jass and others (2000) report on an *Oreamnos harringtoni* (Harrington's Mountain Goat) from Muskox Cave.

Small numbers of bat and other vertebrate bones are known from numerous other caves within the park but have not been studied. Other significant paleontological resources are known from caves adjacent to, but outside of the boundary of, Carlsbad Caverns National Park. On Bureau of Land Management lands just a few hundred feet from the CAVE boundary is the entrance to Big Manhole Cave. This cave has documented fossil occurrences and appears to be very rich in Pleistocene fauna.

REFERENCES CITED

Adams, J.E. and H.N. Frenzel. 1950. Capitan barrier reef, Texas and New Mexico. Journal of Geology 58(4): 289-312.

Baker, J.K. 1963. Fossilization of bat skeletons in the Carlsbad Caverns. *National Speleological Society Bulletin* 25:37-44.

Black, D.M. 1953. Fossil deposits under the entrance of Carlsbad Caverns. *Science* 118:308-309.

Blanchard, W.G. and M.J. Davis. 1929. Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas. American Association of Petroleum Geologists Bulletin 13: 957-995.

Crandall, K.H. 1929. Permian stratigraphy of southeastern New Mexico and adjacent parts of western Texas. American Association of Petroleum Geologists Bulletin 13: 927-944.

Girty, G.H. 1908. *The Guadalupian Fauna*. U.S. Geological Survey Professional Paper 58. 651 pp.

Hayes, P.T. 1964. Geology of the Guadalupe Mountains New Mexico. U.S. Geological Survey Professional Paper 446. 69 pp.

Hill, C.A. 1987. *Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico and Texas*. New Mexico Bureau of Mines Bulletin 117. 150 pp.

Hill, C.A. 1996. Geology of the Delaware Basin, Guadalupe, Apache, and Glass mountains, New Mexico and West Texas. SEPM (Society for Sedimentary Geology), Permian Basin Section, Publication 96-39, 480 p.

Hill, C.A. and D.D. Gillette. 1987. A uranium series date for the Shasta Ground Sloth, *Nothrotheriops shastensis*, from Carlsbad Cavern, New Mexico. *Journal of Mammalogy* 68(3):718-719.

Jablonsky, P.L. 1999. Carbon 14 Analysis of Chiroptera Specimens and Guano Deposits, Carlsbad Cavern, Carlsbad Caverns National Park. Unpublished report to Carlsbad Caverns National Park. 48 pp.

Jablonsky, P.L. 2004. Chiropteran Studies, Lechuguilla Cave, Carlsbad Caverns National Park. Unpublished report to Carlsbad Caverns National Park. 10pp.

Jass, C.N., J.I. Mead, and L.E. Logan 2000. Harrington's extinct mountain goat (*Oreamnos harringtoni* Stock 1936) from Muskox Cave, New Mexico. *Texas Journal of Science* 52(2): 121-132.

Johnson, J.H. 1942. Permian lime-secreting algae from the Guadalupe Mountains, New Mexico. Geological Society of America Bulletin 53: 195-226.

King, P.B. 1942. Permian of west Texas and southeastern New Mexico. American Association of Petroleum Geologists Bulletin 26: 535-763.

King, P.B. 1948. Geology of the southern Guadalupe Mountains, Texas. U.S. Geological Survey, Professional Paper 215, 183 p.

Lloyd, E.R. 1929. Capitan Limestone and associated formations of New Mexico and Texas. American Association of Petroleum Geologists Bulletin 13: 645-658.

Logan, L.E. 1977. *The paleoclimate implications of the avian and mammalian faunas of Lower Sloth Cave, Guadalupe Mountains, Texas*. M.S. Thesis, Texas Tech University, Lubbock. 72 pp.

Logan, L.E. 1978. *A preliminary report on the mammalian fossils from Muskox Cave and their paleoclimatic implications*. National Park Service Report, Carlsbad Caverns National Park. 31 pp.

Logan, L.E. 1979. *The mammalian fossils from Muskox Cave and their paleoecologic implications*. National Park Service Report, Carlsbad Caverns National Park. 72 pp.

Morgan, G. 2002 Slaughter Canyon Cave Research. In Canyons & Caves No. 25 – Summer 2002. p.3. Unpublished report to Carlsbad Caverns National Park.

Newell, N.D., J.K. Rigby, A.G. Fischer, A.J. Whiteman, J.E. Hickox, and J.S. Bradley. 1953. *The Permian Reef Complex of the Guadalupe Mountains Region, Texas and New Mexico: A Study in Paleoecology*. New York: Hafner Publishing Co. 236 pp.

Palmer, A.N. 1995. Carlsbad Caverns National Park. *in* Harris, A.G., E. Tuttle, and S.D. Tuttle. *Geology of National Parks* (fifth edition). Dubuque, Iowa: Kendall/Hunt Publishing Co. Pp. 177-186.

Polyak, V.P., and Y. Asmeron 2002. Slaughter Canyon Cave Research. In Canyons & Caves No. 25. Summer 2002. p. 3. Verbal report to Carlsbad Caverns National Park.

Polyak, V.P. and P. Provencio 1999. Slaughter Canyon Cave News. In Canyons & Caves No. 12. Spring 1999. p. 1. Verbal report to Carlsbad Caverns National Park.

Rigby, J.K., B. Senowbari-Daryan, H. Liu 1998. Sponges of the Permian Upper Capitan Limestone, Guadalupe Mountains, New Mexico and Texas. Brigham Young University Geology Studies 43: 19-117.

Santucci, V.L., J.P Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service Caves. National Park Service Geologic Resources Division Technical Report, NPS/NRGRD/GRDTR-01/02, 50 pp.

Vequist, G. (ed.). 1997. *Research in Carlsbad Caverns National Park: Scientific Exploration and Discovery*. Carlsbad Caverns Guadalupe Mountains Association and National Park Service. 25 Pp.

ADDITIONAL REFERENCES

Achauer, C.W. 1969. Origin of Capitan Formation, Guadalupe Mountains, New Mexico and Texas. American Association of Petroleum Geologists Bulletin 53(11): 2314-2323.

Babcock, J.A. 1974. The role of algae in the formation of the Capitan Limestone (Permian, Guadalupian), Guadalupe Mountains, west Texas – New Mexico. Ph.D. Dissertation, University of Wisconsin, Madision, 241 pp.

Babcock, J.A. 1977. Calcareous algae, organic boundstones, and the genesis of the upper Capitan Limestone (Permian, Guadalupian), Guadalupe Mountains, west Texas and New Mexico. In Hileman, M.E., and S.J. Mazzullo (eds.), Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and West Texas, Field Conference Guidebook, PBS / SEPM Publication 77-16, volume 1: 3-44.

Babcock, J.A. and D.A. Yurewicz. 1989. The massive facies of the Capitan Limestone, Guadalupe Mountains, Texas and New Mexico. In Harris, P.M. and G.A. Grover (eds.), Subsurface and outcrop examination of the Capitan Shelf Margin, northern Delaware Basin, SEPM Core Workshop No. 13, p. 365-371.

Babcock, L.C. 1974. Conodont paleoecology of a Guadalupian (Permian) shelf to basin sequence, Permian Reef Complex, west Texas and New Mexico (abstract). Geological Society of America, Abstracts with Programs, North-Central Section Meeting, p. 489.

Bebout, D.G. and C. Kerans (eds.). 1993. Guide to the Permian Reef Geology Trail, McKittrick Canyon, Guadalupe Mountains National Park, west Texas. Bureau of Economic Geology, University of Texas at Austin, Guidebook 26, 48 pp.

Behnken, F.H. 1972. Leonardian and Guadalupian (Permian) conodont biostratigraphy and evolution in western and southwestern United States. Ph.D. Dissertation, University of Wisconsin, Madison, 184 pp.

Black, T.H. 1954. The origin and development of the Carlsbad Caverns. New Mexico Geological Society Guidebook 5, p. 136-142.

Borer, J.M. and P.M. Harris. 1989. Depositional facies and cycles in Yates Formation outcrops, Guadalupe Mountains, New Mexico. In Harris, P.M. and G.A. Grover (eds.), Subsurface and outcrop

examination of the Capitan Shelf Margin, northern Delaware Basin, SEPM Core Workshop No. 13, p. 305-317.

Bretz, J.H. 1949. Carlsbad Caverns and other caves of the Guadalupe block. Journal of Geology 57: 447-463.

Bullington, N.R. 1968. Geology of Carlsbad Caverns. In Delaware Basin explorations. West Texas Geological Society Guidebook 68-55, p. 20-23.

Cahill, T. and M. Nichols. 1991. Charting the splendors of Lechuguilla Cave. National Geographic Magazine 179(3): 34-59.

Candelaria, M.P. 1982. Sedimentology and depositional environment of upper Yates Formation siliciclastics (Permian, Guadalupian), Guadalupe Mountains, southeast New Mexico. M.S. Thesis, University of Wisconsin, 267 pp.

Cronoble, J.M. 1974. Biotic constituents and origin of facies in Capitan reef, New Mexico and Texas. Mountain Geologist 11(3): 95-108.

Davis, D.G. 1979. Cave development in the Guadalupe Mountains, New Mexico, Texas. Caving International Magazine 3, p. 43.

Davis, D.G. 1980. Cave development in the Guadalupe Mountains: a critical review of recent hypotheses. National Speleological Society Bulletin 42: 42-48.

Davis, D.G., A.N. Palmer, and M.V. Palmer. 1992. Extraordinary subaqueous speleothems in Lechuguilla Cave, New Mexico. National Speleological Society Bulletin 52: 70-86.

DeFord, R.K. and G.D. Riggs. 1941. Tansill formation, west Texas and southeastern New Mexico. American Association of Petroleum Geologists Bulletin 25: 1713-1728.

DuChene, H.R. 1971. Discussion to accompany tectonic map of the Guadalupe Mountains and vicinity, Texas and New Mexico. Unpublished Report to Carlsbad Caverns National Park, 17 pp.

DuChene, H.R. 1978. Geologic history of the Guadalupe Mountains region. National Speleological Society Bulletin 40: 3-6.

DuChene, H.R. 1986. Observations on previous hypotheses and some new ideas on cavern formation in the Guadalupe Mountains. In Jagnow, D.H. (ed.), Geology Field Trip Guidebook, 1986 National Speleological Society Convention, Tularosa, New Mexico, p. 96-100.

Dunham, R.J. 1972. Capitan reef, New Mexico and Texas: facts and questions to aid interpretation and group discussion. Society of Economic Paleontology and Mineralogy, Permian Basin Section, Publication 72-14.

Gale, B.T. 1957. Geologic development of the Carlsbad Caverns. In Hayes, P.T., Geology of the Carlsbad Caverns east quadrangle, New Mexico. U.S. Geological Survey, Geologic Quadrangle Map 98, scale 1:62,500.

Garber, R.A., G.A. Grover, and P.M. Harris. 1989. Geology of the Capitan shelf margin – subsurface data from the northern Delaware Basin. In Harris, P.M. and G.A. Grover (eds.), Subsurface and outcrop examination of the Capitan Shelf Margin, northern Delaware Basin, SEPM Core Workshop No. 13, p. 3-269.

Good, J.M. 1957. Non-carbonate deposits of Carlsbad Caverns. National Speleological Society Bulletin 19: 11-23.

Hart, W.G. 1969. Microfacies analysis of the Permian Reef Complex (Guadalupian), Carlsbad Caverns, New Mexico. Unpublished M.S. Thesis, Texas Tech University, 68 pp.

Hayes, P.T. 1964. Geology of the Guadalupe Mountains, New Mexico. U.S. Geological Survey, Professional Paper 446, 69 pp., 1:62,500 scale.

Hayes, P.T. and Gale, B.T. 1957. Geology of the Carlsbad Caverns East quadrangle, New Mexico, U.S. Geological Survey, GQ-98, 1:62500 scale.

Hayes, P.T. and R.L. Koogle. 1958. Geology of the Carlsbad Caverns West quadrangle, New Mexico-Texas, U.S. Geological Survey, GQ-112, 1:62500 scale

Hayes, P.T. and P.R. Bigsby. 1983. Mineral resource potential and geologic map of the Little Dog and Pup Canyons Roadless Area, Otero County, New Mexico, U.S. Geological Survey, MF-1468, 1:50000 scale

Hayes, P.T., T.D. Light, and J.R. Thompson. 1983. Mineral resource potential and geologic map of the Guadalupe Escarpment Wilderness Study Area, Eddy County, New Mexico, U.S. Geological Survey, MF-1560-A, 1:24000 scale

Hill, C.A. 1986. Geology of Lechuguilla Cave – preliminary observations. Unpublished report to Carlsbad Caverns National Park, 10 pp.

Hill, C.A. 1987. *Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico and Texas*. New Mexico Bureau of Mines Bulletin 117. 150 pp.

Hill, C.A. 1991. Sulfuric acid speleogenesis of Carlsbad Cavern and its relationship to hydrocarbons, Delaware Basin, New Mexico. American Association of Petroleum Geologists Bulletin 74: 1685-1694.

Hills, J.M. 1942. Rhythm of Permian seas, a paleogeographic study. American Association of Petroleum Geologists Bulletin 26: 217-255.

Hornberg, L. 1949. Geomorphic history of the Carlsbad Caverns area, New Mexico. Journal of Geology 57(5): 464-476.

Howard, E.B. 1932. Caves along the slopes of the Guadalupe Mountains. Texas Archeological and Paleontological Society Bulletin 4: 7-20.

Hyndman, Paul and Campbell, H.W. 1999, Digital mining claim density map for Federal lands in New Mexico: 1996, U.S. Geological Survey, Open-File Report OF-99-411, 1:100000 scale

Jagnow, D.H. 1979. Cavern development in the Guadalupe Mountains. Cave Research Foundation, Columbus, Ohio, 55 p.

King, P.B. 1934. Permian stratigraphy of Trans-Pecos Texas. Geological Society of America Bulletin 45: 697-698.

King, P.B. 1944. Geologic map of the southern Guadalupe Mountains, Hudspeth and Culberson Counties, Texas, U.S. Geological Survey, OM-18, 1:48000 scale.

King, P.B. 1948. Geologic map and sections of southern Guadalupe Mountains, Texas, U.S. Geological Survey PP 215, Plate 3, 1:48000 scale

King, P.B. 1948 Map of southern Guadalupe mountains, Texas, showing tectonic features, U.S. Geological Survey, PP 215, Plate 20, 1:48000 scale

King, P.B. 1948. Map of southern Guadalupe mountains, Texas, showing Cenozoic deposits and land forms, U.S. Geological Survey, PP 215, Plate 22, 1:48000 scale

King, P.B. 1948. Topographic and index map of southern Guadalupe Mountains, Texas, showing locations of stratigraphic sections, fossil localities, and panoramic views, U.S. Geological Survey, PP 215, Plate 2, 1:48000 scale

King, P.B. 1949, Regional geologic map of parts of Culberson and Hudspeth Counties, Texas, U.S. Geological Survey, OM-90, 1:150000 scale

Kirkland-George, B. 1992. Distinctions between reefs and bioherms based on studies of fossil algae – *Mizzia*, Permian Capitan reef complex (Guadalupe Mountains, Texas and New Mexico) and Eugonophyllum, Pennsylvanian Holder Formation (Sacramento Mountains, New Mexico). Ph.D. Dissertation, Louisiana State University, 156 p.

