



Carlsbad Caverns National Park

Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/CAVE/NRR—2020/2148



ON THE COVER

A bat encased in flowstone. Photo by NPS.

Carlsbad Caverns National Park

Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/CAVE/NRR—2020/2148

Scott Kottkamp¹, Vincent L. Santucci², Justin S. Tweet³, Rodney D. Horrocks¹, Erin Lynch¹, and Gary S. Morgan⁴

¹Carlsbad Caverns National Park
3225 National Parks Highway
Carlsbad, NM 88220

²National Park Service
Geologic Resources Division
1849 “C” Street, NW
Washington, D.C. 20240

³National Park Service
9149 79th St. S.
Cottage Grove, Minnesota 55016

⁴New Mexico Museum of Natural History and Science
1801 Mountain Road NW
Albuquerque, New Mexico 87104

June 2020

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the [Chihuahuan Desert Inventory & Monitoring Network](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Kottkamp, S., V. L. Santucci, J. S. Tweet, R. D. Horrocks, E. Lynch, and G. S. Morgan. 2020. Carlsbad Caverns National Park: Paleontological resource inventory (public version). Natural Resource Report NPS/CAVE/NRR—2020/2148. National Park Service, Fort Collins, Colorado.

Contents

	Page
Figures.....	vii
Tables.....	ix
Appendices.....	ix
Executive Summary	xi
Acknowledgments.....	xiii
Dedication.....	xv
Introduction.....	1
Significance of Paleontological Resources at CAVE.....	6
Purpose and Need.....	6
Project Objectives.....	7
Summary of 2019–2020 Paleontological Survey	7
History of Paleontological Work at CAVE.....	9
Permian Paleontological Studies	9
Pleistocene/Holocene Paleontological Studies.....	11
Vertebrates.....	11
Microorganisms.....	14
Geology.....	15
Geologic History	15
Late Paleozoic Setting.....	15
Mesozoic (252–66 Ma).....	19
Cenozoic (66 Ma–present)	19
Geologic Formations	20
Shore to Back-Reef Formations (oldest to youngest).....	21
Reef Formations	22
Fore-Reef Formations.....	24
Basin Formations.....	24

Contents (continued)

	Page
Quaternary Sediments	24
Other Formations.....	25
Taxonomy	27
Plants	27
Invertebrates	27
Vertebrates.....	28
Ichnofossils.....	30
Other Fossils.....	31
Paleontology	33
Permian Paleontology.....	33
General Nature of CAVE Permian Paleontological Resources.....	33
Permian Paleoecology at CAVE	33
Permian Paleontological Resource Data at CAVE.....	35
Permian Taxa Present at CAVE	37
Pleistocene–Holocene Paleontology	49
General Nature of CAVE Quaternary Paleontological Resources	49
Age Dating of Cave Paleontological Resources.....	50
Pleistocene / Holocene Climate and Ecological Change in the Guadalupe Mountains	50
Mummified Mammal Remains at CAVE.....	52
Absence of Packrat Middens at CAVE	53
Cultural Resource Connections.....	55
Fossil Localities	59
Permian Paleontological Localities at CAVE	59
Surface.....	59
Caves	62

Contents (continued)

	Page
Pleistocene / Holocene Paleontological Resources at CAVE	69
Caves with Pleistocene / Holocene Paleontological Resources Near CAVE.....	85
Museum Collections and Curation.....	87
Park Collections.....	87
Security.....	88
Photographic Archives	88
Collections in Other Repositories.....	91
Type Specimens.....	92
Park Paleontological Research.....	93
Research Since 1990.....	93
Current Research	95
Paleontological Research Permits	95
Interpretation.....	97
Importance of Paleontological Resources to Interpretation at CAVE.....	97
Current Status of Interpretation of Paleontological Resources at CAVE.....	98
Recommendations for Interpretation at CAVE	100
Paleontological Resource Management and Protection.....	103
National Park Service Policy	103
Law Enforcement Interaction with CAVE Paleontological Resources.....	105
Baseline Paleontology Resource Data Inventories.....	106
Paleontological Resource Monitoring	107
Foundation Documents and Resource Stewardship Strategies.....	108
Geologic Maps.....	109
Paleontological Resource Potential Maps	109
NPS Paleontology Archives and Library	110
E&R Files	110

Contents (continued)

	Page
Paleontological Resource Management Recommendations	111
Literature Cited	115

Figures

	Page
Figure 1. The Natural Entrance to Carlsbad Cavern viewed from the Amphitheater.	2
Figure 2. Geography of CAVE, showing park boundaries, roads, and other features.	3
Figure 3. Geologic map of CAVE and vicinity, based on geologic map data derived from Hayes (1964) and digitized by the NPS Geologic Resources Inventory.	4
Figure 4. Map showing relative paleontological potential of geologic map units of CAVE and vicinity, based on the same data as Figure 3.	5
Figure 5. Lead author Kottkamp holding a scale bar for photographing fossil sponges in a cave wall.	8
Figure 6. Recovery of the <i>Euceratherium</i> skull from Muskox Cave in 1976.	12
Figure 7. Assorted <i>Tadarida constantinei</i> bones deposited within guano at Slaughter Canyon Cave.	13
Figure 8. Pool fingers mark the position of a dry pool in Carlsbad Cavern.	14
Figure 9. A bat has become incorporated into the tip of this speleothem.	29
Figure 10. Woodrat perch/midden in KF-39.	31
Figure 11. Sponge fossils in Carlsbad Cavern.	38
Figure 12. Brachiopod fossils in Lechuguilla Cave.	40
Figure 13. Coiled cephalopod fossil, probably a nautiloid, in Lechuguilla Cave.	42
Figure 14. Bellerophonitid gastropods in Lechuguilla Cave in cross section.	43
Figure 15. A tail segment of the trilobite <i>Anisopyge perannulata</i> , exposed in Carlsbad Cavern.	44
Figure 16. Articulated crinoid columnals from Lechuguilla Cave.	46
Figure 17. Echinoid spines in Lechuguilla Cave.	47
Figure 18. Layers of algal fossils exposed in the ceiling of Left-Hand Tunnel, Carlsbad Cavern.	48
Figure 19. Ringtail mummy in Carlsbad Cavern.	53
Figure 20. Examples of fossils cemented into a display at the Top of the Cross.	57
Figure 21. Mollusk fossils in Left-Hand Tunnel.	63
Figure 22. Brachiopod hash in Left-Hand Tunnel, Carlsbad Cavern.	64

Figures (continued)

	Page
Figure 23. Cephalopod fossil on the ceiling of an alcove in the Big Room lunchroom.	65
Figure 24. Gastropod fossil from the Big Room, Carlsbad Cavern.	66
Figure 25. Ammonite in a large breakdown block at the Top of the Cross, Big Room, Carlsbad Cavern.	67
Figure 26. Permian reef fossils on the ceiling and walls of Fossil Avenue in Slaughter Canyon Cave.	68
Figure 27. A cephalopod in Lechuguilla Cave.	69
Figure 28. Bones and skulls of Constantine’s free-tailed bat, <i>Tadarida constantinei</i> , in guano within Slaughter Canyon Cave.	73
Figure 29. Fossils and/or recent bones at the base of the entrance pit to C-04.	74
Figure 30. A series of photos of a disarticulated carnivoran skeleton in C-29.	78
Figure 31. The <i>Euceratherium</i> skull as it was found in MuskoX Cave, with other bones covered with mineralization.	80
Figure 32. Procyonid bones and skull from C-87.	82
Figure 33. Assorted mammalian fossils and/or modern bones in C-90.	83
Figure 34. Close-up of the KF-39 packrat midden.	84
Figure 35. <i>Camelops</i> bone from Slaughter Canyon Cave in the CAVE museum collections.	88
Figure 36. The <i>Euceratherium</i> skull on a stand for photogrammetric documentation.	89
Figure 37. Creating a photogrammetric model begins with taking multiple photos of a specimen from different but overlapping angles.	90
Figure 38. A 3-D scan of the <i>Euceratherium</i> skull from MuskoX Cave, resulting from the photogrammetry depicted in Figures 36 and 37.	90
Figure 39. The holotype of <i>Plectelasma planidorsatum</i> at the USNM.	92
Figure 40. Fossils of an ammonoid, sponge, and gastropod on exhibit in the visitor center.	99
Figure 41. A diorama of the Permian life of the CAVE area in the visitor center.	99

Tables

	Page
Table 1. Summary of CAVE stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.	20
Table 2. Fossil taxa named from specimens found within CAVE.	92
Appendix Table A-1-a. Permian fossil plant taxa reported from CAVE in stratigraphic context. References are provided where appropriate.	130
Appendix Table A-1-b. Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.	130
Appendix Table A-1-c. Other Permian fossil taxa reported from CAVE in stratigraphic context. References are provided where appropriate.	145
Appendix Table A-2. Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.	147
Appendix Table D-1. Paleontological localities of CAVE.	165

Appendices

	Page
Appendix A. Paleontological Species Lists	129
Appendix B. Outside Repositories of CAVE Fossils	157
Appendix C. Paleontological Resource Law and Policy	159
Appendix D. CAVE Paleontological Locality Summary	165
Appendix E. Geologic Time Scale.....	171

Executive Summary

This document is an inventory of the paleontological resources of Carlsbad Caverns National Park (CAVE), representing a combination of field work and literature synthesis. It begins with background summaries about the park and its geological, paleontological, and scientific history. It then moves into descriptions of paleontological resources including taxa present, fossil localities, and museum collections. Lastly, it finishes by touching on the relationships paleontological resources have with other CAVE programs such as interpretation and law enforcement, general information about paleontological resource management and protection, and management recommendations. Appendices include lists of fossil taxa found within CAVE, a list of external repositories of paleontological resources, a summary of caves within the park with documented paleontological resources, a listing of pertinent laws and authorities on paleontological resources, and a geologic time scale.

Carlsbad Caverns National Park, also a world heritage site, is renowned for the park's namesake cavern, which is extensive, well-decorated, and possesses exceptionally large rooms. Several other caves at the park add to CAVE's fame and importance, such as Lechuguilla Cave, the eighth longest cave in the world. More than 120 other caves, and numerous additional karst features dissolved out of the Permian-age Capitan Limestone and associated formations such as the Seven Rivers, Yates, and Tansill formations, can be found in the park. These rock units represent the slope, reef, back-reef, and nearshore/evaporite facies of a massive reef complex and shelf system that existed during the middle Permian (Guadalupian); the same rock units exposed within the caves can be found at the surface in nearby Guadalupe Mountains National Park (GUMO). Owing to its origins as a reef complex, the bedrock of CAVE is extensively, and often abundantly, fossiliferous. With the exception of one small exposure of a basinal formation, there is likely no section of the park bedrock where fossils could not be found. Besides the Permian fossils, the fossilized remains and traces of terrestrial Pleistocene and Holocene organisms are located within the caves themselves. These are from roosting sites, dens, or natural traps.