Kiver, E.P. and D.V. Harris. 1999. Geology of U.S. Parklands. John Wiley & Sons, Inc., New York, 902 pp.

Lee, W.T. 1924. A visit to Carlsbad Caverns. National Geographic Magazine 45(1): 1-40.

Lee, W.T. 1925. Carlsbad Caverns. Scientific Monthly 21: 186-190.

Mazzullo, S.J. 1993. Geologic studies in Carlsbad Caverns and Guadalupe Mountains National Parks, New Mexico and Texas. In V.L. Santucci (ed.), National Park Service Paleontological Research Abstract Volume 1; National Park Service Technical Report NPS/NRPEFO/NRTR-93-11, p. 50.

Meinzer, O.E., B.C. Renick, K. Bryan 1927. Geology of No. 3 reservoir site of the Carlsbad Irrigation Project, New Mexico, with respect to water tightness, U.S. Geological Survey, Water-Supply Paper 580, 1:31680 scale

Moore, G.W. 1960. Geology of Carlsbad Caverns, New Mexico. National Speleological Society Guidebook, series 1, p. 10-17.

Motts, W.S. 1962, Geology of the West Carlsbad quadrangle, New Mexico, U.S. Geological Survey, GQ-167, 1:62500 scale.

Neese, D.G. and A.H. Schwartz. 1977. Facies mosaic of the upper Yates and lower Tansil Formations, Walnut and Rattlesnake Canyons, Guadalupe Mountains, New Mexico. In Hileman, M.E., and S.J. Mazzullo (eds.), Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and West Texas, Field Conference Guidebook, PBS / SEPM Publication 77-16, volume 1: 437-450.

Newell, N.D. 1955. Depositional fabric in Permian reef limestones. Journal of Geology 63: 301-309.

Queen, J.M. 1981. A discussion and field guide to the geology of Carlsbad Caverns. Unpublished Report to Carlsbad Caverns National Park, 64 pp.

Ruedemann, R. 1929. Coralline algae, Guadalupe Mountains. American Association of Petroleum Geologists Bulletin 13: 1079-1080.

Skinner, J.W. 1946. Correlation of Permian of west Texas and southeast New Mexico. American Association of Petroleum Geologists Bulletin 30: 1857-1874.

Skinner, J.W. and G.L. Wilde. 1955. New fusulinids from the Permian strata of west Texas. Journal of Paleontology 29: 927-940.

Tyrrell, W.W. 1969. Criteria useful in interpreting environments of unlike but time-equivalent carbonate units (Tansill – Capitan – Lamar), Capitan Reef Complex, west Texas and New Mexico. In G.M. Friedman (ed.), Depositional environments in carbonate rocks. Society of Economic Paleontology and Mineralogy Special Publication 14, p. 80-97.

Widmer, U. 1998. Lechuguilla, jewel of the underground. Caving Publications International, Basel, Switzerland.

Yurewicz, D.A. 1977. Origin of the massive facies of the lower and middle Capitan Limestone (Permian), Guadalupe Mountains, New Mexico and West Texas. In Hileman, M.E. and S.J. Mazzullo (eds.), Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and West Texas. Field Conference Guidebook, Permian Basin Section – SEPM Publication 77-16, volume 1: 45-92.

DATA SETS

DS-CAVE-XXX Carlsbad Caverns National Park Paleontological Archives. 5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

DS-CAVE-XXX Carlsbad Caverns National Park Files and Archives. 10/1923–present. (letters, notes, exhibit text, etc.). Originated by CAVE staff; status: Inactive.

DS-CAVE-XXX Smithsonian Institute – National Museum of Natural History - Paleontological Collections. 1975–present. (hard copy data; reports related to Musk Ox Cave). Originated by Logan, Lloyd; status: Inactive.

FORT DAVIS NATIONAL HISTORIC SITE

Fort Davis National Historic Site (FODA) is one of America's best surviving examples of an Indian Wars frontier military post in the Southwest. The site was established as a National Historic Site on September 8, 1961 to preserve the location and remnants of two old frontier forts which were strategically located to protect emigrants, mail coaches, and freight wagons on the Trans-Pecos portion of the San Antonio-El Paso Road and the Chihuahua Trail. The National Park Service preserves twenty-four roofed buildings and over 100 ruins and foundations which were associated with the nineteenth century fort.

The original Fort Davis was constructed in 1854 as part of a network of army outposts on the Texas frontier. The name of the fort was derived from Jefferson Davis, the Secretary of War at the time. Jefferson Davis later became the President of the Confederate States of America during the Civil War. The original post was used by federal troops until the outbreak of the Civil War in 1861 and was in turn surrendered to the Confederacy. The confederates occupied the fort for about a year and eventually abandoned the site.

The fort was reestablished in 1867 by Civil War veteran Wesley Merritt. The site was continuously garrisoned until it was finally abandoned in 1891. During this second period of occupation of FODA, the fort hosted the 24th and 25th U.S. Infantry and the 9th and 10th U.S. Cavalry, the post-Civil War all black regiments including the famous "Buffalo Soldiers".

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

The NPS Geologic Resources Division has not yet sponsored geologic scoping sessions for Fort Davis National Historic Site. No formal paleontological resource inventories have been completed for FODA and no fossil specimens exist in park collections. There are no records of paleontological discoveries inside park boundaries. Since the park consists primarily of Tertiary volcanic rocks, there is low potential for future paleontological resource discoveries at FODA. According to the park curator at FODA, there is an uncataloged fossil specimen in one of the park's storage buildings. There is an old index card associated with the fossil that the following information, *"Right Lower Molar of Imperial Mammoth found San Estaben (sic) Lake in Presidio County by O. Bridiger and son Pat."* (S. McComb, personal communication, 2006). This locality is outside of the FODA boundary in the county to the south near Alamito Creek and therefore does not represent a park specimen.

Geologically, FODA is located in the Davis Mountains of west Texas. The Davis Mountains are a thick Tertiary volcanic pile breached locally by hypabyssal intrusions (Everett 1967). Anderson (1965) provides the most comprehensive geologic overview of the Davis Mountains, however, the work focused on a 2,500 feet thick section of volcanics west of FODA. Everett (1967) presents the first geologic assessment specifically focused on FODA.

The Fort Davis area consists of a series of three concordant volcanic units which are Late Eocene (38 – 31 million years ago) in age. Quaternary colluvium and alluvium cover the lower elevation areas. The topography has developed on a sequence of inter-layered non-resistant and resistant units which form a series of benches and escarpments. The colluvium and alluvium are composed of weathered volcanic rock (Everett 1967).

The oldest exposed geologic unit at FODA is a Tertiary andesitic flow. This andesite is fine-grained, medium gray, pyroxene-rich, and is vesicular in the upper portion. A five foot exposure of the andesite flow is located a few feet northwest of the north end of Officer's Row (Everett 1967). Rock fragments of this andesite are abundant in the alluvium and colluvium at the mouth of Hospital Canyon and along the base of the slopes of the canyon.

Overlying the andesite flow is a section of rhyolite porphyry. This unit is fine-grained with glassy feldspar phenocrysts. The rock color ranges from red and purple for fresh exposures to red and brown for weathered sections. This unit forms an escarpment which dominates the skyline west of FODA. Visitors hiking the "Tall Grass Nature Trail" on the north slope of Hospital Canyon can view fresh exposures of the rhyolite porphyry (Everett 1967).

Above the rhyolite porphyry is an ignimbrite, or ash flow tuff, which grades upward from a black vitrophyre to a vitric-crystal tuff at the top. Everett (1967) informally named this unit the "Fort Davis ignimbrite" due to its widespread use as a building stone in the old fort and in town. After the fort was abandoned in 1891, many of the fort's old stone buildings were dismantled and the stone was incorporated into buildings being constructed in town at that time.

Paleontological Resource Potential

Since the geologic units of FODA are volcanic in origin, the potential for future paleontological discoveries at the site is unlikely. Initial inquiry regarding the existence of potential tree mold or leaf impressions in the volcanic units has not revealed any evidence of these types of fossils.

REFERENCES CITED

Anderson, J.E. 1965. Igneous geology of the central Davis Mountains, Jeff Davis County, Texas. Unpublished Ph.D. dissertation, University of Texas, Austin.

Everett, A.G. 1967. Geologic Reconnaissance of the Fort Davis National Historic Site, Texas. The Pearce-Sellards Series No. 8: Texas Memorial Museum, University of Texas at Austin, 19pp.

ADDITIONAL REFERENCES

Anderson, J.E. 1968. Igneous geology of the central Davis Mountains, Jeff Davis County, Texas. 1:62,000 scale, 18 p.

Barnes, V.E. 1982. Geologic atlas of Texas, Fort Stockton sheet. University of Texas at Austin, Bureau of Economic Geology, 1:250000 scale.

LaRocca, R.B. 1984. Geology of the Davis Mountains Resort Area, Trans Pecos, Texas. Senior Thesis, Baylor University.

Snyder, J.L. 1962. Geologic Investigations, Central Davis Mountains, Texas. Texas Journal of Science 14: 197-215.

Welsh, M. 1996. A Special Place, A Sacred Trust: Preserving the Fort Davis Story: Administrative History of Fort Davis National Historic Site. National Park Service, Intermountain Cultural Resource Center Professional Paper No. 58. (http://www.nps.gov/foda/adhi/adhit.htm).

Zabriskie, W.E. 1951. Geology of Northern Davis Mountains, Jeff Davis County, Texas. Master's Thesis.

DATA SETS

DS-FODA-XXX Fort Davis National Historic Site Paleontological Archives. 5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

GUADALUPE MOUNTAINS NATIONAL PARK

Guadalupe Mountains National Park (GUMO) was established on October 15, 1966 to preserve "an area…of outstanding geologic values...". In fact, the park contains the world's most significant fossilized limestone reef outcrops of Permian age. The park consists of 86,416 acres, of which 46,850 acres are designated wilderness. The park contains a diverse range of elevation-related environments from lowland salt basin to relict conifer forests, including Texas' highest point at 8,749 feet. The park was also designated an International Benchmark Standard for geology and the rich Chihuahuan Desert resources.

Geologists and students from around the world visit the Guadalupe Mountains to study the world-renowned Permian Reef Complex. The sequence of rocks within the Guadalupe Mountains has been established as a measuring standard upon which rocks of similar age all over the world can be compared. Three areas in the park are designated by the International Union of Geological Sciences (IUGS) as Global Stratotype Secions and Points for the Middle Permian Series of the geologic time scale along with their component Roadian, Wordian, and Capitanian stages. The Middle Permian is known worldwide as the Guadalupian Series.

The Guadalupe Mountains are a fault-block range in west Texas and southern New Mexico. A large normal fault defines the western flank of the Guadalupe Mountains, while the eastern edge is marked by the Capitan Reef escarpment. The reef escarpment essentially preserves the ancient depositional profile of the Delaware Basin margin. The Capitan Reef is exposed in both Guadalupe Mountains National Park (GUMO) and Carlsbad Caverns National Park (CAVE). At GUMO the Permian Reef consists of an uplifted block forming this prominent range. At CAVE the Permian Reef is exposed subsurface in the same uplifted block but is at lower elevation due to a regional dip.

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

Geological scoping sessions, sponsored by the Geologic Resources Division, were held for Carlsbad Caverns National Park and Guadalupe Mountains National Park in March 2001. A preliminary assessment of paleontological resources at GUMO was conducted by Vincent L. Santucci in April 1998, however, a formal paleontological scoping session has not yet been undertaken for GUMO. A review of Guadalupe Mountains paleontological resources was included in a comprehensive inventory of paleontological resources associated with National Park Service caves completed in 2001 (Santucci, et al. 2001).

Guadalupe Mountains National Park contains one of the world's most extensive and significant limestone reefs. The "Permian Reef Complex" is located on the northwestern margin of the Delaware Basin and contains one of the largest fossil reefs in the world (Newell et al. 1953). Additionally, the park preserves one of the most complete Permian marine sequences in the world. Forty miles (64 kilometers) of this reef, known as the Capitan Reef, is exposed in the Guadalupe Mountains. The reef is also exposed in the Apache and Glass mountains, however, most of the reef is present in the subsurface. Newell and others (1953) report that the Capitan Reef overlies a slightly older reef called the Goat Seep Reef.

During the Permian (approximately 299 – 251 million years ago) four reef facies developed in southern New Mexico and west Texas in an area referred to as the Delaware Basin. At that time the area was an arid tropical region 5-10 degrees north of the Permian equator. The facies consisted of a reef crest, fore reef, basin debris, and a back reef or lagoonal facies. Different portions of the reef complex are subjected to different physical and environmental conditions. These conditions influence and control deposition and sedimentation. In turn specific types of facies develop within each portion of the reef complex and different groups of organisms inhabit different portions of the reef.

Reef Crest

The reef crest is the main body, structure or framework of the reef. The crest is the highest portion of the reef which is subjected to the most direct sunlight resulting in a zone of rapid biotic development. The skeletons produced by the organisms, largely invertebrates such as sponges, bryozoans, and corals, are incorporated into the framework of the reef proper. The reef crest is represented by the Goat Seep Dolomite and Capitan Limestone.

Fore Reef
The fore reef is the open sea / ocean facing side of the reef complex and is subjected to moderate to high wave action. This energy eventually causes pieces and blocks of both living and dead reef to dislodge from the reef crest. The material separated from the reef accumulates and develops a talus slope in the fore reef zone. The fore reef is represented by the Goat Seep Dolomite and Capitan Limestone.

Basin
These are the deposits which accumulate and develop within the offshore basin typically in deeper water. The basin is represented by the Cutoff, Brushy Canyon, Cherry Canyon, and Bell Canyon formations.

Back Reef
The back reef, sometimes referred to as lagoon, is the area of the reef complex facing most proximal to the shoreline. This area is characterized by relatively low energy, with less exposure to current and wave activity. This area is dominated by fine grained sediment and may exhibit increased salinity or magnesium if there are no streams contributing an inflow of water. The high rate of evaporation in arid regions often results in the precipitation of evaporitic minerals in this portion of the reef complex. The back reef is represented by the Yeso, San Andres, Grayburg, Queen, Seven Rivers, Yates, and Tansill formations.

A voluminous literature exists for geology of the Capitan Reef and of the Guadalupe Mountains. Crandall (1929), Lloyd (1929) and Blanchard and Davis (1929) independently recognized the Capitan Limestone as fossil barrier reef in the same year. King (1942, 1948) present a comprehensive history of investigations focused on the physical stratigraphy and regional geology of the Delaware Basin and the Guadalupe Mountains. Adams and Frenzel (1950) presented a detailed interpretation of the sedimentary history of the Capital Reef including the review of subsurface data. Hayes (1964) and Hill (1987) provide excellent overviews on the geology of the Guadalupe Mountains. Newell and others (1953) provides one of the most definitive interpretations of the geology of the Permian Reef Complex of west Texas and New Mexico.

The oldest series of the Permian (Wolfcampian) is not exposed in the Guadalupe Mountains. The Permian stratigraphy of the Guadalupe Mountains consists of Leonardian, Guadalupian, and Ochoan series rocks. These are approximately equivalent to the Artinskian, Kungurian, Ufimian, Kazanian, and Tartarian of the type Permian section in the Ural Mountains. In the modern IUGS time scale the Wolfcampian and Leonardian are superceded by the Cisuralian Series (Lower Permian) and the Ochoan is superceded by the Lopingian Series (Upper Permian) (Jin et al. 1997).

Yeso Formation (Lower Permian)
The Yeso Formation is a Lower Permian (Leonardian) unit which represents carbonates, sands and muds infilling the Delaware Basin. Alternating beds of dolomite, sandstone, and gypsum form a gently sloping basin and shelf margin. There are some small patch reefs developed within shallow water zones along the rim of the basin.

Brushy Canyon Formation / San Andres Formation (Middle and Upper Permian)
The Upper Permian (Guadalupian) Brushy Canyon Formation represents a period of renewed subsidence in the Delaware Basin. Larger patch reefs were formed along the basin margin. The Brushy Canyon Formation is largely composed of sands deposited in the fore reef and offshore basin. There is a time equivalent facies referred to as the San Andres Formation is represented by a cherty dolomite developed closer to the shore line in the back reef lagoon.

Cherry Canyon Formation / Queen Formation / Grayburg Formation (Middle Permian)
Increased subsidence of the Delaware Basin resulted in an intensified reef development. The reef of this time period grew in height and is referred to the "Goat Seep Reef". This reef resulted in the development of clearly defined reef facies with: the Queen and Grayburg formations representing the back reef / lagoonal facies composed of sandstones and dolomites; the Goat Seep Reef and the Getaway Bank constitute the reef crest and shallow fore reef facies containing dolomitized sponges and algae; and, the Cherry Canyon Formation representing the offshore basin facies composed largely of quartz sandstones.

Bell Canyon Formation (Middle Permian)
The Bell Canyon Formation consists of numerous beds of sedimentary breccia (angular, poorly sorted rock fragments). This represents the deep water facies of the offshore basin and is contemporaneous with the development of the largest reef (Capitan Formation). The source of the breccias is the fore reef and talus slope and the accumulations often result in submarine slides. There are a series of limestone tongues in the Bell Canyon Formation. The youngest of these limestones tongues is the Lamar Limestone. The Bell Canyon Formation is visible at the beginning of the Permian Reef Geology Trail in McKittrick Canyon (Bebout and Kerans 1993).

Capitan Formation (Middle Permian)
During late Guadalupian , the basin stabilized and ceased subsidence. The reef (Capitan Limestone) rapidly expanded into massive skeletal limestones, approximately 350 miles in length, around the rim of the basin. The reef eventually prograded towards the center of the basin. The type section for the Capitan Formation is within Guadalupe Mountains National Park.

Carlsbad Group (Middle Permian)—Seven Rivers Formation , Yates Formation, and Tansill Formation
The Carlsbad Group consists of a number of back reef (near shore – shallow water) facies which exhibit a progressive transition from carbonates through evaporates to terrigenous sediments. These are seen today as dolomites and fine-grained sandstones in the Guadalupe Mountains. These units were also developed contemporaneously with the largest reef (Capitan Limestone). Borer and Harris (1983) and Candelaria (1982) provide detailed geologic interpretation for the Yates Formation.

Castile Formation (Upper Permian)
The ancient reef became extinct in the latest Permian as the connection of the reef to the open ocean became restricted. This is interpreted by most as a drop in the sea level, although this view is still debated. The reduced influx of marine water led to an increased level of evaporation. In turn, the resulting elevation of salinity levels led to species decline and the deposition of gypsum filled the basin to the top of the reef. This gypsum rich deposit is the Castile Formation.

As evaporation of the hypersaline marine waters continued, major deposits of salt and potash were deposited over the Castile Formation and the old shelf areas of the Delaware Basin. These deposits are known as the Salado Formation. Near the end of the Permian, terrestrial sediments migrated over the evaporites. The red siltstones and sandstones have been identified as the Rustler and Dewey Lake formations. Subsequent tectonic activity generated major faulting in the Guadalupe Mountains. The Capitan Formation today is exposed at the peak of the Guadalupe Mountains in GUMO and the eastern escarpment at CAVE.

Fossils of the Guadalupe Mountains
The first collection of fossils from the Guadalupe Mountains area dates to 1855 when Dr. George G. Shumard participated in an expedition searching for artesian water along the 32nd Parallel (Shumard 1958a). George Shumard served as the assistant State Geologist of Texas at the time and made collections of fossils from the White Limestone unit of the Guadalupe Mountains. These fossil collections were given to George Shumard's brother Benjamin Franklin Shumard who was the State Geologist of Texas. The Shumards recognized the fossils from the Guadalupe Mountains represented a Permian age fauna (Shumard, 1858a, 1858b). Benjamin Shumard (1859) described the Permian fauna from the Guadalupe Mountains including many new fossil species.

In 1901 Girty made extensive fossil collections from the Guadalupe Mountains, described the major fauna from throughout the section, and named the Guadalupian Series (Girty 1908). Other than Girty, there was little focus on the paleontology of the area until petroleum was discovered in the area during the 1920s. About this time Wallace Pratt, senior geologist for the Houston based Humble Oil and Refining Company (now Exxon), began to study the geology of the Guadalupe Mountains. Pratt contributed greatly to the understanding of the local geology and was later instrumental in the establishment of the area as Guadalupe Mountains National Park. During the 1920s Pratt purchased thousands of acres of land in the Guadalupe Mountains and eventually donated more than 5,000 acres, including McKittrick Canyon, for inclusion in the park. A transcript from an oral history interview of Wallace Pratt, dated October 2, 1978, is contained within the Guadalupe Mountains National Park archives at the Harpers Ferry Center Library.

The diversity of fossil species is high within the Permian Reef Complex at Guadalupe Mountains National Park. Invertebrate fossils are present throughout the exposed reef including algae, fusulinids, sponges, corals, bryozoans, brachiopods, trilobites, ostracods, gastropods, cephalopods, scaphopods, pelecypods, crinoids, echinoids, and conodonts. The reef limestone (Capitan Formation) is composed primarily of algae, sponges and bryozoans. Johnson (1942) identified and described ecological zones or facies based upon fossil algae in the reef. Hayes (1964) reported stromatolites in the Goat Seep Dolomite within McKittrick Canyon. Newell and others (1953) identified five growth forms of bryozoans and three growth forms in corals in the Permian Reef Complex. Fusilinids, brachiopods and crinoids are more common in the fore reef and back reef deposits.

Newell and others (1953) provide a comprehensive and useful presentation of fossils from the Guadalupe Mountains. They provide excellent stratigraphic and geographic distributions of fossils within the shelf formations. Newell and others (1953) present species lists for fossils identified from the Permian Reef Complex and indicate that a number of specimens represent new taxa that await formal description. One Hundred and fifteen species are identified from the Capitan Formation (Newell et al. 1953). Quantitative relationships between major faunal elements were assessed and show relative percentages of taxonomic groups (Newell et al. 1953). They concluded that there appears to be at least three factors which affect the quantitative importance of the faunal composition: 1) local variation in communities at the reef source; 2) local variations in basin communities; and, 3) selective destruction during transportation and differential preservation.

Sponge diversity is extremely rich in all facies of the reef and the genus *Lemonea* is widely adapted and is one of the dominate sponges in many Late Permian reef faunas (Johns and Kirkland 1998; Rigby and Bell 2006)). Continued paleontological research at GUMO continues to yield new information and even new species of fossils. Bell and others (2002) report on a new occurrence and possible new species of the genus *Gigantospongia* at GUMO. A new hexactinellid sponge is described from the Bell Canyon Formation in GUMO by Rigby and Bell (2005). A large sponge fauna from the Patterson Hills was described by Rigby and Bell (2006) from the Reef Trail Member of the Bell Canyon Formation. This is the youngest Permian sponge fauna known from North America.

Vertebrate fossils occur within the Permian units of the Guadalupe Mountains, however, they are rare by comparison to the invertebrate fossils. The middle Permian submarine fan sandstones of the Brushy Canyon and Cherry Canyon formations within the park contain hundreds of fish remains, including shark's teeth, in small phosphatic nodules. The younger Lamar Limestone Member of the Bell Canyon Formation has also preserved the dentition of a holocephalan (G. Bell, personal communication, 2005; Hunt et al. 2006).

McKittrick Canyon reveals a cross section of the four major reef facies along with many fossils and small caves. An important record of Pleistocene and Holocene paleontological resources is preserved from the caves of the Guadalupe Mountains.

Paleontological Resources in GUMO Caves (Pleistocene / Holocene)
During the late Cenozoic, approximately 3 million years ago, regional uplift raised and tilted the Guadalupe Mountains to the east-northeast (Kiver and Harris 1999). The reef complex is exposed in the Guadalupe, Apache, and Glass Mountains of the Delaware Basin. Sedimentary units overlying the Capitan Reef, including the Castile Formation, were eroded away and the buried Permian reef was once again exposed.

Twenty-seven caves have been documented within Guadalupe Mountains National Park. Most of these are administratively closed to the public. Since the 1930s the Guadalupe Mountains have been recognized for their significant Pleistocene/Holocene cave fossils. Of global significance, four of the ten known sloth dung localities in the world occur in Guadalupe Mountains National Park. The sloth dung is documented from Lower Sloth Cave, Upper Sloth Cave, Dust Cave, and Williams Cave (Spaulding and Martin 1979).

Van Devender and others (1979) established a chronological sequence of Late Pleistocene and Holocene plant communities in the Guadalupe Mountains spanning the last 13,000 years. The chronology is based upon plant macrofossils and pollen collected from four caves in Guadalupe Mountains National Park. The plant communities in the Guadalupe Mountains have gradually changed from relatively mesic woodland and forest associations during pluvioglacial climates in the Late Wisconsin Glacial Epoch to the present xeric Chihuahuan desert scrub (Van Devender et al. 1979).

Burnet Cave, also known as Rocky Arroyo Cave, lies on the eastern slope of the Guadalupe Mountains. Nine feet (3 meters) of unstratified sediments, consisting of wind blown dust and roof spall, cover the floor of the cave. Archeological resources occur in the upper portions of the cave deposits. Charcoal lenses and a few hearths were identified from within the cave sediments. A radiocarbon analysis of one charcoal lens revealed a date of approximately 7,432 years B.P. (Libby, 1954). A Folsom-like spear point was discovered in association with the remains of a bison and muskox in the cave.

A joint expedition into Burnet Cave was undertaken by the University Museum of Philadelphia and the Academy of Natural Sciences of Philadelphia between 1930 and 1933. In 1931, the excavation was visited by Childs Frick and Barnum Brown from the American Museum of Natural History. Sixty-two species were identified including two reptiles, seventeen birds, and forty-three mammals (Schultz and Howard 1935). The avian remains, including bones from a specimen of *Gymnogyps californianus*, were examined and identified by Alexander Wetmore from the United States National Museum (Wetmore 1932). A poorly documented excavation of Burnet Cave was undertaken in 1936 By Edgar Howard. During 1937, Dr. C. Bertrand Schultz (University of Nebraska) and the Academy of Natural Sciences of Philadelphia sent Howard back to excavate Burnet Cave. Sixteen feet (5 meters) of cave sediments were excavated, however, the rock floor of the cave was not reached. More than fifteen thousand specimens of small mammals were recovered (Burnet 1938). A number of the vertebrates collected in Burnet Cave represent boreal species extended to their southernmost limits. These taxa include *Marmota flaviventris*, *Neotoma cinerea*, *Microtus longicaudus*, *Lepus townsendi*, and *Vulpes macroura* (Murray 1957). The *Marmota* specimen has been of particular interest and is considered to be an aberrant member of the fauna (Stearns 1942; Antevs 1954). Remains of the extinct *Euceratherium collinum* and *Navahoceros fricki* were also recovered from Burnet Cave and suggest a northern latitude affinity. The fauna includes a number of forest and arid-desert species. Three herptozoans have been reported from Burnet Cave (Gehlbach and Holman 1974).

Pratt Cave is located on the southwestern portion of McKittrick Canyon. The cave formed within the Lamar Limestone (Bell Canyon Formation). Fossil pollen, molluscs, and vertebrates have been collected from the cave. Although the vertebrate bones are largely disarticulated, they are well preserved. A diverse herpetofauna including eighteen species has been documented from Pratt Cave (Gehlback and Holman 1974). This assemblage of amphibians and reptiles consist of arid-adapted taxa that span the late Wisconsin/Recent boundary. The Pratt Cave herpetofauna are curated in the vertebrate collections at Michigan State Museum.

During 1962, a test excavation in Pratt Cave yielded six avian bones. The bones were identified by Lyndon Hargrave as the remains of the extinct *Geococcyx conklingi* (Conkling's roadrunner) and a turkey. McKusick (1978) concluded that the Pratt Cave fossil bird specimens were deposited as owl pellets. Howard and Miller (1933) published a list of avifauna collected from caves in the Guadalupe Mountains. In January 1966, eighteen feathers were collected from test excavations in Pratt Cave. The feathers were analyzed and identified by Norman Messinger (1978). The feather morphologies represent the remains identified as anseriformes (waterfowl), galliformes (gallinaceous bird), ciconiiformes (heron or egret), and strigiformes (owl). Lundelius (1970, 1979) reported on collections of mammal bones from Pratt Cave. The assemblage of small mammal bones was interpreted either as accumulations of owl pellets or gathered by packrats. An articulated small rodent foot was uncovered with the bone elements held together by dried ligaments. The large mammal bones were interpreted as being transported by carnivores.

Lower Sloth Cave is located on the west side of Guadalupe Canyon. The fauna and flora from the cave spans the transition from Late Wisconsin Stage into the Holocene. Logan (1977) reports on six test trenches that were excavated in Lower Sloth Cave. The remains of two birds and 30 mammal species have been recovered from the cave (Logan and Black 1979). Plant macrofossils and microvertebrates have also been collected from packrat middens. Three of the species are now extinct or locally extinct including the Pleistocene Black Vulture, Bighorn Sheep, and Shasta Ground Sloth. Sloth dung has been identified in this cave and has yielded a radiocarbon date of 10,750–11,060 years B.P. Plant macrofossils and pollen profiles from Lower Sloth Cave span the last 13,000 years (Van Devender et al. 1977). The vegetation indicates an overlap between a Late Pleistocene subalpine forest with grassy meadows. There are a few arid desert species interspersed in the flora. A radiocarbon date of approximately 13,000 years B.P. was obtained from some *Picea* (spruce) needles.