The presence of fossils in the greater Guadalupe Mountains has been known since at least the mid-19th century, but paleontological work at CAVE did not begin until the 1930s and 1940s. Even then, studies of the geology and especially the speleology of the caves has been the greater focus at CAVE, with paleontology often used as a supplement for that work. However, important paleontological studies have been conducted in the park, especially those related to paleoecology and the reconstruction of both CAVE's Permian and Pleistocene ecosystems. Some of the taxonomic groups found within CAVE, such as sponges, have been well-studied. Others, such as gastropods, amphibians, reptiles, and birds, have not received much attention and are thus subject to a significant data gap. Five fossil species have been named from specimens discovered within CAVE. New fossil localities and new specimens in established localities continue to be found at CAVE; collections from Slaughter Canyon Cave in 2002 and 2003 added greatly to the Pleistocene vertebrates known from the park, and almost every expedition into Lechuguilla Cave reveals new invertebrate paleontological resources and localities. Some collected materials from prior projects, such as parts

of the 1970s collection from Muskox Cave, have been only superficially prepared, cataloged, studied, or analyzed.

The geologic formations exposed within CAVE vary horizontally as well as vertically, because different units horizontally trace changes in depositional environment. The entire talus slope and reef of the middle Permian Capitan reef complex are represented by the reef talus and massive members of the Capitan Limestone, respectively. This formation is comprised predominantly of massive carbonate deposits. The back-reef facies of various types are, from oldest to youngest, the Queen, the Seven Rivers, Yates, and Tansill formations; these vary in their clastic, carbonate, and evaporite components both between one another and within a given formation as one moves landward to seaward. The Seven Rivers, Yates, and Tansill formations correspond to the Capitan Limestone, whereas the Queen Formation corresponds to an older reef unit called the Goat Seep Dolomite. Exposures of the Goat Seep are not confirmed from within the park, though at least one researcher hypothesizes that Lechuguilla Cave cuts into it in one portion of the cave. A very small amount of the Castile Formation, a non-fossiliferous basinal formation of late Permian age, is exposed along a southern border in the east end of the park. Quaternary gravels and alluvium are present in canyon washes, at the base of the reef escarpment along most of the south edge of the park, in the interior of some caves, and at the detached Rattlesnake Springs parcel of the park.

Because fossils are nearly omnipresent within CAVE, they are found in a variety of contexts. Some are easily accessed, or even displayed to the public along accessible trails, such as the Slaughter Canyon Cave Trail, and caves, such as the Tour Routes in Carlsbad Cavern. Others are located in wilderness, or in remote and sensitive caves not disclosed to the public. Because fossils are so prevalent, they also occur at historical and archeological sites within the park. While some are merely coincidental, others seem to have cultural significance; such fossils are handled by the park's cultural resource managers.

CAVE does not currently monitor fossil localities except as part of wider surveys and monitoring of caves; thus, those fossils exposed along public trails or roads at the surface have the greatest risk of loss through unauthorized collection or damage (intentional or unintentional). At least one case of attempted fossil theft has occurred at the park, and there is anecdotal evidence of additional theft or vandalism at other sites. It is highly recommended that CAVE begin monitoring at least those surface localities at greatest risk, and that paleontological resources be recorded and monitored in greater detail during cave surveys and monitoring.

Acknowledgments

The NPS staff at CAVE were crucial to the development of this plan, both through direct feedback on the document and by providing support to the authors. Specific individuals and their contributions include: **Erin Gearty**, the Cultural Resource Program Manager, was instrumental in writing about cultural resource connections and for answering specific questions about the museum collections, past research, and tracking down old investigator reports; **Ellen Trautner**, Physical Science Technician, assisted in gathering specific information about localities in several caves, including Carlsbad Cavern. **Julie McGilvray**, Acting Deputy Superintendent, held a meeting with Scott Kottkamp (primary/lead author) about his internship and checked in on his progress. Additionally, CAVE interpretive staff answered questions and offered feedback on the state of paleontological interpretation at the park. Individuals who took the time to offer their feedback included: **Max Berlin**; **David Braumbaugh**; **Jo Ann Garcia**; **Angelina Guerra**; **Harrison Nancarrow**; **Andrew Rankin**; **Emily Rocha**; **David Tise**; and **Colin Walfield**. **Aria Mildice**, a fellow intern at CAVE, was ever-present to answer the primary author's questions about specific places within the park, geology, and sightings of fossils in the surface wilderness. **Hunter Klein** was another CAVE intern, and he assisted in reviewing and editing the CAVE Geology and Permian Paleontology sections.

This report could not have been completed without the gracious support of other NPS staff, who offered critical insights into current NPS policy and supplied access to various data and records essential to the plan. **Jonena Hearst**, Physical Science Program Manager of Guadalupe Mountains National Park (GUMO), met twice with the primary author to discuss the Permian paleontology of CAVE. These meetings with Dr. Hearst were instrumental in clarifying the current state of knowledge about the Permian of the Delaware Basin, and also clearly revealed the data gap present at CAVE in regard to the Permian. **Ron Kerbo**, former Cave Specialist at CAVE, provided an interview about his long history of resource management work at CAVE. **Dale Pate** was another former Cave Specialist at the park who oversaw management of paleontologic resources. **Paul Burger**, NPS Hydrologist, was open to being contacted about CAVE resources at any time. **Tim Connors**, of the NPS Geologic Resources Division (GRD), created the geologic and paleontological potential maps for CAVE and reviewed this document. **Andy Hubbard**, network program manager for the Sonoran Desert Inventory & Monitoring Network, oversaw the peer review process. **Jack Wood**, of the NPS GRD, handled photography and image processing as part of creating an interactive online model of a shrub ox (*Eucatherium*) skull from Muscox Cave housed in the Smithsonian Institution.

Finally, the writing of this report was greatly assisted by several individuals and organizations outside of the NPS. Geologist **Harvey DuChene** provided many important academic sources critical to the report, photographs of fossils, answered questions over phone and email, and reviewed/critiqued an early draft of the geology and stratigraphy section. **Patricia Jablonsky's** field notes and work on chiropterans were key to this report, and she also provided an interview about her work in Carlsbad Cavern and Lechuguilla Cave. **Julio Betancourt**, U.S. Geological Survey emeritus, answered questions about the presence/absence of packrat middens at CAVE. **Stan Allison**, of the Bureau of Land Management and former CAVE staff member, responded to emailed questions about

specific caves and localities he had documented while at CAVE. **Lloyd Logan** was a paleontologist who worked in Muskox Cave during the 1970s; his writings on the cave's Pleistocene/Holocene faunal assemblage and its paleoecological implications were critical to this report. Dr. Logan also sat for an interview about his work at CAVE, especially his research in Muskox Cave. **Katie Nemmer** was the Stewards Program Coordinator for the primary author, and ensured the internship ran smoothly. **Max Wisshak**, Senckenberg am Meer (Senckenberg Gesellschaft für Naturforschung), gave permission to use his photographs. **The American Geosciences Institute** funded an additional two weeks of work for the primary author on the report in order to see it to completion. Particular thanks to **Ed Robeck**, who coordinated setting up the contract with AGI despite short notice and being in the field on the other side of the world. **Steve West** provided a good deal of information about modern ecological problems in New Mexico, for which the paleoecological implications of CAVE may be relevant.

Dedication

We are pleased to dedicate this paleontological resource inventory for Carlsbad Caverns National Park to our friend and colleague Ronal C. Kerbo. Ron's lifetime of advocacy and work in support of all aspects of cave and karst resources stewardship is legendary and far reaching within the National Park Service and around the world. Growing up as a boy in the shadow of the Guadalupe Mountains, his education and career led him to join the National Park Service (NPS) in 1976 at CAVE. Ron was hired as the park's physical science technician with duties as a cave resource specialist. His 15 years' work at CAVE involved exploration, discovery, and mapping of the diverse cave resources of this world-renowned park, promoting scientific research, protection of the fragile cave resources, and helping to define how parks manage these resources.

Ron's work at CAVE was widely recognized by leaders in the NPS and in the caving community. In 1991, John Cook, the Southwest Regional Director for the NPS, invited Ron to work in the regional office in Santa Fe, New Mexico, to serve as the de facto servicerwide cave and karst resource specialist for the NPS. In 1996, Ron moved to Denver to continue his work as the NPS National Cave and Karst Program Manager in the newly established NPS Geologic Resources Division. From this national platform, Ron mentored several generations of park resource managers in the principles and practices related to cave resources and helped to develop agency policy promoting conservation of cave resources.

During his more than three decades of service to the NPS, Ron helped to coordinate the discovery and documentation of Lechuguilla Cave, established partnerships with other agencies and organizations to help protect caves, helped to draft a 1994 Report to Congress on the significance of cave and karst resources, and participated in planning which led to the enactment of the Federal Cave Resources Protection Act (1988) and the establishment of the National Cave and Karst Research Institute (NCKRI) by Congress in 1998. Since Ron's retirement from the NPS in 2007, he has continued to be a voice for and champion of cave and karst resource issues.



A photo of Ron Kerbo (DIANNIA KERBO).

Introduction

Carlsbad Caverns National Park (CAVE) encompasses 18,926 hectares (46,766 acres) of land in southwestern Eddy County, southeastern New Mexico. Approximately 13,405 hectares (33,125 acres) of that land was designated by Congress as wilderness in 1978. All of its land is under federal administration. CAVE was established as Carlsbad Cave National Monument by presidential proclamation on October 25, 1923 to preserve Carlsbad Cavern, a cave of “*extraordinary proportion and of unusual beauty and variety of natural decoration*” (Figure 1). On May 14, 1930, Congress expanded and redesignated the area as Carlsbad Caverns National Park. The namesake cave, Carlsbad Cavern, has many exceptionally large and well decorated rooms, including the enormous Big Room. Thanks to a combination of its natural topography, trail development efforts, and the installment of an elevator directly into the Big Room, it is one of the most easily visited large caves in the United States. Since then, more than 120 other caves have been discovered within the park, though most of them are considered sensitive and are not available and/or disclosed to the public. Of special note, Lechuguilla Cave is the second deepest limestone (non-lava tube) cave in the United States, the eighth longest cave in the world, with more than 240 km (150 mi) surveyed, and it contains spectacular speleothems and fossil deposits rivaling those of Carlsbad Cavern. CAVE also contains: wilderness that preserves the fragile environment of the northern Chihuahuan Desert; cultural/archeological site/resources that document millennia of American Indian inhabitation of the region; and historical resources related to early herding, mining, and exploration within the park. In several instances, paleontological resources have been found in the contexts of these other types of resources. CAVE was designated a World Heritage Site in 1995 for its pristine cave environments, rare/unique speleothems, and utility to geology, biology, and paleontology. CAVE’s boundaries have changed four times: on May 14, 1930; February 21, 1933; February 3, 1939; and December 30, 1963.