Logan (1977) interpreted the accumulations of vertebrate bones from both natural death assemblages and carnivore transport. The remains of immature birds and bats exhibit little breakage prior to deposition and represent a natural death assemblage of taxa inhabiting the cave. The carnivore-transported assemblages show breakage and evidence of feeding. Small bone accumulations were associated with owl pellets and small carnivore scats (i.e., *Bassariscus, Spilogale, Canis*) Upper Sloth Cave preserves packrat middens containing plant macrofossils and microvertebrates. Logan (1975) reported on Pleistocene vertebrates from the cave. Sloth dung from the cave yielded a radiocarbon date of approximately 11,760 years B.P. *Picea* needles from a packrat midden yielded a radiocarbon date of about 13,000 years B.P. Williams Cave (Indian Cave) is located in the southern portion of the Guadalupe Mountains. The cave floor is covered with fine dust and rocks dropped from the cave ceiling. The cave was excavated during 1934 and 1935 when seven-foot deep trenches were dug about halfway to the rear of the cave. Ayer (1936) reported the remains of one reptile (snake vertebrae), one bird, and twenty-two mammal species from Williams Cave. The mammal genera include *Cynomys* (prairie dogs), *Citellus* (ground squirrel), *Cratogeomys* (pocket gopher), *Perognathus, Neotoma, Erethizon, Lepus, Sylvilagus, Canis, Urocyon, Felis, Lynx, Ursus, Odocoileus, Cervus* (deer), *Antilocarpa, Ovis, Equus,* and *Nothrotheriops*. Additional cave fauna include five locally extinct taxa including the grizzly bear, dire wolf, elk, horse, and ground sloth. Well-preserved sloth dung was also collected and has been curated in the Academy of Natural Sciences in Philadelphia. Remnants of packrat middens are plastered to the cave walls. Radiocarbon dating of cave deposits range between 11,140 and 12,100 years B.P. Ernest Lundelius and the Texas Archeological Society Field School visited Williams Cave in June 1970. The Guadalupe Mountains National Park has copies of the typed field notes from this site visit.

Dust Cave has plant macrofossils and microvertebrate remains that have been preserved in packrat middens. The remains of a black vulture and bighorn sheep have been documented from Dust Cave. Ground sloth dung is preserved in this cave. Redemption Pit is a separate karst feature at Guadalupe Mountains National Park that contains vertebrate bones, but there is little information available about this cave.

REFERENCES CITED

Adams, J.E. and H.N. Frenzel. 1950. Capitan barrier reef, Texas and New Mexico. Journal of Geology 58(4): 289-312.

Antevs, E. 1954. Climate of New Mexico during the last glacio-pluvial. *Journal of Geology* 62:182-191.

Ayer, M.Y. 1936. The archeological and faunal material from Williams Cave, Guadalupe Mountains, Texas. *Proceedings of the Academy of Natural Sciences* 86:599-618.

Bebout, D.G. and C. Kerans (eds.). 1993. Guide to the Permian Reef Geology Trail, McKittrick Canyon, Guadalupe Mountains National Park, west Texas. Bureau of Economic Geology, University of Texas at Austin, Guidebook 26, 48 pp.

Bell, G.L. C.J. Crow, and J.K. Rigby. 2002. Newly recognized reef fabric from the middle Capitan Reefs (Middle Permian), Guadalupe Mountains, Texas. Geological Society of America, Abstracts with Programs, 160-17.

Blanchard, W.G. and M.J. Davis. 1929. Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas. American Association of Petroleum Geologists Bulletin 13: 957-995.

Borer, J.M. and P.M. Harris 1989. Depositional facies and cycles in Yates Formation outcrops, Guadalupe Mountains, New Mexico. In Harris, P.M. and G.A. Grover (eds.), Subsurface and outcrop examination of the Capitan Shelf Margin, northern Delaware Basin, SEPM Core Workshop No. 13, p. 305-317.

Burnet, R.M.P. 1938. Early man and extinct fauna of the Carlsbad Region. *New Mexico Archeologist* 2(2):44-45.

Candelaria, M.P. 1982. Sedimentology and depositional environment of upper Yates Formation siliciclastics (Permian, Guadalupian), Guadalupe Mountains, southeast New Mexico. M.S. Thesis, University of Wisconsin, 267 pp.

Crandall, K.H. 1929. Permian stratigraphy of southeastern New Mexico and adjacent parts of western Texas. American Association of Petroleum Geologists Bulletin 13: 927-944.

Gehlbach, F.R. and J.A. Holman. 1974. Paleoecology of amphibians and reptiles form Pratt Cave, Guadalupe Mountains National Park, Texas. *Southwestern Naturalist* 19:191-198.

Girty, G.H. 1908. *The Guadalupian Fauna*. U.S. Geological Survey Professional Paper 58. 651 pp.

Hayes, P.T. 1964. *Geology of the Guadalupe Mountains New Mexico*. U.S. Geological Survey Professional Paper 446. 69 pp.

Hill, C.A. 1987. *Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico and Texas*. New Mexico Bureau of Mines Bulletin 117. 150 pp.

Howard, H. and A.H. Miller. 1933. Bird remains from cave deposits in New Mexico. *The Condor* 35(1):15-18.

Hunt, R.K., V.L. Santucci, and J. Kenworthy. 2006. A preliminary inventory of fossil fish from National Park Service units. In Lucas, S.G., Speilman, J.A., Hester, P.M., Kenworthy, J.P., and Santucci, V.L.

(eds.), Fossils from Federal Lands, New Mexico Museum of Natural History and Science Bulletin, 14, p. 63-69.

Jin, Y., B.R. Wardlaw, B.F. Glenister, and G.V. Kotlyar 1997. Permian Chronostratigraphic Subdivisions. Episodes 20(1): 10-15.

Johns, R.A. and B.L. Kirkland. 1998. Patterns of sponge diversity in the middle Capitan Reef of the Guadalupe Mountains, Texas. In DeMis, W. and M.K. Nelis (editors), The Search Continues into the 21st Century – West Texas Geological Society Fall Symposium. West Texas Geological Society Publication 98-105: 77-87.

Kurtén, B. and E. Anderson. 1980. *Pleistocene mammals of North America*. New York: Columbia University Press. 442 pp.

Libby, W.F. 1954. Chicago radiocarbon dates. *Science* 119:135-140.

Lloyd, E.R. 1929. Capitan limestone and associated formations in New Mexico. American Association of Petroleum Geologists Bulletin 13: 645-657.

Logan, L.E. 1975. The Quaternary vertebrate fauna of Upper Sloth Cave, Guadalupe Mountains National Park, Texas (abstract). *South-central Section, Geological Society of America*. P. 210.

Logan, L.E. 1977. *The paleoclimate implications of the avian and mammalian faunas of Lower Sloth Cave, Guadalupe Mountains, Texas*. M.S. Thesis, Texas Tech University, Lubbock. 72 pp.

Logan, L.E. and C.C. Black. 1979. The Quaternary Vertebrate fauna of Upper Sloth Cave, Guadalupe Mountains National Park, Texas. *in* Genoways, H.H. and R.J. Baker eds.). *Biological Investigations in the Guadalupe Mountains National Park, Texas*. National Park Service Proceedings and Transactions Series 4. Pp. 141-158.

Lundelius, E.L., Jr. 1970. *Mammalian remains from Pratt Cave, Culberson County, Texas*. Unpublished Report, Department of Geological Sciences, University of Texas, Austin. 42 pp.

Lundelius, E.L., Jr. 1979. Post Pleistocene mammals from Pratt Cave and their environmental Significance. *in* Genoways, H.H. and R.J. Baker (eds.). *Biological Investigations in the Guadalupe Mountains National Park, Texas*. National Park Service Proceedings and Transactions Series 4. Pp. 239-258.

McKusick, C.R. 1978. Avian remains, Pratt Cave, McKittrick Canyon, New Mexico. *in* Schroeder, A. (ed.). *Pratt Cave Studies*. Guadalupe National Park files. Pp. 234-251.

Messinger, N.G. 1978. An analysis of feathers from Pratt Cave. *in* Schroeder, A. (ed.). *Pratt Cave Studies*. Guadalupe National Park files. Pp. 228-231.

Murray, K.F. 1957. The Pleistocene climate and the fauna of Burnet Cave, New Mexico. *Ecology* 38(2):129-132.

Newell, N.D., J.K. Rigby, A.G. Fischer, A.J. Whiteman, J.E. Hickox, and J.S. Bradley. 1953. *The Permian Reef Complex of the Guadalupe Mountains Region, Texas and New Mexico: A Study in Paleoecology*. New York: Hafner Publishing Co. 236 pp.

Rigby, J.K. and G.L. Bell, Jr. 2005. A new hexactinellid sponge from the Reef Trail Member of the Upper Guadalupian Bell Canyon Formation, Guadalupe Mountains National Park, Texas. Journal of Paleontology, vol. 79(1): 200-204.

Rigby, J.K. and G.L. Bell, Jr. 2006. Sponges from the Reef Trail Member of the Upper Guadalupian (Permian) Bell Canyon Formation, Guadalupe Mountains National Park, Texas. Journal of Paleontology 80 (supplement to 5), Memoir 66, 42 p.

Santucci, V.L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service Caves. National Park Service Geologic Resources Division Technical Report, NPS/NRGRD/GRDTR-01/02, 50 pp.

Schultz, C.B. and E.B. Howard. 1935. The fauna of Burnet Cave, Guadalupe Mountains, New Mexico. *Proceedings of the Academy Natural Sciences of Philadelphia* 87:273-298.

Shumard, B.F. 1858a. On Permian rocks in the Guadalupe Mountains, New Mexico. Transactions of the Academy of Sciences of Saint Louis 1: 113-1114.

Shumard, B.F. 1858b. Notice of new fossils from the Permian strata of New Mexico and Texas, collected by Dr. George G. Shumard, geologist for the United States government expedition for obtaining water by means of Artesian wells along the 32nd Parallel, under the direction of Captain John Pope, U.S. Topographic Engineers. Transactions of the Louis Academy of Sciences of Saint Louis 1: 290-297.

Shumard, B.F. 1859. Notice of fossils from the Permian strata of New Mexico and Texas, obtained by the United States Expedition under Captain John Pope for boring Artesian wells along the 32nd Parallel, with descriptions of new species from these strata and the coal measures of that region. Transactions of the Louis Academy of Sciences of Saint Louis 1: 290-297.

Spaulding, W.G. and P.S. Martin. 1979. Ground sloth dung of the Guadalupe Mountains in Biological Investigations. *in* Genoways, H.H. and R.J. Baker (eds.). *Biological Investigations in the Guadalupe Mountains National Park, Texas*. National Park Service Proceedings and Transactions Series 4. Pp. 259-269.

Stearns, C.E. 1942. A fossil marmot from New Mexico and its climatic significance. *American Journal of Science* 240:867-878.

Van Devender, T.R., P.S. Martin, and A.M. Phillips III. 1977. Late Pleistocene biotic communities from the Guadalupe Mountains Culberson County Texas. *in* Wauer, R.H. and D.H. Riskind (eds.). *Transactions of the Symposium on the Biological Resources of the Chihuahuan Desert Region, United States and Mexico*. National Park Service Proceedings and Transactions Series 3. Pp. 107-113.

Van Devender, T.R., W.G. Spaulding and A.M. Phillips III. 1979. Late Pleistocene Plant communities in the Guadalupe Mountains Culberson County Texas. *in* Genoways, H.H. and R.J. Baker (eds.). *Biological Investigations in the Guadalupe Mountains National Park, Texas*. National Park Service Proceedings and Transactions Series 4. Pp. 13-30.

Wetmore, A. 1932. Additional records of birds from cavern deposits in New Mexico. *The Condor* 34(3):141-142.

ADDITIONAL REFERENCES

Achauer, C.W. 1969. Origin of Capitan Formation, Guadalupe Mountains, New Mexico and Texas. American Association of Petroleum Geologists Bulletin 53(11): 2314-2323.

Adams, J.E. 1932. Anhydrite and associated inclusions in the Permian limestones of west Texas. Journal of Geology 40: 30-45.

Adams, J.E. 1944. Upper Permian Ochoa series of Delaware Basin, west Texas and southeast New Mexico. American Association of Petroleum Geologists 28: 1596-1625.

Babcock, J.A. 1974. The role of algae in the formation of the Capitan Limestone (Permian, Guadalupian), Guadalupe Mountains, west Texas – New Mexico. Ph.D. Dissertation, University of Wisconsin, Madision, 241 pp.

Babcock, J.A. 1977. Calcareous algae, organic boundstones, and the genesis of the upper Capitan Limestone (Permian, Guadalupian), Guadalupe Mountains, west Texas and New Mexico. In Hileman, M.E., and S.J. Mazzullo (eds.), Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and West Texas, Field Conference Guidebook, PBS / SEPM Publication 77-16, volume 1: 3-44.

Babcock, J.A. and D.A. Yurewicz. 1989. The massive facies of the Capitan Limestone, Guadalupe Mountains, Texas and New Mexico. In Harris, P.M. and G.A. Grover (eds.), Subsurface and outcrop examination of the Capitan Shelf Margin, northern Delaware Basin, SEPM Core Workshop No. 13, p. 365-371.

Babcock, L.C. 1974. Conodont paleoecology of a Guadalupian (Permian) shelf to basin sequence, Permian Reef Complex, west Texas and New Mexico (abstract). Geological Society of America, Abstracts with Programs, North-Central Section Meeting, p. 489.

Babcock, L.C. 1974. Statistical approaches to the conodont paleoecology of the Lamar Limestone, Permian Reef Complex, west Texas. Ph.D. Dissertation, University of Wisconsin, Madison, 175 pp.

Babcock, L.C. 1976. Conodont paleoecology of the Lamar Limestone (Permian), Delaware Basin, west Texas. In C.R.. Barnes (ed.), Conodont Paleoecology: Geological Association of Canada Special Paper No. 15, p. 279-294.

Babcock, L.C. 1976. Life in the Delaware Basin – the paleoecology of the Lamar Limestone. In Upper Guadalupian Facies, Permian Reef Complex, Guadalupe Mountains, New Mexico and West Texas 1977 field conference guidebook; Permian Basin Section – SEPM Publication 77-16, p. 357-390.

Behnken, F.H. 1972. Leonardian and Guadalupian (Permian) conodont biostratigraphy and evolution in western and southwestern United States. Ph.D. Dissertation, University of Wisconsin, Madison, 184 pp.

Croft, J.S. 1972. A description and paleoecologic study of conodonts from the Pinery Limestone Member of the Bell Canyon Formation (Upper Permian), Guadalupe Mountains, west Texas. M.S. Thesis, Ohio State University, Columbus, Ohio, 54 pp.

Croft, J.S. 1978. Upper Permian conodonts and other microfossils from the Pinery and Lamar limestone members of the Bell Canyon Formation and from the Rustler Formation, west Texas. M.S. Thesis, Ohio State University, Columbus, Ohio, 176 pp.

Cronoble, J.M. 1974. Biotic constituents and origin of facies in Capitan reef, New Mexico and Texas. Mountain Geologist 11(3): 95-108.

Davis, D.G. 1979. Cave development in the Guadalupe Mountains, New Mexico, Texas. Caving International Magazine 3, p. 43.

Davis, D.G. 1980. Cave development in the Guadalupe Mountains: a critical review of recent hypotheses. National Speleological Society Bulletin 42: 42-48.

DeFord, R.K. and G.D. Riggs. 1941. Tansill formation, west Texas and southeastern New Mexico. American Association of Petroleum Geologists Bulletin 25: 1713-1728.