CAVE is located in the northern Chihuahuan Desert, at the eastern edge of the Guadalupe Mountains. These mountains formed from the deposition of a large Permian reef complex ringing a paleo-basin called the Delaware Basin. The units found within the Delaware basin are highly variable, reflecting a complex sequence of deposition, but those found within CAVE both above and underground are largely limited to the carbonate reef proper, a carbonate talus slope seaward of it, and mixed carbonate/clastic/evaporite back-reef, lagoonal, tidal, and sabkha facies landward of the reef (Hayes 1964; Graham 2007). Similar exposures of the Capitan Reef can be found at Guadalupe Mountains National Park (GUMO), 7 km (4 mi) to the southwest of CAVE, and the Glass Mountains, approximately 220 km (140 mi) south of CAVE. Other rocks associated with the Delaware Basin, especially basinal and post-reef evaporite fill units, are extensively found throughout the area surrounding and between these three locales (Graham 2007). A small privately owned center of business and lodging called White’s City is situated adjacent to the main eastern entrance into the park, with the nearest city being Carlsbad, New Mexico, about 27 km (17 mi) to the northeast. El Paso, Texas, is approximately 170 km (105 mi) to the south and west. CAVE is one of seven NPS units included in the Chihuahuan Desert Inventory and Monitoring Network (CHDN).



Figure 1. The Natural Entrance to Carlsbad Cavern viewed from the Amphitheater (NPS/SCOTT KOTTKAMP).

The boundaries of CAVE encompass a crescentic polygon oriented southwest-northeast, and the small detached Rattlesnake Springs unit (Figure 2). The visitor center is located at the end of the Walnut Canyon road, in the eastern portion of the park; the majority of CAVE is undeveloped wilderness area, though there are more than 32 km (20 mi) of trails that run overland. The southern boundary of the park roughly parallels a steep escarpment that rises above the flat plain to the south which represents part of the Delaware Basin. The escarpment is situated within the Permian Capitan Limestone (middle Permian), with exposures of the Permian Tansill, Yates, and Seven Rivers formation (all middle Permian, youngest to oldest) respectively dominating the surface as one moves north and west through the park (Figure 3). A small amount of upper Permian Castile formation is exposed at the base of the reef-escarpment in one eastern segment of the park. There is a shallow exposure of the Queen Formation on a northwestern edge of the park. The detached Rattlesnake Springs unit of the park encompasses the namesake springs that are CAVE's main source of potable water. This unit is situated over Quaternary gravels that cover the basinal formations below. Most of the park's caves formed in either the Capitan Limestone, the Yates Formation, or the Tansill Formation. Canyons run throughout the park, intersecting caves and older units of rock than are exposed along the canyons' walls. With the exception of the small exposure of Castile Formation, all

of the formations exposed within the park are fossiliferous, in some areas abundantly so (Figure 4). The Capitan Limestone is especially productive. Permian fossils are usually preserved in situ, except where erosion has moved them as talus. The Pleistocene/Holocene fossils were not deposited within bedrock, but are instead found in guano deposits, in alluvium on the surface, on the floor of caves, buried in detrital sediment fill at the bottom of pits, or encased within flowstone. Thus, it is often uncertain if the specimens are in situ at their places of death; transport of cave fossils after flooding events has been observed at CAVE.

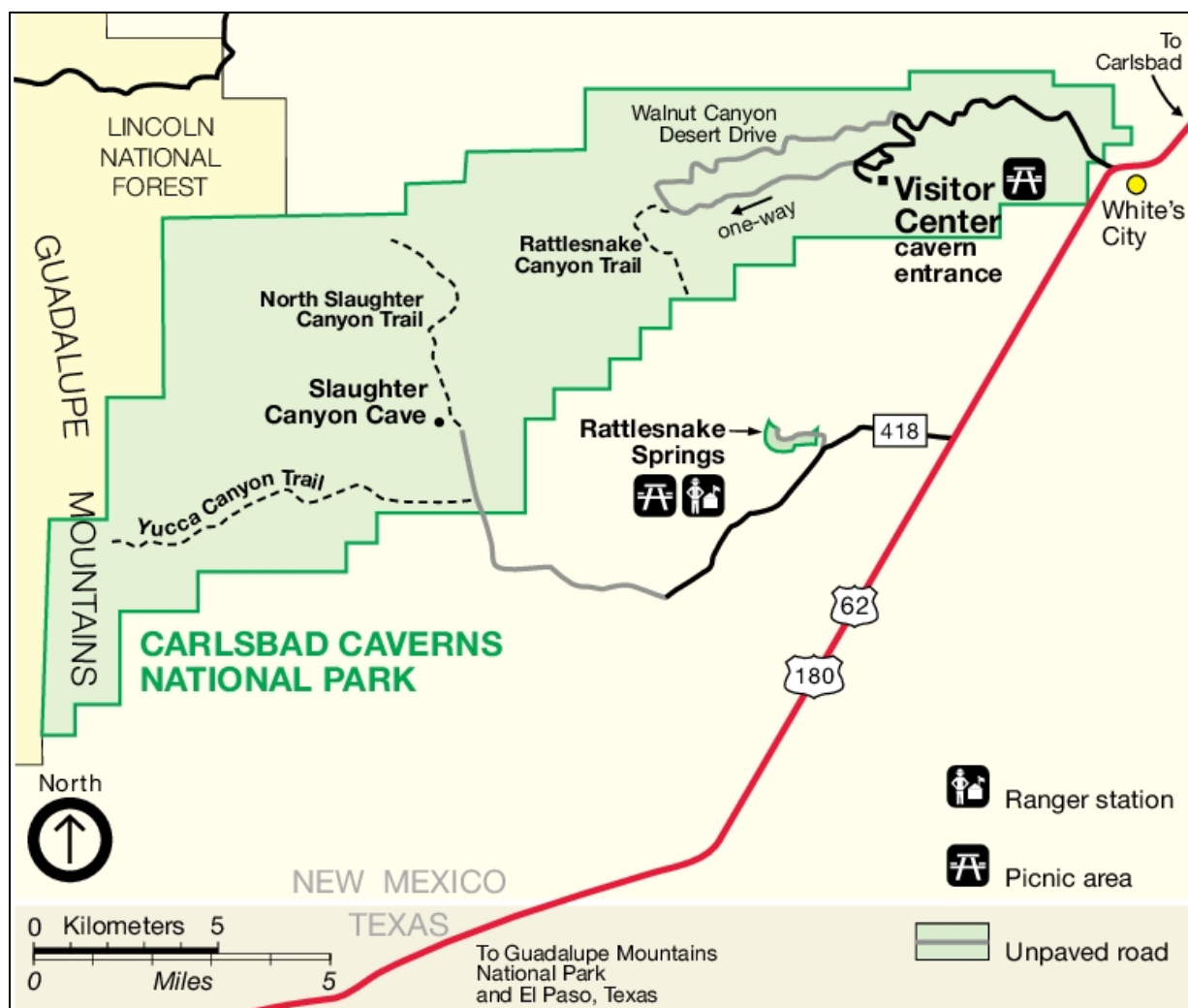


Figure 2. Geography of CAVE, showing park boundaries, roads, and other features (NPS).

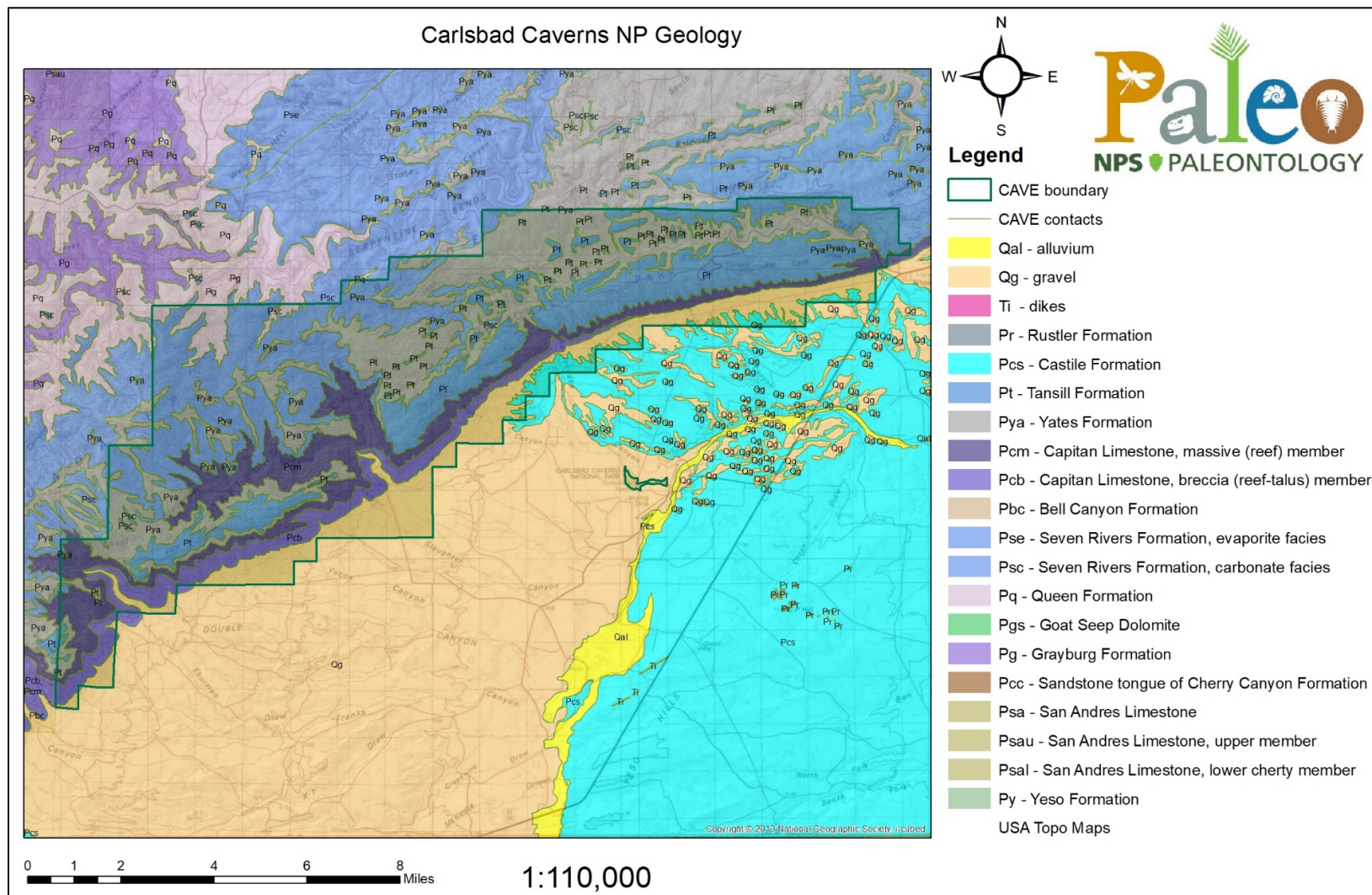


Figure 3. Geologic map of CAVE and vicinity, based on geologic map data derived from Hayes (1964) and digitized by the NPS Geologic Resources Inventory (GRI). Refer to the “Geologic Maps” section for more information about this product and the GRI program. Units with a capital “Q” in their unit symbol (e.g., “Qal”) were deposited in the Quaternary Period. Units with a capital “T” date to the Tertiary period. Units with a capital “P” were deposited in the Permian Period.