DuChene, H.R. 1971. Discussion to accompany tectonic map of the Guadalupe Mountains and vicinity, Texas and New Mexico. Unpublished Report to Carlsbad Caverns National Park, 17 pp.

DuChene, H.R. 1978. Geologic history of the Guadalupe Mountains region. National Speleological Society Bulletin 40: 3-6.

DuChene, H.R. 1986. Observations on previous hypotheses and some new ideas on cavern formation in the Guadalupe Mountains. In Jagnow, D.H. (ed.), Geology Field Trip Guidebook, 1986 National Speleological Society Convention, Tularosa, New Mexico, p. 96-100.

Dunham, R.J. 1972. Capitan reef, New Mexico and Texas: facts and questions to aid interpretation and group discussion. Society of Economic Paleontology and Mineralogy, Permian Basin Section, Publication 72-14.

Erwin, D.H. 1989. Regional paleoecology of Permian gastropod genera, southwestern United States and the end Permian mass extinction. Palaios 4: 1.

Finks, R.M. 1960. Late Paleozoic sponge faunas of the Texas region. Bulletin of the American Museum of Natural History 120: 1-161.

Garber, R.A., G.A. Grover, and P.M. Harris. 1989. Geology of the Capitan shelf margin – subsurface data from the northern Delaware Basin. In Harris, P.M. and G.A. Grover (eds.), Subsurface and outcrop examination of the Capitan Shelf Margin, northern Delaware Basin, SEPM Core Workshop No. 13, p. 3-269.

Hayes, P.T. 1964. Geology of the Guadalupe Mountains, New Mexico. U.S. Geological Survey, Professional Paper 446, 1:62,500 scale.

Hayes, P.T. and R.L. Koogle. 1958. Geology of the Carlsbad Caverns West Quadrangle, New Mexico and Texas. U.S. Geological Survey Geological Quadrangle Map GQ-112.

Hill, C.A. 1996. Geology of the Delaware Basin, Guadalupe, Apache, and Glass mountains, New Mexico and West Texas. SEPM (Society for Sedimentary Geology), Permian Basin Section, Publication 96-39, 480 p.

Hills, J.M. 1942. Rhythm of Permian seas, a paleogeographic study. American Association of Petroleum Geologists Bulletin 26: 217-255.

Howard, E.B. 1932. Caves along the slopes of the Guadalupe Mountains. Texas Archeological and Paleontological Society Bulletin 4: 7-20.

Hurley, N.F. 1978. Facies mosaic of the Lower Seven Rivers Formation (Permian), North McKittrick Canyon, Guadalupe Mountains, New Mexico. M.S. Thesis, University of Wisconsin, Madison, 198 p.

Hurley, N.F. 1989. Facies mosaic of the lower Seven Rivers Formation, McKittrick Canyon, New Mexico. In Harris, P.M. and G.A. Grover (eds.), Subsurface and outcrop examination of the Capitan Shelf Margin, northern Delaware Basin, SEPM Core Workshop No. 13, p. 325-346.

Jagnow, D.H. 1977. Geologic factors influencing speleogenesis in Capitan Reef Complex, New Mexico and Texas. M.S. Thesis, University of New Mexico, 203 pp.

Jagnow, D.H. 1979. Cavern development in the Guadalupe Mountains. Cave Research Foundation, Columbus, Ohio, 55 p.

Johnson, J.H. 1942. Permian lime-secreting algae from the Guadalupe Mountains, New Mexico. Geological Society of America Bulletin 53: 195-226.

King, P.B. 1934. Permian stratigraphy of Trans-Pecos Texas. Geological Society of America Bulletin 45: 697-698.

King, P.B. 1942. Permian of west Texas and southeastern New Mexico. American Association of Petroleum Geologists Bulletin 26: 535-763.

King, P.B. 1944. Geologic map of the southern Guadalupe Mountains, Hudspeth and Culberson Counties, Texas. U.S. Geological Survey, OM-18, 1:48,000 scale.

King, P.B. 1948. Geology of the southern Guadalupe Mountains, Texas. U.S. Geological Survey, Professional Paper 215, 183 p.

King, P.B. 1949. Regional geologic map of parts of Culberson and Hudspeth Counties, Texas. U.S. Geological Survey, OM-90, 1:150,000 scale.

Kirkland-George, B. 1992. Distinctions between reefs and bioherms based on studies of fossil algae – *Mizzia*, Permian Capitan reef complex (Guadalupe Mountains, Texas and New Mexico) and Eugonophyllum, Pennsylvanian Holder Formation (Sacramento Mountains, New Mexico). Ph.D. Dissertation, Louisiana State University, 156 p.

Kiver, E.P. and D.V. Harris. 1999. Geology of U.S. Parklands. John Wiley & Sons, Inc., New York, 902 pp.

Logan, L.E. 1983. Paleoecological implication of the mammalian fauna of Lower Sloth Cave Guadalupe Mountains, Texas. National Speleological Society Bulletin 45: 3-11.

Mazzullo, S.J. 1993. Geologic studies in Carlsbad Caverns and Guadalupe Mountains National Parks, New Mexico and Texas. In V.L. Santucci (ed.), National Park Service Paleontological Research Abstract Volume 1; National Park Service Technical Report NPS/NRPEFO/NRTR-93-11, p. 50.

Metcalf, A.L. and R.W. Fullington. 1976. A new fossil *Ashmunella* (Pulmonata: Polygyridae) from the Guadalupe Mountains National Park, Texas. The Nautilus 30: 49-??

Miller, A.K. and W.M. Furnish. 1940. Permian ammonoids of the Guadalupe Mountains region and adjacent areas. Geological Society of America Special Paper No. 26, Waverly Press, Baltimore.

Neese, D.G. 1989. Peritidal facies of the Guadalupian shelf crest, Walnut Canyon, New Mexico. In Harris, P.M. and G.A. Grover (eds.), Subsurface and outcrop examination of the Capitan Shelf Margin, northern Delaware Basin, SEPM Core Workshop No. 13, p. 295-303.

Neese, D.G. and A.H. Schwartz. 1977. Facies mosaic of the upper Yates and lower Tansil Formations, Walnut and Rattlesnake Canyons, Guadalupe Mountains, New Mexico. In Hileman, M.E., and S.J. Mazzullo (eds.), Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and West Texas, Field Conference Guidebook, PBS / SEPM Publication 77-16, volume 1: 437-450.

Newell, N.D. 1955. Depositional fabric in Permian reef limestones. Journal of Geology 63: 301-309.

Parsley, M.J. and J.K. Warren. 1989. Characterization of an Upper Guadalupian barrier-island complex from the middle and upper Tansill Formation (Permian), east Dark Canyon, Guadalupe Mountains, New Mexico. In Harris, P.M. and G.A. Grover (eds.), Subsurface and outcrop examination of the Capitan Shelf Margin, northern Delaware Basin, SEPM Core Workshop No. 13, p. 279-285.

Rigby, J.K. 1957. Relationships between *Acanthocladia guadalupensis* and *Solenopora texana* and the bryozoan-algal consortium hypothesis. Journal of Paleontology 31(3): 603-606.

Ross, C.A. 1983. Late Paleozoic foraminifera as depth indicators (abstract). American Association of Petroleum Geologists Bulletin 67: 542-543.

Ruedemann, R. 1929. Coralline algae, Guadalupe Mountains. American Association of Petroleum Geologists Bulletin 13: 1079-1080.

Skinner, J.W. 1946. Correlation of Permian of west Texas and southeast New Mexico. American Association of Petroleum Geologists Bulletin 30: 1857-1874.

Skinner, J.W. and G.L. Wilde. 1955. New fusulinids from the Permian strata of west Texas. Journal of Paleontology 29: 927-940.

Smith, A.R. 1978. The cave of McKittrick Canyon: Geology. In C.E. Kunath (ed.), The Caves of McKittrick Hill, Texas Speleological Survey Publication, 87 pp.

Strum, J.J. 1975. Conodont biostratigraphy and paleoecology of the Hegler and Pinery members, Bell Canyon Formation (Permian) in the Delaware Basin of west Texas. M.S. Thesis, Texas Tech University, Lubbock, Texas, 68 pp.

Tyrrell, W.W. 1962. Petrology and stratigraphy of near-reef Tansil-Lamar strata, Guadalupe Mountains, Texas and New Mexico. In Permian of the central Guadalupe Mountains, Eddy County, New Mexico, field trip guidebook and geological discussions: West Texas Geological Society Publication No. 62-48, p. 59-75.

Tyrrell, W.W. 1969. Criteria useful in interpreting environments of unlike but time-equivalent carbonate units (Tansill – Capitan – Lamar), Capitan Reef Complex, west Texas and New Mexico. In G.M. Friedman (ed.), Depositional environments in carbonate rocks. Society of Economic Paleontology and Mineralogy Special Publicaiton 14, p. 80-97.

Yurewicz, D.A. 1977. Origin of the massive facies of the lower and middle Capitan Limestone (Permian), Guadalupe Mountains, New Mexico and West Texas. In Hileman, M.E. and S.J. Mazzullo (eds.), Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and West Texas. Field Conference Guidebook, Permian Basin Section – SEPM Publication 77-16, volume 1: 45-92.

DATA SETS

DS-GUMO-XXX	Guadalupe Mountains National Park Paleontological Archives. 5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

DS-GUMO-XXX	Guadalupe Mountains National Park Files and Archives. 10/1966–present. (letters, notes, exhibit text, etc.). Originated by GUMO staff; status: Inactive.
DS-GUMO-XXX	Guadalupe Mountains National Park Georesources Database. 03/2000–present. (GPS data, photographs, maps, database records, etc.). Originated by GUMO staff; status: Active.

RIO GRANDE WILD AND SCENIC RIVER

Rio Grande Wild and Scenic River (RIGR) was officially established on November 10, 1978 as an addition to the Wild and Scenic River Act of 1968. The Rio Grande Wild and Scenic River is located along the Texas – Mexico border, where the river forms the international boundary. RIGR encompasses 196 river miles (315 river km) from the Chihuahua-Coahuila State Line in Mexico to the Terrell Val Verde County Line in the United States. The designation is only on the United States side to the center of the river, which complicates river management. Of the designated shoreline, 51 percent is privately owned and 49 percent is in public ownership. Water quality and quantity issues the impacts to aquatic systems rank as the important issues facing management of the unit.

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

The NPS Geologic Resources Division conducted a geologic scoping session for Big Bend National Park, including the Rio Grande Wild and Scenic River, during January 2002. The purpose of this meeting was to inventory the park's geologic resources and geologic issues, review the status of geologic maps, and to assess resource management issues and needs. A paleontological resource scoping session was held for Big Bend National Park, including Rio Grande Wild and Scenic River, in April 2000.

The Paleozoic and Cretaceous rocks of the Big Bend area of Texas were uplifted during the mid-Cenozoic and formed many fault block mountains and intermontane basins. The drainage development of the Trans-Pecos region is not completely understood. King (1935) provides a detailed discussion of the history of the Rio Grande River. Eley (1938) refers to the Rio Grande River as an antecedent stream maintaining a course through a number of folds and faults. The major tributaries of the Rio Grande along Big Bend National Park include Terlingua Creek in the west and Tornillo Creek on the east.

The late Cenozoic history of the Rio Grande is one of erosion. Large quantities of soft sediments were eroded and transported away by the river. In areas with hard rock ridges, narrow steep-walled canyons formed. Three main canyons are formed along the Rio Grande National Scenic River along Big Bend National Park. These include: Santa Elena Canyon, Mariscal Canyon, and Boquillas Canyon.

Santa Elena Canyon is perhaps the most spectacular canyon cut by the Rio Grande River at Big Bend. The river is about 18 miles long and cuts through massive Cretaceous limestones forming a gorge which sustains walls 1500 feet high. In some areas the walls are shear cliffs which are only 30 feet apart across the river. The area near where Terlingua Creek enters the Rio Grande presents the best cross section of Lower Cretaceous rocks in the park. On the Mexican side the Cretaceous rocks form the Sierra Ponce and on the U.S. side they form Mesa de Anguila.

The lowest unit exposed in Santa Elena Canyon is the Glen Rose Formation. Approximately 100 feet of the Glen Rose Formation lines the base of the canyon wall at river level. Overlying the Glen Rose is the Telephone Canyon Formation. A massive vertical cliff above the Telephone Canyon Formation is formed in the Del Carmen Limestone. The middle slope in Santa Elena Canyon is formed by the Sue Peaks Formation. The upper canyon wall is formed by the Santa Elena Limestone.

Mariscal Canyon represents a portion of the Rio Grande River which has cut through the Mariscal Mountain. The canyon is 1600 feet deep in some places cutting into Lower Cretaceous Santa Elena Limestone (Maxwell 1968). The units exposed in Mariscal Canyon are predominantly the Santa Elena Limestone, along with the overlying Del Rio Clay, Buda Limestone and Boquillas Formation (Maxwell 1968).

Boquillas Canyon is approximately a 25 mile stretch of the Rio Grande River beginning 3 miles down river from the town of Boquillas. Cliff walls along the canyon reach 1500 feet above the river cutting into the

southern portion of the Sierra del Carmen Range. The Santa Elena Limestone is exposed at the entrance to Boquillas Canyon. A small exposure of Sue Peaks Formation is mapped slightly down stream from Boquillas. Most of the canyon walls are exposures of the massive Del Carmen Limestone (Maxwell 1968).

Below is a description of the stratigraphic units which occur within the canyons of the Rio Grande Wild and Scenic River. For additional information on the geology, refer to the section on Big Bend National Park in this report.

Glen Rose Limestone (Lower Cretaceous)
The first evidence of an expanding Cretaceous seaway in the Big Bend area is represented by the Lower Cretaceous (Albian) Glen Rose Limestone. The Glen Rose Limestone is exposed near Persimmon Gap near the north entrance to BIBE. The mollusks *Exogyra quitmanensis* and *Orbitolina texana* are preserved in the Glen Rose Limestone (Maxwell and Dietrich 1965).

Telephone Canyon Formation (Lower Cretaceous)
The Lower Cretaceous (Albian) Telephone Canyon Formation is a buff, nodular, marly limestone which overlies the Glen Rose Limestone. One of the best exposures in the park is at the mouth of the Santa Elena Canyon. The type locality for this formation is in Telephone Canyon where Heath Creek crosses the Sierra del Caballo Muerto Range (Maxwell and Dietrick 1965). This unit contains fossil clams, oysters, gastropods and echinoids. *Exogyra texana* and *Gryphaea mucronata* are common pelecypod taxa of the Telephone Canyon Formation.

Del Carmen Limestone (Lower Cretaceous)
Overlying the Telephone Canyon Formation is the Lower Cretaceous (Albian) Del Carmen Limestone. This unit is a massive, heavy-bedded, cherty limestone unit. The Del Carmen Limestone forms vertical cliffs escarpments in Sierra del Carmen (type locality), Santa Elena Canyon, Mariscal Canyon, and in the Christmas Mountains (Maxwell and Dietrich 1965). This unit contains many rudistids and a few species of pelecypods and gastropods.

Sue Peaks Formation (Lower Cretaceous)
Above the Del Carmen Limestone is the Lower Cretaceous Sue Peaks Formation. This unit is a shaley, marly and nodular limestone which is named for the exposure at Sue Peaks in the Sierra del Carmen. The Sue Peaks Limestone is also exposed in Boquillas and Mariscal Canyons and in the Christmas Mountains (Maxwell and Dietrich 1965). The ammonites *Craginities* sp., *Idiohamites fremonti*, *Pervinquieria* sp., *Mortoniceras* sp., and *Prohysteroceras* sp. occur within the Sue Peaks Limestone at BIBE.

Santa Elena Limestone (Lower Cretaceous)
Continuing up in the Lower Cretaceous sequence is the Santa Elena Limestone (Albian). This unit is a massive, cherty limestone with a type section defined within the vertical walls of Santa Elena Canyon which are 730 feet thick in BIBE. In addition to the Santa Elena Canyon, this limestone is exposed on the ridge tops of the Sierra del Carmen Range, Mariscal Mountain, Sierra San Vicente, and the Christmas Mountains (Maxwell and Dietrich 1965). Rudists are extremely abundant in this unit along with *Gryphaea* sp.

Devils River Limestone (Lower Cretaceous)
There are some inconsistencies and confusion regarding use of stratigraphihc nomenclature for the Lower Cretaceous (Albian) stratigraphy of the Big Bend region. Some authors such as Eley (1938) and Smith and others (2000) recognize the Devils River Limestone as the Lower Cretaceous (Albian) rock unit which is widespread in southern Texas along the Rio Grande River (see section on Amistad National Recreation Area). The Devils River Limestone may be interpreted by others such as Maxwell and Dietrich (1965) as the Albian sequence including the Telephone Canyon Formation, Del Carmen Limestone, Sue Peaks Formation, and Santa Elena Limestone. This review is not intended to determine or establish which stratigraphic interpretation is correct. Thus both stratigraphic perspectives are presented.

According to Eley's interpretation the Devils River Limestone (Albian) is best exposed on the eastern escarpment of Mesa de Anguila (western portion of park) and within the Mariscal and San Vicente Mountains in the southeastern portions of the park. The Devils River Limestone is also exposed in the western escarpments of the Sierra del Caballo Muerta Mountains (eastern portion of park) and the Christmas Mountains (mostly outside of north-central boundary of the park). The uppermost beds of the Devils River Limestone are exposed in the Santiago Mountains near Persimmon Gap and Dog Canyon in the most northern part of the park. Fragments of invertebrate shells occur in the unit but tend to be poorly preserved locally (Eley 1938). A few interbedded shale layers occur in the cliffs at Mesa de Anguila contain good specimens of *Gryphea marcoui* and *Exogyra texana* (Eley 1938).

The faunal composition of the Devils River Formation appears to vary throughout the section as sediment deposition changed from mud-dominated to grain-dominated environments (Kerans and Zahm 1998). Fossils groups from within the Devils River Formation include benthic forams (Kerans and Zahm 1998, Johnson 2001, Scott 2002), corals (Kerans and Zahm 1998, Johnson 2001), rudist bivalves (Miller 1984, Kerans and Loucks 2002), oysters (Kerans and Loucks 2002), and ammonites (Young 1961, 1979).

Del Rio Clay (Upper Cretaceous)
The Del Rio Clay was established within an Upper Cretaceous (Cenomanian) marine clay unit in the Rio Grande Valley near Del Rio, Texas (see section on Amistad National Recreation Area). The Del Rio Clay conformably overlies the Devils River Limestone (or equivalent stratigraphic unit in the Big Bend area) and has often been referred to as the *Exogyra arietina* clay in older literature based upon the abundance of this fossil. This unit is a light gray to buff epicontinental deposit representing near shore sediments. The Del Rio Clay thins northward and eventually the Buda Limestone lies directly on the Devils River Limestone.

The Del Rio Clay is exposed along the Rio Grand River from Hot Springs to the Mariscal Mountains in Big Bend National Park (Maxwell and Dietrich, 1965). However, the Del Rio Clay is very thin in this area and only the uppermost beds are present. The more common fossil taxa include *Exogyra artietina, E. graysonana, E. cartledgei, Heteraster texanus,* and *Haplostiche texana.*

Buda Limestone (Upper Cretaceous)
The Buda Limestone at Big Bend National Park is an Upper Cretaceous (Cenomanian) unit which is subdivided into three members: 1) basal limestone member; 2) middle marly nodular limestone member; and 3) upper limestone member (Maxwell and Dietrich 1965). All three members are exposed along the west side of the Sierra del Carmen. Most of the fossils are concentrated in the middle marly limestone member and some of the more common taxa include: *Budaiceras* sp., *Exogyra clarki, Gryphaea graysonana, Lima wacoensis, Pecten romeri, Heteraster* sp., *Trigonia* sp., and *Turritella* sp.

Boquillas Formation (Upper Cretaceous)
The Upper Cretaceous Boquillas Formation unconformably overlies the Buda Limestone in the Big Bend area. The Boquillas Formation is divided into two members; the lower Ernst Member and upper San Vicente Member (Maxwell and Dietrich 1965). The Ernst Member (Turonian) is a gray, buff, and yellow-brown flaggy limestone interbedded with gray and buff marl. The San Vicente Member (Coniacian) is a gray and blue-gray chalk and gray to buff argillaceous flaggy limestone. The contact between the two members is well represented in the San Vicente – Hot Springs area of the park. Maxwell and Dietrich (1965) present a biostratigraphic zonation of ammonites in the Boquillas Formation. The "*Coilopoceras* Zone" marks the top of the Ernst Member. The top of the San Vicente Member of the Boquillas Formation is identified by the presence of *Inoceramus undulatoplicatus*.

The Department of Geology, Colorado School of Mines conducted a field trip to Big Bend National Park during March 1967. During the field trip a collection of marine invertebrates and a few shark's teeth were obtained from the Boquillas Formation.

The Cenomanian – Turonian boundary has been established within the Boquillas Formation in Big Bend National Park (Powell 1963, Frush 1973). Foraminifera were collected from a locality on the bluffs along the Rio Grande River between points 50 meters downstream to 150 meters upstream of Hot Springs. Frush and Eicher (1975) reported that the Cenomanian – Turonian boundary occurred at this location 37 meters above the base of the Boquillas Formation based on the last occurrence of the foram genus *Rotalipora*. Powell (1963, 1965) established the base of the Turonian at approximately 22.5 meters above the base of the Boquillas Formation from a locality just east of BIBE based upon molluscan fauna (*Tragodesmoceroides* and *Inoceramus labiatus*).

The remains of the marine reptile known as mosasaurs have been reported from at least two localities in the Ernst Member of the Cretaceous Boquillas Formation in the eastern portion of Big Bend National Park (Bell 1991, 1995). Bell has proposed that two taxa of mosasaurs are represented in the collection of isolated remains recovered. The mosasaur remains are associated with the ammonite *Collignoniceras woollgari* indicating a Middle Turonian age. Teeth of sharks, pycnodonts, and teleost fish also occur within the Ernst Member of the Boquillas Formation at BIBE (Bell 1991, 1995).

Pen Formation (Upper Cretaceous)
The Upper Cretaceous Penn Formation (Coniacian – Santonian) is a dark grayish-blue gypsiferous marl and clay that weathers yellow. The unit consists of concretionary limestone and layers of calcareous sandstone. Many of the concretions are disk-shaped, large (up to 4 feet in diameter), and sometimes contain fossils. One of the most fossiliferous concretionary beds is within a yellow clay generally about 300 feet above the base of the formation. This zone contains very large ammonites, pelecypods, and gastropods. Some of the more common fossil taxa include: *Exogyra ponderosa, Veniella conradi, Cyprimeria* sp., *Placenticeras* sp., *Delawarella delawarensis, Texanites* sp., *Entrephoceras* sp., *Durania terlinguae, Trigonia* sp., and *Turritella* sp. (Maxwell and Dietrich 1965). Udden (1907) referred to this unit as the Terlingua Beds.

Mosley (1993) assessed the McKinney Springs tongue of the Pen Formation and determined the unit to contain four lithologic facies. According to Mosley, these integrading facies are, ascending order: the calcareous shale facies; interbedded sandstone and shale facies; the phosphate nodule facies; and, the silty shale facies. This series of lithofacies records deposition in a muddy shelf or prodeltic setting during the marine transgression, high water still stand, and subsequent deltaic progradation. The fauna in this unit is not abundant and exhibits a low species diversity (Mosley 1993).

The calcareous shale facies contains two different types of trace fossils. These include the ichnogenera *Fodichnia* and *Gyrolithes* (Mosley 1993). *Fodichnia* are horizontal and randomly directed feeding burrows. *Gyrolithes* traces are vertically oriented and spiral aburrows. Macrofauna consists of large oysters (*Exogyra ponderosa*) and other bivalves including *Inoceramus vanuxemi* and *Durania* sp. Many of the bivalves exhibit evidence of epibionts which have encrusted or bored into the valves. Fragments of turtle shell and dinosaur bones are also present in this unit.

The interbedded sandstone and shale facies contains alternating thin beds of sandstone and shale. The sandstone beds contain poorly preserved specimens of *Inoceramus* sp. The shale beds contain Exogyra ponderosa ranging in size from 15 to 20 centimeters in diameter, oriented in life position, and contain clionid sponge and lithophagid borings in the shell material (Mosley 1993).

The phosphate nodule facies is a lag deposit which contains rounded and abraided skeletal material. Shark teeth from three species are common including: *Scapanorhynchus texanus, Squalicorax kaupi*, and *Cretolamna* sp. (Mosley 1993). Small inoceramid bivalves, small mactrid bivalves, small gastropods, and an occasional crab are also known from this unit (Mosley 1993).

Within the silty shale facies, there are several thin sandstone beds which contain well developed trace fossils (*Fodichnia*). Macrofauna consists of occasional shark teeth and fish vertebrae. Two types of

ammonites (*Placenticeras* sp. and *Baculites* sp.) are present in the upper portion of the facies (Mosley 1993). Small clusters of *Inoceramus biconstrictus* bivalves also occur in this facies.

REFERENCES CITED

Bell, G.L. 1991. Middle Turonian Mosasauroids from the Cretaceous Boquillas Formation, in Big Bend National Park, Texas. Geological Society of America, Abstracts with Programs, Rocky Mountain Section Meeting, Abstract No. 2050, p. 3.

Bell, G.L. 1995. Middle Turonian (Cretaceous) Mosasauroids from Big Bend National Park, Texas. In V.L. Santucci and L. McClelland (eds.), National Park Service Paleontological Research, Volume 2, NPS/NRPO/NRTR-95-16, p. 55-64.

Eley, H.M., 1938. The invertebrate paleontology of the Big Bend Park, Marathon, Texas. M.S. thesis, School of Geology, the University of Oklahoma, 118 pp.

Frush, M.P., 1973. Cenomanian and Turonian foraminfera, Big Bend region of Texas and Mexico. Unpublished M.S. Thesis, University of Colorado, Boulder.

Frush, M.P. and D.L. Eicher 1975. Cenomanian and Turonian foraminifera and paleoenvironments in the Big Bend Region of Texas and Mexico. Geological Association of Canada Special Paper No. 13: 277-301.

Johnson, C.C. 2001. Taxonomic and morphologic changes in corals and rudists from Aptian and Albian strata, Texas and Puerto Rico. Geological Society of America Abstracts with Programs 33(6):13.

Kerans, C. and R.G. Loucks. 2002. Stratigraphic setting and controls on occurrence of high-energy carbonate beach deposits; Lower Cretaceous of the Gulf of Mexico. Gulf Coast Association of Geological Societies Transactions 52:517-526.

Kerans, C. and L.C. Zahm. 1998. Facies partitioning at the high-frequency sequence scale in carbonate ramp systems. American Association of Petroleum Geologists Annual Meeting Abstracts.

King, P.B., 1935. Outline of structural development of Trans-Pecos Texas. American Association of Petroleum Geologists Bulletin 19: 221-261.

Maxwell, R.A., 1968. The big bend of the Rio Grande: A guide to the rocks, landscape, geologic history, and settlers of the area of Big Bend National Park. University of Texas at Austin, Bureau of Economic Geology, Guidebook #7, 1:62500 scale.

Maxwell, R.A. and J.W. Dietrich, 1965. Geologic summary of the Big Bend region. West Texas Geological Society Publication 65-51: 11-33.

Miller, B.C. 1984. Physical stratigraphy and facies analysis, Lower Cretaceous, Maverick Basin and Devils River Trend, Uvalde and Real counties, Texas. Bulletin of the American Association of Petroleum Geologists 68(4):508.

Mosley, J.L., 1993, Distribution of fossil material in the McKinney Springs Tongue of the Pen Formation (Late Cretaceous) Big Bend National Park, Texas, *in* Santucci, V.L., ed., National Park Service Paleontological Research Abstract Volume, National Park Service Petrified Forest National Park Technical Report NPS/NRPEFO/NRTR-93/11, p. 15.

Powell, J.D., 1963. Cenomanian – Turonian (Cretaceous) ammonites from Trans-Pecos Texas and northeastern Chihuahua, Mexico. Journal of Paleontology 37(2): 309-322.

Powell, J.D. 1965. Late Cretaceous platform – basin facies, northern Mexico and adjacent Texas. American Association of Petroleum Geologists Bulletin 49(5): 511-525.

Scott, R.W. 2002. Upper Albian benthic foraminifers new in West Texas. Journal of Foraminiferal Research 32(1):43-50.

Smith, C.I., J.B. Brown, and F.R. Lozo. 2000. Regional stratigraphic cross sections, Comanche Cretaceous (Fredericksburg-Washita Division), Edwards and Stockton plateaus, West Texas; interpretation of sedimentary facies, depositional cycles, and tectonics. University of Texas Bureau of Economic Geology, Austin, TX. 39 pages.

Udden, J.A. 1907. A sketch of the Geology of the Chisos country, Brewster County, Texas, University of Texas Bulletin, 93: 101.pp.

Young, K. 1961. Edwards Plateau ammonite localities. Pages A3-A5 *in* Southern Edwards Plateau. Gulf Coast Association of Geological Societies. Annual Meeting Guidebook.

Young, K. 1979. Edwards Plateau ammonites. Pages 59-75 *in* P. R. Rose, editor. Stratigraphy of the Edwards Group and equivalents, eastern Edwards Plateau, Texas. South Texas Geological Society, San Antonio, TX. Edition 2.

ADDITIONAL REFERENCES

Adkins, W.S., 1933. Mesozoic System in Texas. In The Geology of Texas, vol. 1, Sellards, E.H., Adkins, W.S., and Plummer, F. (eds.), University of Texas Bulletin 3232: 240-518.

Ager, D.V., J.R. Underwood, and R.K. DeFord, 1963. New Cretaceous brachiopod from Trans-Pecos Texas. Journal of Paleontology, 37(2): 371-378.

Baker, C.L., 1927. Exploratory geology of a part of south-western Trans-Pecos Texas: Austin, The University of Texas Bulletin 2746, 70 p.