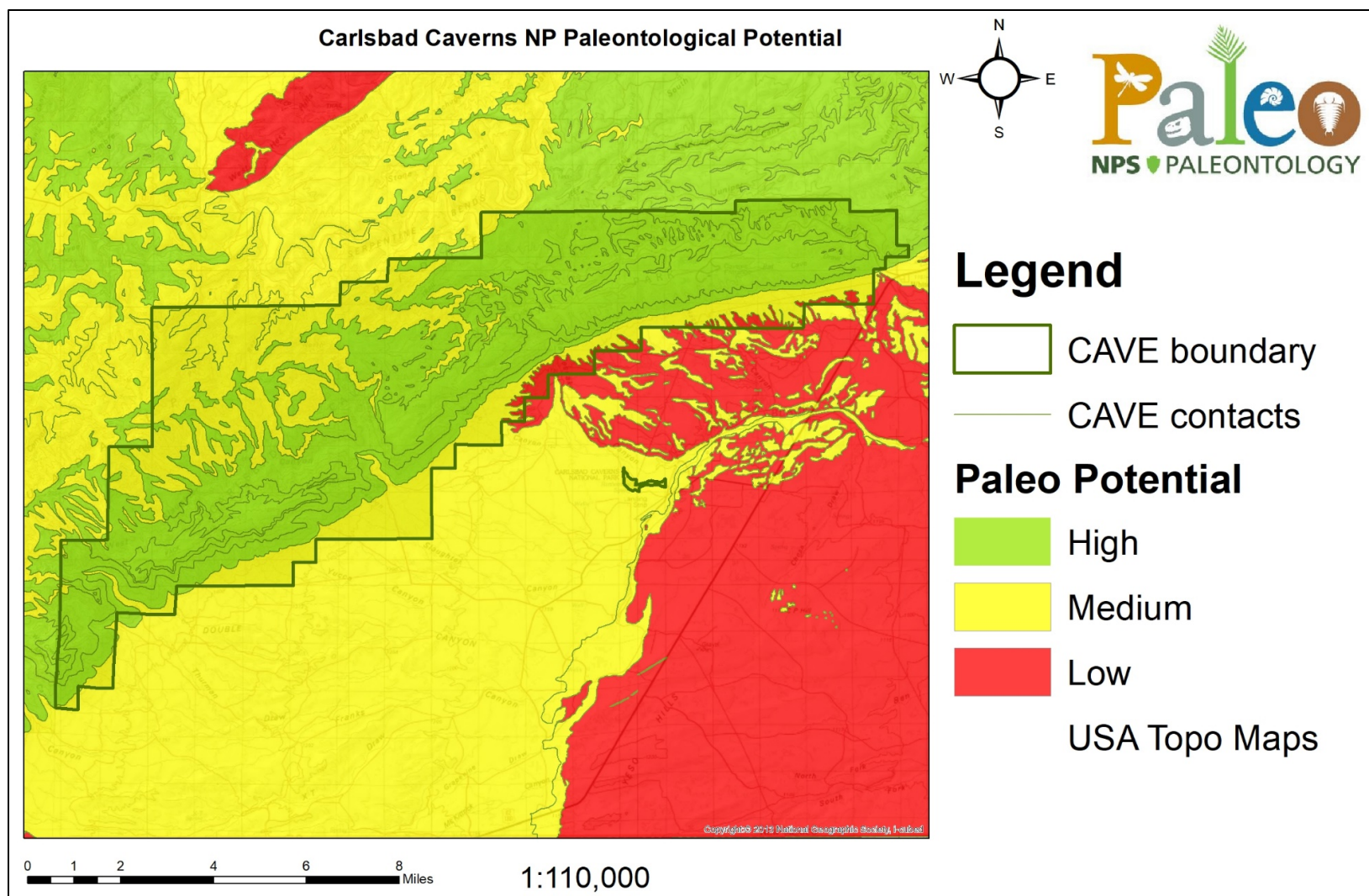


Figure 4. Map showing relative paleontological potential of geologic map units of CAVE and vicinity, based on the same data as Figure 3. High potential indicates fossils were documented from that unit within the park. Medium potential indicates fossils were documented from that unit elsewhere. Low potential indicates units where fossils are unlikely to be preserved. These ratings apply to Permian bedrock, not Quaternary cave deposits (NPS/TIM CONNORS).

Significance of Paleontological Resources at CAVE

The fossils of CAVE help to show the complete picture of the park and contribute to two of the park's significance statements (listed in the CAVE Foundation Document, NPS 2017):

- Carlsbad Caverns National Park protects a portion of the Permian Age Capitan Reef, one of the world's best preserved and accessible reef complexes with unique opportunities to view the reef from the inside.
- Past environments and climates can be understood at Carlsbad Caverns National Park by studying fossil resources and conducting paleoclimate research using speleothems.

A full understanding of the paleoecology of the Capitan reef complex is essential to hypotheses surrounding the structure of the shelf and basin. According to the park's Foundation Document (NPS 2017), the Capitan Reef is a fundamental resource of the park: *Capitan Reef. Carlsbad Caverns National Park protects one of the best-preserved exposed Permian-age fossil reefs in the world. The park's deep canyons and caves provide visitors and scientists with unique opportunities to view and study this fossil reef from the inside.*

Pleistocene terrestrial remains in caves document periods during which the caves were open, reveal the presence of now-closed entrances, and record ways in which regional ecology has changed or remained consistent (e.g., evidence of colonial bats from Slaughter Canyon Cave compared to the modern roosts in Carlsbad Cavern). Fossils from the Permian and the Pleistocene document changing environments and climates in ways that are relevant to modern ecosystems. Paleontological resources are also useful educational and outreach tools. For example, the clear divisions between Permian sea, Pleistocene boreal and grassland habitat, and the modern desert can be clearly communicated to visitors by using fossils. In addition, they are of concern for resource management because many of the fossils have characteristics that make them appealing for the casual or souvenir collector: they are portable, durable, some are easily recognized as fossils, and in some cases can be found on or near trails or roads. Though hard bedrock serves as a deterrent, isolated sites in the park display possible chisel marks, vertebrate fossils have gone missing from caves between surveys, and there is at least one recorded incidence of attempted fossil theft at CAVE.

Purpose and Need

The NPS is required to manage its lands and resources in accordance with federal laws, regulations, management policies, guidelines, and scientific principles. Authorities and guidance directly applicable to paleontological resources are cited in Appendix C and include, but are not limited to, the Paleontological Resources Preservation Act (2009) and the Federal Cave Resources Protection Act (1988), NPS Management Policies (2006), and Directors Order 77 (DO 77). Paleontological resource inventories have been developed by the NPS in order to compile information regarding the scope, significance, distribution, and management issues associated with fossil resources present within parks. This information is intended to increase awareness of park fossils and paleontological issues in order to inform management decisions and actions that comply with these laws, directives, and policies. See Appendix C for additional information on applicable laws and legislation.

Project Objectives

This park-focused paleontological resource inventory project was initiated to provide information to CAVE staff for use in formulating management activities and procedures that would enable compliance with related laws, regulations, policy, and management guidelines. Additionally, this project will facilitate future research, proper curation of specimens, and resource management practices associated with the paleontological resources at CAVE. Methods and tasks addressed in this inventory report include:

- Locating, identifying, and documenting paleontological resource localities through field reconnaissance and perusal of archives using photography, GPS data, standardized forms, and cave surveyor reports.
- Assessing collections of CAVE fossils maintained within the park collections and in outside repositories; documenting current information on Permian and Pleistocene/Holocene faunal assemblages and hypothetical paleoecological reconstructions.
- A thorough search for relevant publications, unpublished geologic notes, and outside fossil collections from CAVE.

Summary of 2019–2020 Paleontological Survey

This report represents work conducted from October 21, 2019 through January 24, 2020. Field work was conducted in Slaughter Canyon Cave on October 25, 2019 by Scott Kottkamp and Vincent Santucci, with the guidance and aid of CAVE's Chief of Resource Management Rod Horrocks and New Mexico Museum of Natural History and Science Curator of Paleontology Gary Morgan. The lead author also conducted field inventories on several occasions within easily accessed portions of Carlsbad Cavern, either alone or with the accompaniment of Rod Horrocks, as well as some personal trips along the surface trails and in the backcountry to observe the paleontological resources found there (Figure 5).

The majority of the inventory involved compiling data from published sources, CAVE's museum collections, sensitive park records, gray literature, and expert first-hand accounts of the paleontological resources within the park. The lead author conducted an extensive literature search and review as part of this inventory, in addition to examining the sensitive files for every cave indicated to contain vertebrate fossil remains. In all, 44 caves, one karst feature, one archeological site, two springs, and one untyped surface locality were found to contain Pleistocene/Holocene paleontological resources. Fourteen named surface localities and three caves containing Permian paleontological resources are detailed in this report; however, most of the park's caves likely contain Permian fossils and the lead author's observations indicate surface exposures of fossils are much more extensive than those detailed in this report. The local CAVE museum collection (those materials not loaned to external repositories) was inventoried for paleontological resources with the assistance of Rod Horrocks, and some preliminary reorganization of the vertebrate paleontological specimens was also undertaken. Specimens on loan to other institutions were located with the help of Cultural Resource Program Manager Erin Gearty and Gary Morgan.

A faunal list of species found within CAVE (and some Permian taxa from nearby analogous units suspected to be at CAVE) was developed as part of this project for both the Permian and Pleistocene/Holocene (Appendix A). Overall, 208 Permian taxa and 95 Pleistocene/Holocene taxa were identified in literature and records about the park. These should not be considered finalized lists, as there is material from both time periods in external repositories that has never been analyzed (in particular, the avian and herpetological assemblages of the Pleistocene/Holocene) and no comprehensive field inventory/survey of Permian paleontological resources has ever been undertaken at CAVE. Along with these faunal lists, current hypotheses about the paleoenvironment, paleoclimate, and paleoecology of the CAVE region during the Permian, the Pleistocene, and the transition into the Holocene are summarized in this report. Current work suggests major ecological and climate changes occurred during both periods, with the resulting patterns of adaptation, migrations, and extinction being extremely relevant to modern conservation paleobiology efforts.

It is strongly recommended that future work take place at CAVE to add to the results of this inventory. Field inventories of backcountry wilderness and caves and identification of fossils to genus and species are especially needed. Other recommendations include creating formal paleontology focused interpretive programs at CAVE, examining paleontological localities more comprehensively for signs of vandalism, theft, or natural erosion/instability, and setting up a monitoring program for paleontological localities separate from or in tandem with the current monitoring and surveying program for caves.



Figure 5. Lead author Kottkamp holding a scale bar for photographing fossil sponges in a cave wall (NPS/ROD HORROCKS).

History of Paleontological Work at CAVE

The history of paleontological research in the Guadalupe Mountains is extensive, going back to George Shumard's 1855 collections obtained as part of John Pope's U.S. Government Expedition to the region (described by his brother Benjamin Shumard in 1858 and 1859), with George H. Girty of the U.S. Geological Survey following up a half-century later (Girty 1908). These early works, and others since, have established a rich assemblage of fossils in the region and developed a picture of the environment and ecosystems these Paleozoic organisms inhabited. However, the scope of this report is limited to the paleontological resources of CAVE and associated research. Likewise, this is not a comprehensive report on geologic resources or geologic research, even that occurring within CAVE. While these other studies are important in that they predict potential paleontological resources at CAVE or provide context, and are referenced elsewhere in this paper where appropriate, they will not be recounted here. The following section will focus only on paleontological studies that involved collection or observation within the modern boundaries of CAVE, or were performed on specimens originally collected from within CAVE's boundaries.

Formal oral history interviews were completed with several individuals who have been involved in paleontological research or resource management at CAVE over the past few decades. The interviews capture first-hand historical and scientific information related to CAVE paleontology that may not be available through other sources or records. The interviews provide a means of preserving information that otherwise may be ephemeral and lost over time with staff turnover at the park and the passing of the individuals. Interviews were completed with Ron Kerbo (retired NPS Cave and Karst Program Manager), Pat Jablonsky (retired paleontologist, Denver Museum of Nature and Science), Lloyd Logan (retired paleontologist, Texas Tech University), and Gary Morgan (paleontologist, New Mexico Museum of Natural History and Science) between November 2019 and February 2020. Digital audio recordings were obtained during each interview which were used to prepare a written transcript. The transcripts were shared with each of the interviewees to allow them to make any edits or corrections to the content and spelling. The final digital audio recordings and transcript, along with a signature release form, have been archived in the NPS Paleontology Archives, the NPS Oral History Archives, and at the park.

Permian Paleontological Studies

There is no evidence that Shumard or Girty described any fossils collected from within the current boundaries of CAVE. The first paleontological work known to have been done at CAVE in regard to Paleozoic taxa was by J. Harlan Johnson (Colorado School of Mines) around 1942, who collected algal fossils from within the park as well as elsewhere in the Guadalupe Mountains (Johnson 1942). In the late 1940s and early 1950s Norman Newell (American Museum of Natural History and Columbia University) was also collecting in the Guadalupe Mountains, and at some point prior to 1953 collected from three localities within CAVE in time to include them in Newell et al. (1953). This book introduced the hypothesis that the Delaware Basin, including CAVE, had once been a sponge and bryozoan ("moss animal") based barrier reef; though later supplanted by other hypotheses, such as the marginal mount or mesophotic reef hypothesis, Newell et al.'s (1953) image of a Permian reef greatly influenced interpretation of the paleontological resources at CAVE.

Gustav Arthur Cooper (Smithsonian Institution), an acquaintance of Newell, was active in the Delaware Basin for many years between 1939 and 1968. His primary area of focus was the Glass Mountains, but he collected in the Guadalupe Mountains on several occasions. Years when he was active in the Guadalupe Mountains include 1952, 1953, 1959, and 1961 (Cooper and Grant 1972). Cooper and various field assistants collected from several localities within CAVE, with these collections ultimately being published in a series of monographs on Permian brachiopods (Cooper and Grant 1972, 1976, 1977). Other authors would eventually publish on some of the non-brachiopod organisms found within the Cooper and Grant collections (e.g., Yochelson 1960; Batten 1989; Brezinski 1992). Babcock (1974, 1977) worked on the algae of the region, including specimens from CAVE, but does not seem to have undertaken additional collections. Other work involving fossils around this time was focused on their use as identifying features of stratigraphy, such as Hayes (1957, 1964), Hayes and Koogler (1958), and geological studies that proposed new hypotheses about the depositional environment of the Delaware Basin (Dunham 1972).

The 1990s were a time of renewed interest in paleontological and paleoecological research at CAVE, as part of a wider reopened debate about the nature of the Capitan Reef. Brenda Kirkland George (University of Texas at Austin) wrote a dissertation (Kirkland George 1992) and several papers on the algae *Mizzia* that argued in favor of the old Newell et al. (1953) barrier reef model, including observations from localities within CAVE. Rachel Wood (University of Cambridge) published several papers on the paleoecology of the Capitan Reef (Wood et al. 1994; Wood 1999, 2001), drawing from information gathered at localities throughout the Guadalupe Mountains, including those at CAVE. The park was visited again for collecting purposes by Baba Senowbari-Daryan (Institut für Paläontologie, Universität Erlangen-Nürnberg) and J. Keith Rigby (Brigham Young University) several times during the 1990s, with their collections within CAVE largely focusing upon sponges (Senowbari-Daryan 1990; Rigby and Senowbari-Daryan 1996; Rigby et al. 1998). Their research uncovered a new species of giant Permian sponge, *Gigantospongia discoforma*, first just outside of CAVE and later within the park itself (Rigby and Senowbari-Daryan 1996). The overall results of this research were published in a comprehensive inventory of sponge taxa from the Guadalupe Mountains, including CAVE (Rigby et al. 1998). Around the same time, Weidlich and Fagerstrom (1998), Fagerstrom and Weidlich (1999), and Wood (1999) published large works summarizing the paleoecology of the Capitan Reef. Also, exploration of Lechuguilla Cave throughout the 1990s revealed hundreds of fossil localities, most of which have yet to be fully documented. Fossils at many of these sites have been differentially dissolved from the walls and stand out in relief. Some of the findings were published by researchers, including a brief overview of the cave's overall fossil assemblage (DuChene 2000) and the largest Permian gastropod (Kues and DuChene 1990).

New fossil discoveries continue to occur in Lechuguilla Cave even today, but no further formal paleontological study beyond photography and basic presence/absence inventorying has been done on the specimens in the intervening decades (NPS Records 2020). Likewise, researcher interest in CAVE's surface Permian fossil resources seems to have waned after the early 2000s, except for their continued utility for geologic/stratigraphic research. Paleontology in the wider Delaware Basin has been of keen interest to petroleum geologists and companies for decades. However, because of

CAVE's protected status as a national park and the near total absence of basin facies within the park, such research has primarily occurred outside of the park.

Pleistocene/Holocene Paleontological Studies

Vertebrates

While collection of vertebrate fossils in the greater Guadalupe Mountains had been documented through the early 1900s and potentially earlier (Schultz and Howard 1935), the first major specimens to be documented from CAVE were two skeletons of the mountain deer *Navahoceros fricki* in 1938 by Harry Tourtelot (University of Nebraska State Museum). In the 1940s, a *Nothrotheriops* (ground sloth) was recovered from Carlsbad Cavern (Bretz 1949; Gale 1957). Black (1953) soon after reported on the contents of a debris pile near the entrance that contained Quaternary mammal and reptile remains. The first publication on CAVE's fossil chiropterans (bats) was Lawrence (1960), which described the new extinct species *Tadarida constantinei* from Slaughter Canyon Cave, collected by CAVE staff member Denny Constantine in 1958. This was followed by Baker's (1963) report on bats from Carlsbad Cavern. Baker (1963) revealed the presence of bat mummies within the cave, as well as generally boreal or tree dwelling taxa such as the hoary bat, *Aeorestes cinereus*. The latter supports the hypothesis that the region around CAVE was wetter and woodier in the past. In the 1970s, Charlie Peterson (National Park Service) and Lloyd Logan (Texas Tech University) investigated Wen Cave and found a Holocene fossil assemblage within a debris pile. In early May 1976 Logan (now in a joint appointment with the NPS and the Smithsonian Institution) excavated at Muskox Cave (Figure 6), revealing excellent Pleistocene and Holocene assemblages, including species such as the shrub ox, dire wolf, the American cheetah, and several shrew species critical to paleoecological reconstruction (Logan 1979, 1981). The results of this work, and Baker's (1963) earlier observations on bats, supported Murray's (1957) hypothesis about a major climate change event in the late Pleistocene and early Holocene that aridified the Guadalupe Mountains. A summary of the overall findings from these years, synthesized with correlated research elsewhere in the Guadalupe Mountains, Chihuahuan Desert, and mountain ranges in northern New Mexico, was published in Harris (1985).

Uranium-series dating done on the *Nothrotheriops* from Carlsbad Cavern by Hill and Gillette (1985, 1987a) revealed it to be about 110,000 years old, greatly expanding the hypothesized age of the fossils within CAVE and indicating that Carlsbad Cavern had been open to the surface at least that long. During the 1990s Patricia Jablonsky (Denver Museum of Nature and Science) undertook a major inventory of chiropteran taxa and fossil resources in Carlsbad Cavern and Lechuguilla Cave. This study confirmed several more bat species from both caves (Jablonsky 1993, 1996, 2004?), vastly expanded the estimated age of some bat fossils/guano in Carlsbad Cavern from ~17,000 years old to 40,000–50,000 years old (Jablonsky 2001), and investigated a mass-die off of a colony of Mexican free-tailed bats in Lower Cave. At the same time, investigation of Lechuguilla Cave revealed another *Nothrotheriops* and a *Bassariscus astutus* (ringtail) skeleton encased in flowstone. Fossils found near the entrance of Lechuguilla Cave, but not recorded in Jablonsky (2004?), include cougar and bear. Both of these specimens are kept in CAVE's museum collections. A *Bison* sp. specimen, the only one confirmed from within the park boundaries, was recovered from Rattlesnake Springs in the 1990s as well.