Baker, C.L., 1928. Desert range tectonics of Trans-Pecos Texas: Pan-American Geologist, v. 50, p. 341-373.

Baker, C.L., 1935. Major structural features of Trans-Pecos Texas: *in* Sellards, E.H., and Baker, C.L., The geology of Texas, Volume II, Structural and economic geology: The University of Texas at Austin, Bulletin 3401, p. 137-214.

Berry, E.W., 1919. An Eocene flora from Trans-Pecos Texas. U.S. Geological Survey Professional Paper P-125A, pp. 1-9.

Brawley, T.R., 1961. Micropaleontology of the Del Rio Formation of Brewster County, Texas. Unpublished M.S. Thesis, Texas Tech University, Lubbock, Texas, 142 pp.

Busby, A.B. and T.M. Lehman, 1989. Vertebrate paleontology, biostratigraphy and depositional environments, latest Cretaceous and Tertiary, Big Bend area, Texas. Guidebook, Field Trip Numbers 1A, B, and C, 49th Annual Meeting of the Society of Vertebrate Paleontology, Austin, Texas.

Chang, S.W., 1973. Petrified Wood from the Paleocene, Black Peaks Formation, Big Bend National Park, Texas. M.S. Thesis. Sul Ross State University, Alpine, Texas.

Cochran, R.A. and J.L. Rives, 1985. Soil survey of Big Bend National Park, part of Brewster County, Texas. Soil Conservation Service, Alpine, Texas, 117 p.

Colbert, E.H., and R.T. Bird, 1954. A Gigantic Crocodile from the Upper Cretaceous beds of Texas. American Museum of Natural History Novitates 1688, 22 pp.

Davies, K.L., 1983. Hadrosaurian dinosaurs of Big Bend National Park, Brewster County, Texas. MA. thesis, University of Texas, Austin, 235 pp. (E)

Deal, D.E. 1979. Evolution of the Rio Conchos-Rio Grande drainage system, in Walton, A.W., and Henry, C.D., eds., Cenozoic Geology of the Trans-Pecos Volcanic Field of Texas: The University of Texas at Austin, Bureau of Economic Geology, Guidebook 19, 193 p., p. 137-146.

DeCamp, D.W., 1985. Structural geology of Mesa de Anguila, Big Bend National Park, Texas, *in* Dickerson, P.W., and Muehlberger, W.R., eds., Structure and Tectonics of Trans-Pecos Texas: Field Conference Guidebook, West Texas Geological Society Publication 85-81, 278p., p. 127-135.

Dickerson, P.W., 1980. Structural zones transecting the southern Rio Grande Rift-preliminary observations, in Dickerson, P.W., and Hoffer, J.M., eds., Trans-Pecos region: New Mexico Geological Society 31st Annual Field Conference Guidebook, southeastern New Mexico and West Texas, 314 p., p. 63-70.

Eley, H.M., 1938. Paleontology (invertebrate) of Big Bend region of Brewster County, Texas. Abstract – Oil and Gas Journal.

Ellison, S.P., 1962. Conodonts from Trans Pecos Paleozoic of Texas. Bulletin of the American Association of Petroleum Geologists 46(2): 266.

Henry, C.D., 1998. Geology of Big Bend Ranch State Park, Texas. University of Texas at Austin, Bureau of Economic Geology, Guidebook #27, 1:50,000 scale.

Henry, C.D., J.G. Price, and F.W. McDowell, 1983. Presence of the Rio Grande Rift in west Texas and Chihuahua, *in* Clark, K.F., and Goodell, P.C., Geology and mineral resources of north-central Chihuahua: El Paso Geological Society, Guidebook for the 1983 Field Conference, 455p., p. 108-118.

Hill, R.T., 1887. Present conditions of knowledge of the geology of Texas. U.S. Geological Survey Bulletin No. 45: 9-89.

Hill, R.T. 1901. Running the canyons of the Rio Grande. Century Magazine 61: 371-387.

Hopkins, E.M.H., 1965. Sedimentology of the Aguja Formation, Big Bend National Park, Brewster County, Texas. M.A. Thesis, University of Texas, Austin, Texas.

Horgan, P. 1954. Great river – the Rio Grande in North American history. Rinehart and Company, Inc., New York, vol. 1 and 2, 1020 p.

Jacobs, L., 1995. Lone Star dinosaurs. Texas A&M Press, College Station, Texas, 160 p.

Johnson, Jesse Harlin, 1944. Algal reefs in Cretaceous Austin chalk of Terlingua District, Brewster County, Texas. Bulletin of American Association of Petroleum Geologists 28(1): 123-124.

Klein, J.J., 1986. Paleoecology of the Aguja Formation, Brewster County, Texas. M.S. Thesis, Stephen F. Austin State University, Nacogdoches, Texas.

Kiver, E.P. and D.V. Harris, 1999. Geology of U.S. Parklands. John Wiley & Sons, Inc., New York, 902 pp.

Langston, W.L. 1970. Unpublished field notes, University of Texas at Austin.

Langston, W.L., 1971. Vertebrate paleontology in Big Bend National Park. Open File Report, Texas Memorial Museum, Austin, Texas.

Langston, W., 1973. Report of Vertebrate Paleontological Investigations, Big Bend National Park, Texas. Typewritten Report, The University of Texas at Austin, Texas.

Langston, W., 1978. Summary of Paleontological Investigations, Big Bend National Park, Texas. The University of Texas at Austin, Texas.

Lawson, D.A., 1972. Paleoecology of the Tornillo Formation, Big Bend National Park, Brewster County, Texas. M.A. Thesis, University of Texas, Austin, 182 pp.

Lehman, T.M., 1985a. Stratigraphy, sedimentology, and paleontology of Upper Cretaceous (Campanian-Maastrichtian) sedimentary rocks in Tran-Pecos Texas. Ph.D. dissertation, University of Texas, Austin. 299.pp

Lehman, T.M., 1985b. Transgressive-regressive cycles and environments of coal deposition in Upper Cretaceous strata of Trans-Pecos Texas. Transactions of the Gulf Coast Association of Geological Societies, 35: 431-438.

Lehman, T.M., 1986. Late Cretaceous sedimentation in Trans-Pecos Texas, in Pause', P.H., and Spears, R.G., eds., Geology of the Big Bend area and the Solitario Dome: West Texas Geological Society 1986 Field Trip Guidebook, publication 86-82, 279 p., p. 105-110.

Lehman, T.M. 1987. Late Maastrichtian paleoenvironments and dinosaur biogeography in the western interior of North America. Palaeogeography, Palaeoclimatology, Palaeoecology 60: 189-217.

Lehman, T.M., 1988. Stratigraphy of the Cretaceous-Tertiary and Paleocene-Eocene transition rocks of Big Bend National Park, Texas: a discussion: Journal of Geology, v. 96, 621-631.

Lehman, T.M., 1989a. Upper Cretaceous (Masstrich) paleosols in Trans-Pecos Texas: Geological Society of America Bulletin, v. 101, p. 188-203.

Lehman, T.M. 1990a. "Upper Cretaceous (Maastrichtian) paleosols in Trans-Pecos Texas. Bulletin of the Geological Society of America 101: 188-203.

Lehman, T.M., 1990b. Paleosols and the Cretaceous / Tertiary transition in the Big Bend region of Texas. Geology, vol. 18: 362-364.

Lonsdale, J.T., R.A. Maxwell, J.A. Wilson, and R.T. Hazzard 1955. Geology of Big Bend National Park. West Texas Geological Society Guidebook, 1955 Spring Field Trip, Midland, Texas, 142 p.

Mauldin, R.A., 1985. Foraminiferal biostratigraphy, paleoecology, and correlation of the Del Rio Clay (Cenomanian) from Big Bend National Park, Brewster County, Texas, to the Cerro de Muleros Area, Dona Ana County, New Mexico. M.S. Thesis, University of Texas, El Paso.

Maxwell, R.A., 1940. A brief history of the Big Bend Museum with list of specimens, U.S. Department of Interior National Park Service, unpublished report, 181 pp.

Maxwell, R.A. and J.W. Dietrich, 1965. Geologic summary of the Big Bend region. West Texas Geological Society Publication 65-51: 11-33.

Maxwell, R.A. and J.W. Dietrich, 1972. Geology of the Big Bend area, Texas: Field Trip Guidebook, West Texas Geological Society Publication 72-59, reprint, with additions, of Publication 65-51, 248 p.

Maxwell, R.A., J.T. Lonsdale, R.T. Hazzard, and J.A. Wilson, 1967. Geology of Big Bend National Park, Brewster County, Texas. University of Texas, Bureau of Economic Geology Publication 6711, 320 pp.

Miller, H.T., 1978. Sedimentology and Petrology of the Javelina Formation, Big Bend National Park, Brewster County, Texas. M.S. Thesis. West Texas State University, Canyon, Texas.

Moon, C.G., 1953. Geology of the Agua Fria Quadrangle, Brewster County, Texas: Geological Society of American Bulletin, v. 61, p. 151-196.

Record, R.S., 1988. Paleoenvironmental analysis of coastal marsh deposits in the Aguja Formation, Late Cretaceous, Trans-Pecos Texas. M.S. Thesis, Texas Tech University, Lubbock, Texas.

Reeder, W.G., 1987. Summary of vertebrate paleontological investigations, 1985 – 1987, Big Bend National Park, Texas. Open File Report, Texas Memorial Museum, Austin, Texas.

Romer, A.S., 1940. Fossil collecting in the Texas Redbeds. Harvard Alumni Bulletin, 42: 1045-1049.

Rowe, T., 1990. Summary of vertebrate paleontological investigations, 1998-1990, Big Bend National Park, Texas. Open File Report – Office of Science and Resources Management, Big Bend National Park.

Rowe, T., R.L. Cifelli, T.H. Lehman, and A. Weil, 1992. The Campanian Terlingua Local Fauna, with a summary of other vertebrates from the Aguja Formation, Trans-Pecos Texas. Journal of Vertebrate Paleontology, 12(4): 472-493.

Runkel, A.C., 1989. Stratigraphy and depositional history of Cretaceous and Paleogene rocks, Trans-Pecos Texas, *in* Dickerson, P.W., Stevens, M.S., and Stevens, J.B., eds., Geology of the Big Bend and Trans-Pecos Texas: South Texas Geological Society Guidebook, prepared for the 74th Annual Convention, American Association of Petroleum Geologists.

Sanders, R.B., 1988. Sedimentology and isotope geochemistry of the Upper Cretaceous Ernst Member of the Boquillas Formation, Big Bend National Park, Texas. M.S. Thesis, Texas Tech University, Lubbock, Texas.

Schroeder, M.R., 1988. Sedimentology and petrography of a distributary channel complex in the Aguja Formation (Late Campanian), Big Bend National Park, Texas. M.S. Thesis, Texas Tech University, Texas.

Simpich, F. 1939. Down the Rio Grande. National Geographic 76(4): 415-462.

Skiles, R., J. Morlock, and G. Simmons, 1988. An administrative history of the Rio Grande Wild and Scenic River with focus on major concerns and public comment. National Park Service Report, 27 p.

Small, T.A., 1949. Cretaceous guide to fossils of the Rio Grande Valley, Big Bend District, Upper Dams and Reservoir Investigations. International Boundary and Water Commission, El Paso, Texas.

Smiser, J.S., 1936. Cretaceous echinoids from Trans-Pecos Texas. Journal of Paleontology 10(6): 449-480.

Stevens, J.B., 1969. Geology of the Castolon area, Big Bend National Park, Brewster County, Texas [PhD dissertation]: Austin, The University of Texas, 129 p.

Stevens, J.B., and M.S. Stevens, 1986, An outline of the Cenozoic geologic history of the area around Big Bend National Park, *in* Stevens, J.B., Roberts, D.C.., and Stevens M.S., eds, Field seminar on the Big Bend, Trans-Pecos region, Texas: Houston Geological Society Spring Field trip Guidebook, 120 p., p. 45-73.

Strain, W.S., 1939. Three quarries for dinosaur bones. Work Progress Administration. Texas College of Mines and Metallurgy, El Paso, Texas.

Strain, W.S., 1940. Report on Works Progress Administration Paleontological project sponsored by the Texas College of Mines and Metallurgy. Unpublished report submitted to the Works Progress Administration upon completion of Projects W.P. 10106, O.P. 465-66-3-374, 20 pp.

Tomlinson, S. 1997.Late Cretaceous and Early Tertiary Turtles from the Big Bend Region, Brewster County, Texas. Unpublished PhD Dissertation, Texas Tech University. x + 194 p.

Tunnell, C. and R.J. Mallouf, 1975. Cultural resources in the canyons of the Rio Grande. Report presented at the conference on the archeology and history of Northeastern Mexico and Texas. Monterrey, Nuevo Leon, Mexico. Texas Historical Commission, Office of the State Archeologist, Special Report No. 17.

Wagner, J. 2001. The Hadrosaurian Dinosaurs (Ornithischia: Hardrosaur) of Big Bend National Park, Brewster County, Texas, with Implications for Late Cretaceous Paleozoogeography. Unpublished Masters Thesis, Texas Tech University. xvi + 417.

Wheeler, E. A. and T. M. Lehman. 2000. Late Cretaceous woody dicots from the Aguja and Javelina Formations, Big Bend National Park, Texas, USA. IAWA Journal 21(1): 83-120.

Wheeler, E.A. and T.M. Lehman, 2005. Upper Cretaceous- Paleocene conifer woods from Big Bend National Park, Texas. Paleogeography, Paleoclimatology, Paleoecology 226: 233-258,

Wheeler, E. A., T. M. Lehman, and P. E. Gasson 1994. Javelinoxylon, an Upper Cretaceous dicotyledonous tree from Big Bend National Park, Texas, with presumed malvalean affinities. American Journal of Botany 81(6): 703-710.

White, J.C., 2002. The geology of Big Bend National Park: What have we learned since Maxwell et al., 1967? Field Trip Guide, Geological Society of America, South-Central Section Meeting, Alpine, Texas, 67 pp.

Wilson, J.A., 1967b. Report on vertebrate paleontological and geological investigations, Big Bend National Park, Texas. Open File Report – University of Texas, Austin, Texas.

Wilson, J.A., 1972. Vertebrate biostratigraphy of Trans-Pecos Texas and northern Mexico, *in* Seewald, K., and Sundeen, D., eds., The geological framework of the Chihuahua Tectonic Belt: symposium honoring R.K. DeFord, West Texas Geological Society Publication 71-59, 205 p., p. 159-66

Wilson, J.A., 1980. Geochronology of the Trans-Pecos Texas volcanic field. New Mexico Geological Society Guidebook, 31st Field Conference, Trans-Pecos Region: 205-211

Wilson, J.A., 1984. Vertebrate faunas 49 to 36 ago and additions to species of *Leptoreodon* (Mammalia: Artiodactyla) found in Texas, J. Vert. Paleo. 4: 199-207.

Wilson, J.A., 1986. Stratigraphic occurrence and correlation of early Tertiary vertebrate faunas, Trans-Pecos Texas: Agua Fria-Green Valley Areas, J. Vert. Paleo. 6:350-373.

Wolleben, J.A., 1967. Senonian (Cretaceous) mollusca from Trans-Pecos Texas and northeastern Chihuahua, Mexico. Journal of Paleontology 41(5): 1150-1165.

DATA SETS

DS-RIGR-XXX Rio Grande Wild and Scenic River Paleontological Archives. 5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

DS-RIGR-XXX Rio Grande Wild and Scenic River Files and Archives. 1978–present. (letters, notes, exhibit text, etc.). Originated by BIBE staff; status: Inactive.

WHITE SANDS NATIONAL MONUMENT

White Sands National Monument (WHSA) was established on January 18, 1933 in order to preserve one of the world's largest gypsum sand dune fields. The Monument lies at the northern end of the Chihuahuan Desert in the Tularosa Basin of south-central New Mexico. The gypsum dune field encompasses 143,733 acres in south central New Mexico.

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

The NPS Geologic Resources Division has not yet completed geologic scoping sessions for White Sands National Monument. No formal paleontological resource inventories have been completed for WHSA and no fossils can be substantiated from within the Monument. However paleontological discoveries are documented from an area adjacent to the monument boundary (Conrod, personal communication, 1997). Future paleontological field work may yield other paleontological resources both in and around White Sand National Monument.

Herrick (1900) provides one of the earliest descriptions for the geology of the White Sand of New Mexico. Jicha (1954) and Kiver and Harris (1999) present more recent geologic interpretations of the White Sands. Herrick (1961) produced a geologic map for the White Sands area.

The gypsum dunes have accumulated in a large graben that extends southward to the Texas border and northward to the Malpais basalt flows. The graben is part of a major structural feature known as the Rio Grand Rift. The local graben is referred to as the Tularosa Basin graben and is bounded on the west by the San Andres Mountains and by the Sacramento Mountains on the east (Baldridge and Olsen 1989). The Tularosa Basin graben is 37 miles (60 km) wide. Tularosa Basin is a true bolson, a desert area with internal drainage and no discharge outside of the basin.

The northern part of the White Sands dune field grades into yellowish, wind-deposited, quartz sands. The source of the gypsum has been the subject of some scholarly debate, however, the most likely source of the White Sands gypsum seems to be the local Paleozoic formations (LeMone 1987). During the Paleozoic shallow seas advanced (transgression) and retreated (regression) over the New Mexico area. Thick evaporate deposits were deposited during the Permian including the Yeso Formation which consists of over 500 feet (152 m) of gypsum. The Permian Yeso (Spanish for gypsum) Formation is suggested by LeMone (1987) as the most reasonable source for the gypsum at the Monument.

The gypsum sand is primarily medium-grained, ranges from angular to subrounded, and has fair to good sorting (LeMone 1987). A wide variety of dune morphologies are documented at the Monument including: dome-shaped, V-shaped, U-shaped, blowout, parabolic, barchan, and transverse dunes. Dune heights and rates of movement are directly related to morphology. The tallest dunes rise to 65 feet (20 m) in some areas. Winds blow almost constantly from the southwest with velocities reaching gusts of 55 mph.

Paleontological Resource Potential

There is a limited potential for the discovery of fossils at White Sands National Monument in the future. Historical reports and recent archaeological and geological surveys suggest the possibility of some fragmentary fossils from within the monument and confirmed paleontological resources from outside park boundaries. These fossil-bearing deposits include vertebrate trace fossils from a locality which should be periodically monitored for preservation of paleontological resources.

Vandiver (1936) reports on the possible occurrence of fossil bones and teeth of a mammoth from within the boundaries of the Monument. He personally visited the locality referenced for the mammoth remains

and was able to find only fragmentary bones. Vandiver (1936) also describes some external molds of plants at WHSA. These appear to be the remains of cacti and other plants which have become replaced or encrusted by gypsum crystals.

Bill Conrod (personal communication, 1997) reports the presence of Pleistocene mammalian trackways on the nearby White Sands Missile Range managed by the Department of Defense. A site visit to a fossil track locality on the White Sands Missile Range, referred to as the "Big Footprints" locality, on September 11, 1981. Geologists John Hawley, David Love (USGS) and Donald Wolberg participated in this site visit. The field party encountered three different types of vertebrate tracks which were preserved as pedestals above the ground surface. The tracks were determined to be mammalian in morphology and likely ascribed to camel, proboscidian, and some other undetermined mammalian track maker.

REFERENCES CITED

Baldridge, W.S. and K.H. Olsen. 1989. The Rio Grande Rife. American Scientist 77: 240-247.

Herrick, C.L. 1900. The geology of the White Sands of New Mexico. Journal of Geology, vol. 8, p. 112-128.

Herrick, E.H. 1961. Geologic map of White Sands Missile Range Headquarters area, Dona Ana County, New Mexico, showing location of wells, contours on the water table, and location of proposed dams, reservoirs and recharge-discharge wells. U.S. Geological Survey, Hydrologic Investigations Atlas.

Jicha, H.L. 1954. The White Sands, a short review. New Mexico Geological Society Guidebook, 5th Field Conference, p. 88-92.

Kiver, E.P. and D.V. Harris. 1999. Geology of U.S. Parklands. John Wiley & Sons, Inc., New York, 902 pp.

LeMone, D.V. 1987. White Sands National Monument, New Mexico. Geological Society of America Centennial Field Guide, Rocky Mountain Section. P. 451-454.

Vandiver, V.W. 1936. Geological Report on White Sands National Monument. Southwestern Monuments Special Report No. 5. Department of Interior, National Park Service, p. 381-400.

ADDITIONAL REFERENCES

Blair, T.C., J.S. Clark, and S.G. Wells. 1990. Quaternary continental stratigraphy, landscape evolution, and application to archeology: Jarilla piedmont and Tularosa graben floor, White Sands Missile Range, New Mexico. Geological Society of America Bulletin 102: 749-759.

Botkin, C.W. 1933. White Sands National Monument. Pam American Geologist, 60: 304-305.

Brady, F.W. 1905. The White Sands of New Mexico: Formation of nearly pure gypsum sand. Mines and Minerals Publication, p. 529-530.

Gould, C.N. 1939. The Great White Sands [of New Mexico]. Mines Magazine, vol. 29, p. 379-381.

Jones, B.R. 1959. A sedimentary study of dune sands, Lamb and Bailey counties, Texas and White Sands National Monument, New Mexico. Master's Thesis, Texas Tech University, Lubbock, Texas, 95 pp.

McKee, E.D. 1966. Structure of dunes at White Sands National Monument, New Mexico. Sedimentology, vol. 7 69 pp.

McKee, E.D. and R.J. Moiola. 1975. Geometry and growth of White Sand dune field, New Mexico. Journal of Research U.S. Geological Survey, 3: 59-66.

McKee, E.D. and J.R. Douglass. 1971. Growth and movement of dunes at White Sands National Monument, New Mexico. U.S. Geological Survey Professional Paper, D108-D114.

Russell, C.P. 1935. The White Sands of Alamogordo. National Geographic Magazine, vol. 64, no. 2.

Simpson, E.L. and D.B. Loope. 1985. Amalgamated interdune deposits, White Sands, New Mexico. Journal of Sedimentary Petrology. Vol. 55, p. 361-365.

Talmadge, S.B. 1933. Source and growth of the White Sands of New Mexico. Pan American Geologist, 60: 304.

Weir, J.E. 1965. Geology and availability of ground water in the northern part of the White Sands Missile Range and vicinity, New Mexico. U.S. Geological Survey Water Supply Paper, 78pp.

DATA SETS

DS-WHSA-XXX	White Sands National Monument Paleontological Archives. 5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.
DS-WHSA-XXX	White Sands National Monument Museum Collections. 1/1933–present. (museum specimens, collection records, specimen notes, ANCS+ records). Originated by WHSA staff; status: Active.

ACKNOWLEDGEMENTS

The authors graciously thank all those individuals, both within and outside of the National Park Service who have contributed valuable information, comments, and suggestions for this report. Reports such as this are impossible without extensive input from those people who know the resources the best.

Special thanks to NPS park staff who provided information, comments, suggestions, and/or reviewed their park's section: Hildy Reiser (CHDN), Rick Slade (AMIS), Don Corrick, Frank Deckert, Vidal Davila, and Mark Spier (BIBE), Gopaul Noojibail, Dale Pate, Carolyn Richards and Paul Burger (CAVE), Susan McComb (FODA), Gorden Bell, Fred Armstrong, Jan Wobbenhorst and Ellis Richards (GUMO), Diane White (WHSA), and Bill Conrod (NPS retired). We also acknowledge the great support received from Jessica Toubman and Scott Gainer, two paleontology interns assigned to Big Bend National Park.

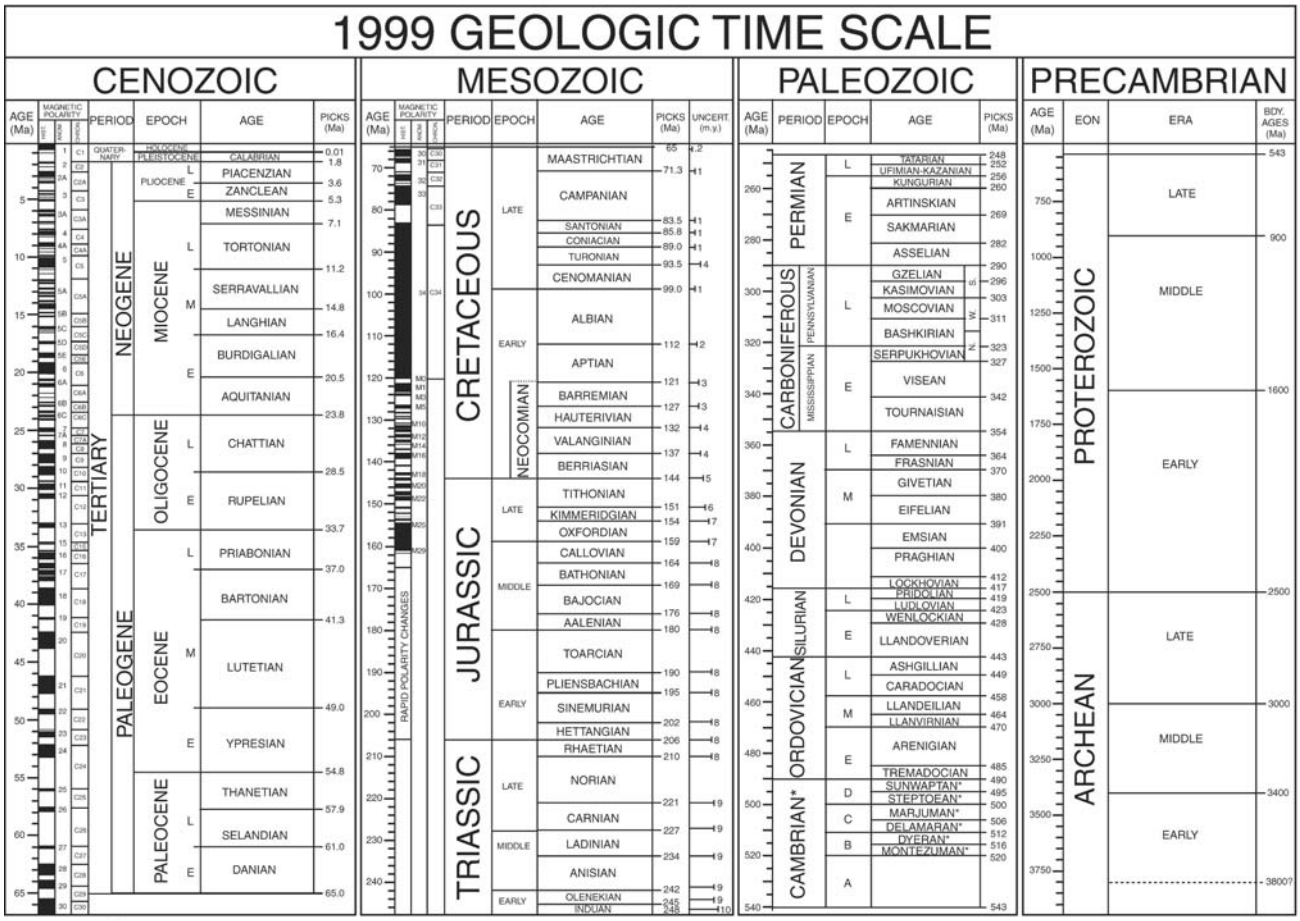
A number of staff members at George Washington Memorial Parkway (GWMP) provided excellent administrative and logistical support toward the completion of this report especially Nick Bartolomeo (IT specialist) and Betty Bell (IRRM Division Secretary). The support of the entire GWMP IRRM Division is greatly appreciated. Additionally, we extend our thanks to NPS Librarian David Nathanson at the Harpers Ferry Center Library for his continued assistance with our use of National Park Service archives.

The continued valuable support and information provided by the NPS Geologic Resources Division (GRD), in particular Tim Connors, Bruce Heise, Ron Kerbo, Bob Higgins, Jim F. Wood, Judy Geniac, Lindsay McClelland, Dave Shaver, and Jim C. Woods is greatly appreciated.

A number of individuals from institutions outside of the NPS were also instrumental in the creation of this report. Thanks to Wann Langston, Jr., Ernest Lundelius, and John A. Wilson of the Texas Memorial Museum whom this report is dedicated. In addition, thanks are also extended to Anthony Fiorillo (Dallas Museum of Natural History), Tom Lehman (Texas Tech University), Judith Schiebout (LSU) and ReBecca Hunt (Augustana College). Thanks are also due to the excellent staff of the USGS Library in Reston, VA.

Finally, this report would not have been possible without the support of Bert Frost (Assistant Director for Natural Resources) and Gary Williams (NPS Inventory and Monitoring Program). A sincere thanks is extended to Bert and Gary for providing the means upon which this work, and similar work, can be accomplished.

APPENDIX A: GEOLOGIC TIME SCALE



© 1999, The Geological Society of America. Product code CTS004. Compilers: A. R. Palmer, John Geissman

*International ages have not been established. These are regional (Laurentian) only. Boundary Picks were based on dating techniques and fossil records as of 1999. Paleomagnetic attributions have errors, Please ignore the paleomagnetic scale.

Sources for nomenclature and ages: Primarily from Gradstein, F., and Ogg, J., 1996, *Episodes*, v. 19, nos. 1 & 2; Gradstein, F., et al., 1995, SEPM Special Pub. 54, p. 95–128; Berggren, W. A., et al., 1995, SEPM Special Pub. 54, p. 129–212; Cambrian and basal Ordovician ages adapted from Landing, E., 1998, *Canadian Journal of Earth Sciences*, v. 35, p. 329–338; and Davidek, K., et al., 1998, *Geological Magazine*, v. 135, p. 305–309. Cambrian age names from Palmer, A. R., 1998, *Canadian Journal of Earth Sciences*, v. 35, p. 323–328.

GEOLOGICAL SOCIETY OF AMERICA

Note: Picks (Ma) = age of the geologic time unit boundary in millions of years (Ma).

This timescale is available online as a PDF: http://www.geosociety.org/science/timescale/timescl.pdf