Figure 6. Recovery of the *Euceratherium* skull from Muskox Cave in 1976. The skull is encased in a protective plaster jacket. The *Euceratherium* fossils collected from the cave were among the best preserved and most complete skeletons for the taxon at the time, and were also relatively abundant compared to the other macro-vertebrate fossils from Muskox Cave (NPS/RON KERBO).

Gary Morgan's 2002 and 2003 work in Slaughter Canyon Cave greatly expanded the known assemblage from that cave and the park at large. In addition to detailing the full scale of the hundreds of thousands of *Tadarida constantinei* contained within the cave's guano deposits (Figure 7), indicating the presence of a massive colony over thousands of years, Morgan's (2002) work documented desert tortoise, a large raptorial bird, several rodents, a dwarf pronghorn, and the medium-sized extinct pronghorn *Stockoceros* (initially identified as an ursid), among others. Later review works by Morgan, Lucas, and Harris (Morgan and Lucas 2006; Morgan and Harris 2015) synthesized this work with earlier finds from CAVE. Further research at Slaughter Canyon Cave by Lundberg and McFarlane (2006) and Polyak et al. (2006) focused on age-dating the guano fossil deposits, using uranium-series dating on the flowstone layers above them as minimum age proxies. These studies, combined with observations on the diagenetic alteration of the bat bones and the guano, indicate that the bat fossils within Slaughter Canyon Cave are at least more than 200,000 years old and likely more than 500,000 years old. In the same time period, Jass et al. (2000) identified a mountain goat from the Muskox Cave collection as the extinct species *Oreamnos harringtoni*. Carraway (2010) documented additional shrew species, with comments on

paleoecology, from caves near the park like Big Manhole Cave; however, the reassessment of some shrew taxonomy was also applicable to studies done within CAVE like Logan (1979, 1981).



Figure 7. Assorted *Tadarida constantinei* bones (dark objects) deposited within guano at Slaughter Canyon Cave. The guano within this cave contains hundreds of thousands of bat bones. Boxes on scale bar are 1 cm square (NPS).

Since 2010, no collections or major studies on vertebrate paleontology have taken place at CAVE, although specimens collected from CAVE continue to appear in review works about the region (e.g., Morgan and Harris 2015). However, CAVE staff continue to survey caves and document the fossils found within, including vertebrate body fossils and ichnofossils. CAVE staff have also done salvage collections at archeological sites, springs, surface exposures, and some caves. These specimens are stored in the CAVE museum collections and include a felid skull, horse teeth and rodent bones found near archeological sites, the previously mentioned *Bison* sp., a bighorn sheep horn and skull fragment, and more (NPS Records 2019). Additionally, there remains a large amount of unpublished fossil material at external repositories, such as Texas Tech and the U.S. National Museum of Natural History (Smithsonian Institution), dating from the collections at Wen Cave and Muskox Cave. In particular, the herpetological and avian remains collected from several caves have yet to be identified or analyzed (G. Morgan, pers. obs., November 2019).

Microorganisms

Several caves within the park, notably Carlsbad Cavern and Lechuguilla Cave, preserve speleothems hypothesized to be bacterial in origin. These include “pool fingers,” the calcified-over remnants of hair-like strands of bacteria (Figure 8), and the “rusticles” within Lechuguilla Cave that may actually preserve imprints of iron-oxidizing bacteria. Palmer and Palmer (1990) summarized possible microbial fossils and karst features from Carlsbad Cavern, Lechuguilla Cave, and other caves in the Guadalupe Mountains. Melim et al. (2001, 2008) investigated the possible microbial origin of pool fingers within Carlsbad Cavern. Cunningham et al. (1995) first reported on the biokarst of Lechuguilla Cave, followed by Provencio and Polyak’s (2001) study on the iron-oxidizing bacterial fossils from Lechuguilla. Further studies on cave dwelling bacteria, both living and fossil, continues at CAVE to the present (R. Horrocks, pers. obs., January 2020). In most cases, these bacterial remains date to the Pleistocene or Holocene (R. Horrocks, pers. obs., January 2020). However, it is possible that some bacterial fossils or traces could date from the early speleogenesis of the cave (Provencio and Polyak 2001); given the current 12–4 Ma (million year) estimates for speleogenesis (DuChene et al. 2017), this would potentially place the formation of these fossils in the Pliocene or Late Miocene (see Appendix B for a geologic time scale).



Figure 8. Pool fingers mark the position of a dry pool in Carlsbad Cavern. This speleothem/fossil forms when hair-like strands of colonial bacterial are calcified over. It may date to the Pleistocene (NPS/ROD HORROCKS).

Geology

Geologic History

This section has been adapted in part from Graham (2007), with additional material and citations where appropriate.

Late Paleozoic Setting

During the late Carboniferous (323–299 Ma), and into the early Permian (299–273 Ma), the continents Gondwana (the modern southern continents) and Laurasia (the modern northern continents) collided to form the supercontinent Pangaea (Hill 1996). In what is now south-southwest North America this collision deformed the interior of the continent into a series of north-northwest trending basins flanked by zones of uplifted blocks called the Ancestral Rocky Mountains (Kluth and Coney 1981). According to Kluth and Coney (1981) this continent-continent collision would have been similar to the impact of India into Asia (which continues to uplift the Himalayas), forming areas of tremendous uplift and subsidence. Ye et al. (1996) instead proposed the existence of a northwest-trending ocean-continent collision more similar to the modern Andes Mountains along the southwest edge of North America, which formed the greater Ancestral Rocky Mountains as the overriding plate was shortened and uplifted. Regardless of the specific tectonic setting, in both hypotheses the resulting deformation divided the pre-existing (Cambrian-age) Tobosa rift basin into three subsiding sections, with one of these three sections being the Delaware Basin that CAVE is situated upon (Hill 1996; Ye et al. 1996).

During the Permian Period (299–252 Ma), after tectonism declined, the Carlsbad Caverns region was near the equator, specifically within the northern trade wind belt at about 6–7 degrees north latitude (Fischer and Sarnthein 1988; Graham 2007). Following changes in climate accompanying the formation of Pangaea, a shallow tropical sea inundated western North America while a broad alluvial plain spread across eastern North America. An arm of this Permian sea flooded into the Delaware Basin, in what is now New Mexico and west Texas (Graham 2007). The Delaware Basin was a relatively deep basin, on the order of 600 m (2,200 ft) deep, connected to the open ocean through a channel (King 1948; Hill 1996; New Mexico Institute of Mining and Geology 2000). It had been proposed that the channel lay along the south edge of the basin in the location of the modern Glass Mountains southeast of CAVE; named the Hovey Channel, it was speculated to have restricted water flow into the basin much like the Strait of Gibraltar restricts the connection of the Mediterranean Sea with the Atlantic Ocean (King 1942). This would have resulted in poor circulation within the basin and an anoxic environment at depth. However, Hill (1999) pointed out that reassessment of the area supposedly occupied by the Hovey Channel identified the rock there as shallow marine instead of deep basin. Hill (1999) hypothesized that the channel into the Delaware Basin was actually located in the area of Salt Basin south of CAVE where the Capitan Limestone is missing or was never deposited.

One model for the Capitan Limestone proposes a mesophotic (30–150 m, or 100–490 ft, below sea level, below the zone of greatest light penetration) reef formed on the leading edge of the slope into the basin, with a reef-crest approximately 45–50 m (150–160 ft) below sea level (Kirkland et al.

1999; Wood 2001; Hunt et al. 2003; J. Hearst, pers. comm., December 2019). Other researchers do not define this structure as a reef because its structure does not match that of a modern reef, instead designating the structure as a series of large organic bioherms (Dunham 1972; H. DuChene, pers. comm., November 2019). An older model proposing that the Capitan Limestone was a barrier reef is not well supported, except maybe in localized regions near the end of the reef's life as it shallowed out (Newell et al. 1953; Kirkland George 1992; Hill 1996; Wood 2001). Current depositional models for the Delaware Basin indicate that the topography of the shelf changed over time, and thus the bioherm patches and the mesophotic reef-rimmed shelf hypotheses are not mutually exclusive (Kerans and Kempter 2002). In all models except the barrier reef, the reef/bioherms were not situated near the shelf-crest and did not serve as an effective barrier to circulation. Instead, clastic mud mounds, sand bars, and islands that formed on and behind the shelf-crest were the primary restrictors of flow into the lagoonal regions of the shelf (Dunham 1972; Pray and Esteban 1977; Graham 2007). Depositional environments landward of the reef complex included redbeds, sabkha (salt flat) evaporites, lagoonal mudstones, pisolitic grainstones, and back-reef grainstones; seaward of the shelf margin edge, fore-reef and basin deposits formed (Newell et al. 1953; Hayes 1957, 1964; Hayes and Koogler 1958; Hill 1996). The slope into the basin was a submarine debris fan composed of poorly sorted carbonate fragments (Newell et al. 1953; Hayes 1964). The slope of this debris fan into the basin was more gradual than the archetypal modern barrier reef's sharp break and drop-off (Garber et al. 1989; Hill 1996).

The terrigenous redbed deposits closest to the Permian shore and the more seaward adjacent sabkha facies have few to no fossils. The shallow subtidal facies directly seaward of both are also sparsely fossiliferous, and may have represented shallow, isolated, and possibly hypersaline lagoons (Newell et al. 1953; Hayes 1957, 1964; Hayes and Koogler 1958; Graham 2007).

Farther seaward the evaporite facies transitions to a pisolitic grainstone (pisolitic meaning comprised of concretionary grains >2 mm (0.08 in) in size, usually formed of calcium carbonate) (Graham 2007). The most common fossils here are beds of skeletal debris (mostly from sponges and algae) mixed in with millimeter to >5 cm (2 in) sized pisoids that comprise most of the rock. This facies is almost always a transitional zone between the fossil-barren landward evaporites and the highly fossiliferous marine grainstones, packstones, and wackestones making up the back-reef, reef, and fore-reef. It exists throughout all of the formation associated with the back-reef and further landward facies: the Queen, Seven Rivers, Yates, and Tansill formation (listed lowest to uppermost). This is the facies associated with the "teepee" structures found in CAVE and GUMO, especially within the Tansill Formation.

The back-reef grainstone facies lies seaward of the pisolite facies. This facies shows signs of open marine circulation, with normal to slightly hypersaline conditions (Graham 2007). Marine fossils are abundant, especially fusulinids and other foraminifera ("amoebas with shells"), gastropods, bivalves, green algae (especially *Mizzia*), blue-green algal boundstones, oncoids (spherical layered structures formed by microbes), and other skeletal grains (Graham 2007). The common occurrence of many mobile taxa, like the bivalves and gastropods, suggests that the back-reef bottom was likely a

constantly shifting and sandy environment. The lithology of these facies is mostly grainstones and packstones (Newell et al. 1953; Hayes 1957, 1964; Hayes and Koogler 1958; Graham 2007).

The back-reef grainstone facies was topographically elevated. Small, coalescing sand waves and islands, perhaps with intervening tidal passes, formed on the seaward edge of this facies and acted as an overall deterrent to water movement farther landward (Pray and Esteban 1977; Esteban and Pray 1983; Kirkland George 1992; Graham 2007). Unlike the other back-reef and shallow facies, which experienced widespread pore-filling by evaporites, the grainstone-island belt was only partially dolomitized and has relatively minor pore-filling cementation by evaporites. Rocks of this facies are often hydrocarbon reservoirs due to their porosity and proximity to overlying evaporites that plug the pores, preventing liquids from migrating upward (Graham 2007). They have literally fueled oil and gas extraction in the region for decades.

Seaward of the back-reef grainstone facies was the main carbonate-producing facies of the area, the Capitan Reef (Newell et al. 1953; Hayes 1964; Graham 2007). This mesophotic reef or series of bioherms acted as a “carbonate factory,” producing a high volume of carbonate material that rapidly caused the shelf to prograde into the basin and formed a platform of carbonate material that kept the margins of the Delaware Basin shallow (Graham 2007). The Capitan Reef was the zone of maximum faunal diversity in the Delaware Basin (Newell et al. 1953; Kirkland George 1992; Weidlich and Fagerstrom 1998). It differed from modern reefs in that it formed in deeper water, 45–50 m (150–160 ft) deep, whereas most modern reefs are in water less than 20–30 m (66–98 ft) deep; comparable modern reefs have a mix of light-dependent organisms and those that live in zones of low light penetration. It also differed in that it was primarily composed by a micro-framework of encrusting organisms, mostly bryozoans and red or blue-green algae, which helped to bind the reef together and lithify the carbonate platform after death along with infilling of pore spaces by calcium carbonate (Newell et al. 1953; Wood et al. 1994; Graham 2007). However, Kirkland George (1992) and Wood (2001) argued for the existence of at least some expansive reefs with a significant macro-organismal framework, especially in the Guadalupe, Apache, and Glass Mountains (Hill 1996). The animals that comprised the macro-framework were mostly patches of sponges instead of widespread colonial corals (Weidlich and Fagerstrom 1998). However, in localized areas (or, alternatively, time periods) other organisms seem to be the primarily bioherm/reef builders, most notably strophosomiid and richthofenioid brachiopods (lamp shells) (Senowbari-Daryan and Rigby 1996a). The bioherms/reefs also contained a wide variety of ancillary organisms including, but not limited to: scarce solitary corals; other brachiopods; mollusks; trilobites; ostracods (seed shrimp); and echinoderms (both crinoids [sea lilies] and echinoids [sea urchins]) (Newell et al. 1953; Graham 2007). Some deep reefs off modern Belize may be good analogs for the Capitan reef (Graham 2007).

Massive amounts of contemporaneous marine cementation played a major factor in the formation of the Capitan reef complex. Carbonate cement precipitated directly from ambient seawater, rapidly filled cavities (Wood et al. 1994; Graham 2007). This cementation reduced porosity to such a degree that the reef facies is not a significant hydrocarbon reservoir despite the fact that locally extensive fracturing has created zones of high permeability (Graham 2007). The rapid rate of marine cementation, coupled with the very high rate of biological productivity, produced more material in

the reef margin zone than could be accommodated, given limited rates of subsidence. This excess material was transported into back-reef and fore-reef environments. The Capitan reef complex of the Guadalupe Mountains prograded seaward between 5 to 10 km (3 to 6 mi) despite sitting at the margin of a nearly 600-m (1,800 ft) deep basin. Such progradation required a very large volume and a high rate of sediment production (Graham 2007). The intense contemporaneous cementation of the Capitan reef complex, coupled with rapid progradation of largely unconsolidated and compactable debris, led to extensive fracturing of the cemented reef slab during the depositional process (Wood et al. 1994; Graham 2007).

Further seaward, the fore-reef talus apron is one of the most volumetrically important carbonate facies in the Permian reef complex (Graham 2007). Material from the reef, near-back-reef, and upper slope was transported by rock fall, grain flow, debris flow, and turbidity currents and deposited in a relatively uniform apron of steeply dipping rubble. Grain size varies greatly, and bedding angles may exceed 35 degrees on the upper slope, gradually flattening to a few degrees near the basin floor (Hayes 1964; Graham 2007). Isolated sand-filled channels up to 9 m (30 ft) thick are present in some areas of the upper and middle slope. Carbonate debris beds interfinger with sandstone beds. The carbonate beds thin into the basin while the sandstone beds, derived from the continent, thicken basinward (Graham 2007).

Basinal rocks and sediments are roughly 90% clastic and 10% carbonates (Graham 2007). The carbonates are very fine-grained and are generally finely laminated and dark-colored, although organic carbon content rarely exceeds one percent (Graham 2007). Basin carbonate strata are mostly unfossiliferous except for a few radiolarians (another type of “shelled” microorganism) (Hayes 1964; Graham 2007), though Newell et al. (1953) found low-diversity assemblages in older basin units not exposed within CAVE’s boundaries. The basin clastics are very fine-grained subarkosic sandstones and coarse siltstones that are compositionally very similar to the thin clastic units found on the shelf. This large amount of clastic sediment in the basinal facies is evidence of changes in sea level over time and also suggests how the reef system came to an end—when the basin it occupied was filled in by sediment (Graham 2007).

Reefs and/or grainstone shoals in the Delaware Basin flourished during high sea level stands, with the bioherms/reefs building up large carbonate platforms (Graham 2007). Landward of the reef, broad carbonate-evaporite lagoons occupied much of the platform’s shelf area. Thin, but widespread, carbonate turbidite units were deposited in the basins, and these are the basinal carbonate strata found today (Hayes 1964; Graham 2007). Clastic sediments were either trapped in vegetated dunes or interdune flats, on sabkhas, or in shoreline deposits well up on the shelf (Graham 2007).

When sea level decreased, fluvial and eolian sands and silts spread across the shelf area, accumulating on the margins and eventually transported into the basins to form thick sandstone sequences. Some of these sands and silts may also have moved through channels or tidal passes in the bioherm/reef complex during times of carbonate sedimentation. This would account for some lenticular sandstone beds, but the cyclic distribution of both shelf and basin carbonate-clastic packages indicates that some form of sedimentation with sea level change is required to explain the overall sediment distribution (Sarg 1985, 1986; New Mexico Institute of Mining and Geology 2000).

In very late Permian time, as the final suturing of Pangaea took place (Graham 2007), the connection to the open ocean became restricted (Hill 1996). Evaporation exceeded the inflow of normal marine water so that salinity increased. With increased salinity, life on the shelf and shelf margin ceased and carbonate production ended with it (Hill 1996; Graham 2007). Thick tracts of evaporites were then deposited. This loss of coastal marine environments coincident with the formation of Pangaea is mirrored at Permian reefs found elsewhere in the world, and may have played into the devastating Permian–Triassic mass extinction alongside other hypothesized causes like climate change. Though the end of the reef system at CAVE predates the Permian–Triassic extinction by several million years, its end aligns with a smaller mass extinction event at the end of the Guadalupian epoch of the Permian (273–260 Ma; named for the rocks of the Guadalupe Mountains in GUMO). However, that extinction is more often associated with climatic and water chemistry changes tied to large-scale volcanic eruptions (Jost et al. 2014).

Eventually, thick deposits of gypsum filled the Delaware Basin and buried the reef core (Hill 1996; Graham 2007). Gypsum was followed by anhydrite (CaSO₄), halite (NaCl), sylvite (KCl), and other evaporitic minerals as the water depth continued to decrease and conditions became even more hypersaline (Hill 1996; Graham 2007). The subsequent Salado Formation tidal salt-flats (found on BLM land nearby, but not at CAVE) covered over the basin entirely (Hill 1996; Graham 2007). Commercial deposits of potash minerals (potassium salts and carbonates) have been exploited in these thick, last-stage Permian evaporite deposits of the Delaware Basin (Graham 2007).

Mesozoic (252–66 Ma)

For most of the Mesozoic Era, the Permian Basin region (which includes the Delaware Basin) was part of a tectonically stable province (Hill 1996; Graham 2007) even as Pangaea began to separate in the Triassic and Jurassic. There were occasional and localized depositional phases in the Triassic (terrestrial) and early Cretaceous (marine), but if such deposition ever occurred within CAVE's boundaries it has since eroded away. During the Laramide mountain-building event beginning in the Late Cretaceous, the Guadalupe Mountains were locally uplifted accompanied by faulting and southeastward tilting, contributing to the erosion of Mesozoic deposits (Hill 1996; Graham 2007). Some karst development occurred during Mesozoic non-depositional periods within the Capitan Limestone and the shelf evaporite facies (Hill 1996; Graham 2007). In the broader Guadalupe Mountains, but not within CAVE, Mesozoic paleokarst and sinkholes have been found and sometimes contain vertebrate fossils (H. DuChene, pers. comm., 2019).

Cenozoic (66 Ma–present)

The bulk of speleogenesis that created the modern karst systems and features at CAVE occurred within the last 12 million years (DuChene et al. 2017). The origin, timing, and process of this speleogenesis is complex, subject to ongoing debate, and beyond the scope of this paleontologic inventory. Those interested can find more information in the following sources: DuChene et al. (2017); DuChene and Cunningham (2006); Graham (2007); Hill (1987, 1996, 2000); and Queen (1994a, 1994b, 2009).

Post-speleogenetic erosion eventually cut down into the subsurface cave systems (DuChene and Martinez 2000), allowing animals to access or become trapped in the caves (Santucci et al. 2001;

Lundberg and McFarlane 2006; Morgan and Harris 2015). As a result, Pleistocene and Holocene fossil vertebrate bones from the Irvingtonian (1.4–0.25 Ma), Rancholabrean (250,000–12,000 years ago), and Santarosean (12,000–400 years ago) North American Land Mammal Ages can be found in many of the caves within CAVE. Bat fossils are the most common, especially within Slaughter Canyon Cave, but specimens of ring-tailed cat, Shasta ground sloth, large felids, shrub oxen, pronghorn, mountain goat, dire wolf, shrew, marmot, horse, and an extinct vulture have been found as well (Morgan and Harris 2015). The ages of some of these fossils indicates that portions of the cave systems must have been open to the surface at least 500,000 years ago, and also suggest the existence of cave entrances different than those found today. Examples of caves with strong evidence for additional natural entrances that have since collapsed include Carlsbad Cavern and Lechuguilla Cave (Santucci et al. 2001; Jablonsky 2004?). Additionally, at Slaughter Canyon Cave, flowstone exposed outside on the canyon slope and breccia near the modern cave entrance clearly indicate the existence of now collapsed or eroded cave passages (DuChene and Martinez 2000; G. Morgan, pers. obs., 2019).

Geologic Formations

A summary of the geologic formations of CAVE and their fossils is presented in Table 1.

Table 1. Summary of CAVE stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text.

Formation	Age	Fossils Within CAVE	Depositional Environment
Quaternary cave fossils	Late Pleistocene (up to about 112 ka)–Holocene	Turtles, lizards, snakes, birds including vultures, ground sloths, shrews, rodents, rabbits, bats, big cats, wolves, skunks, procyonids, horses, camels, shrub oxen, mountain goats, pronghorns, deer, bison, and bat guano deposits	Within caves
Quaternary gravel (Qg)	Pleistocene–Holocene	Bison from within surficial deposits	Fluvial
Castile Formation (Pcs)	late Permian	None to date	Basin
Tansill Formation (Pt)	middle Permian	Dasycladacean algae, brachiopods, gastropods, crinoids, and fusulinid foraminifera most common; others present	Shore to back-reef
Yates Formation (Pya)	middle Permian	Dasycladacean algae, bivalves, gastropods, scaphopods, and fusulinid foraminifera are most common; others present	Shore to back-reef
Capitan Limestone (massive [or reef] member [Pcm] over breccia [reef talus] member [Pcb])	middle Permian	Dasycladacean algae, sponges, corals, bryozoans, brachiopods, bivalves, cephalopods, gastropods, scaphopods, trilobites, crinoids, echinoids, foraminifera, red algae, <i>Tubiphytes</i> , and possibly monoplacophorans	Reef to fore-reef
Seven Rivers Formation (Pse and Psc)	middle Permian	Dasycladacean algae, bivalves, gastropods, scaphopods, and fusulinid foraminifera	Shore to back-reef
Queen Formation (Pq)	middle Permian	Dasycladacean algae, bryozoans, bivalves, gastropods, scaphopods, crinoids, echinoids, and fusulinid foraminifera	Shore to back-reef

Shore to Back-Reef Formations (oldest to youngest)

Queen Formation (Pq)

The Queen Formation is exposed in the far west-northwest wilderness section of CAVE (Graham 2007). Only thin layers on the tops of plateaus are exposed within CAVE's boundaries. Lechuguilla Cave is the only cave to intersect part of the Queen Formation within the park (DuChene 2000).

The Queen Formation is comprised of a very pale orange to yellowish-gray fine-grained laminated dolomite mostly in beds 0.1 to 1.2 m (0.3 to 4 ft) thick interbedded with very pale orange silty dolomite, calcareous quartz siltstone, and very fine-grained sandstone in beds 0.1 to 0.9 m (0.3 to 3 ft) thick (Hayes and Koogler 1958; Hayes 1964). The sandstone is largely confined to the basal part and siltstone is predominant in the upper 30 m (100 ft) (the Shattuck Member). Outside of CAVE, the outer (paleo-landward) portions of the formation include evaporite facies, similar to the Seven Rivers, Yates, and Tansill formations (Graham 2007). Within this formation there are ripple marks, cross-bedding, and channel cuts in many beds. Exposures are typically not very thick in CAVE, but the thickness at the type locality on U.S. Forest Service land west of CAVE is 128 m (421 ft) (Graham 2007). The Shattuck Member is unstable and readily erodes, but the rest of the unit is more resistant.

Common fossils in the back-reef facies include algae, bryozoans, bivalves, gastropods, scaphopods, crinoids, echinoids, and foraminifera (Hayes and Koogler 1958; Graham 2007). Fossils are rare in the evaporite facies, and these facies/fossils are not found within CAVE's boundaries.

Seven Rivers Formation (Pse and Psc)

Outcrops of the Seven Rivers Formation are found in CAVE's northwest wilderness land, and the unit is also exposed in several park caves including Lechuguilla Cave.

The Seven Rivers Formation consists of several different facies, and is a classic example of carbonate to evaporite facies change in a nearshore environment. The evaporite facies are not exposed at the surface within CAVE, though there is a prominent exposure about 5 km (3 mi) north of the park's central-north boundary (Graham 2007). The evaporite facies include white gypsum with associated light olive gray to pale-red aphanitic dolomite and pale reddish-brown siltstone (Hayes 1957, 1964; Hayes and Koogler 1958; Sarg 1981). This portion of the formation is 110 to 200 m (335 to 600 ft) thick. The back-reef carbonate facies are formed of yellowish-gray fine-grained laminated rarely pisolitic dolomite mostly in beds 0.3 to 0.9 m (1 to 3 ft) thick with rare thin beds of very pale orange quartz siltstone (Hayes 1964; Graham 2007). The dolomite of both facies is highly resistant and forms a caprock for the more easily eroded underlying Queen Formation.

Fossils found within the formation include algae, bivalves, gastropods, scaphopods, and fusulinid foraminifera near the reef; fossils are rare in the evaporite facies (Graham 2007).

Yates Formation (Pya)

The Yates Formation crops out in canyons throughout CAVE. It is also exposed in some park caves, most notably along the Main Corridor trail in Carlsbad Cavern: below Bat Cave (where it is in

contact with the Tansill Formation) and above Iceberg Rock (where it is in contact with the Capitan Limestone) (Graham 2007).

Yates strata consist of very pale orange to yellowish-gray fine-grained laminated commonly pisolitic dolomite, mostly in beds 0.1 to 0.6 m (0.3 to 2 ft) thick, alternating with grayish-orange to pale yellowish orange calcareous quartz siltstone or very fine-grained sandstone (Hayes 1957, 1964; Graham 2007). Yates Formation beds range from 2.5 cm (1 in) to 1+ m (3+ ft) thick. The formation is 82 m (270 ft) thick in North Slaughter Canyon to 125 m (375 ft) thick closer to the Capitan Limestone. This unit's clastic siltstone and sandstone beds erode to form slopes that alternate with ledges of more resistant dolomite (Graham 2007).

The fossil assemblage in the Yates is comprised of bivalves, gastropods, scaphopods, fusulinid foraminifera, and other organisms adapted to living in a sandy and shifting back-reef substrate. Fossils are more common near the reef; shallow landward depositional environments rarely have fossils.

Tansill Formation (Pt)

The Tansill Formation is exposed on ridgetops in CAVE along the south edges of the reef escarpment. The visitor center is built directly on top of this formation. The Natural Entrance and Bat Cave sections of Carlsbad Cavern are within this unit (Graham 2007).

The Tansill Formation is composed of light olive gray to very pale orange fine-grained laminated occasionally pisolitic dolomite, mostly in beds 0.2 to 1.5 m (0.5 to 5 ft) thick, and rare thin beds of very pale orange very fine-grained quartz sandstone or siltstone (Hayes 1964). It is at least 90 m (300 ft) thick near the mouth of Slaughter Canyon, but is normally between 30 to 46 m (100 and 150 ft) thick elsewhere (Hayes 1957; Hayes and Koogler 1958; Graham 2007). The Tansill Formation erodes slowly and forms a resistant caprock above the Yates Formation and Capitan Limestone reef.

Common fossils include algae, gastropods, crinoids, and fusulinids (Newell et al. 1953); fossils tend to be present in greater abundance nearer to the contact with the Capitan Reef (Hayes 1964). Back-reef structural geologic features and associated sedimentary structures (e.g., mudcracks, lagoonal deposits, and “teepee” structures) are excellently preserved in the Tansill Formation (Hayes 1964; Graham 2007).

Reef Formations

Goat Seep Dolomite (Pgs)

This unit is not exposed at the surface at CAVE. The nearest surface exposures are in the Guadalupe Mountains to the southwest. There is a possibility that the North Rift or a large room in the Far East of Lechuguilla Cave (above the Lake of the White Roses) may intersect the Goat Seep Dolomite (H. DuChene, pers. comm., 2019). However, DuChene's (2000) investigation of Lechuguilla Cave's mineralogy and lithology did not discover any rocks matching the Hayes (1964) description of the Goat Seep Dolomite. Fusulinids of possible Goat Seep age were discovered in breakdown, but were too eroded to positively identify (H. DuChene, pers. comm., 2019).

The nearest surface exposure to CAVE is found on U.S. Forest Service land to the west, and is a highly resistant, thick-bedded to massive, finely crystalline to saccharoidal, cream to light-gray dolomite (Hayes 1964; Graham 2007). It underlies the Capitan Limestone and represents an ancestral reef to the Capitan (Newell et al. 1953). Sponges, corals, bryozoans, brachiopods, bivalves, crinoids, and other echinoderms are common in the unit; gastropods and ammonoids are rare.

Capitan Limestone (Massive Member) (Pcm)

The Capitan Limestone is extensively cavernous, and many of the largest caves within CAVE intersect it (Graham 2007). This includes the lower parts of the Main Corridor, the scenic rooms, the Big Room, Lower Cave, and Left-Hand Tunnel in Carlsbad Caverns and the majority of Lechuguilla Cave. At the surface the Massive Member of the Capitan Limestone is exposed in a thin band along the southern escarpment in the eastern half of the park; in the western half of the park more extensive exposures are revealed along the bottoms of canyons, especially West Slaughter Canyon (Graham 2007).

This unit represents the main fixed reef associated with the back-reef Seven Rivers, Yates, and Tansill formations (Hayes 1964; Hill 1996). The Capitan Limestone's Massive Member is formed of very light gray to light olive gray limestone formed from the remains of reef-building organisms and carbonate cement, and may contain irregularly branching dikes of grayish-orange calcareous quartz siltstone (Hayes 1964). It is 250 to 335 m (750 to 1,000 ft) thick and is a highly resistant cliff forming unit above ground (Hayes 1957; Hayes and Koogler 1958). Massive blocks of gypsum exist within the caverns of this unit, remnants of its unusual form of speleogenesis by sulfuric acid (Graham 2007). Some regions of Lechuguilla Cave have elemental sulfur deposits. Well-developed speleothems are common throughout the cavernous portions of the unit (Graham 2007).

The unit is extensively fractured in addition to being cavernous, but is otherwise highly resistant to the flow of water because of its extensive lithification; thus, groundwater flow largely follows the fracture zones. The caves themselves, however, are relatively dry at this time and very few have underground streams. Water is found mostly in perched pools, although the lowest points in Lechuguilla Cave reach the water table (Turin and Plummer 2000).

Reef framework species include: calcareous sponges (*Guadalupia*, *Amblysiphonella*, *Cystauletes*, *Cystothalamia*); *Tubiphytes*; algae (phylloid or encrusting blue-green algae and red *Solenopora*); and bryozoans (Newell et al. 1953; Wood et al. 1994; Weidlich and Fagerstrom 1998). The primary reef formers vary geospatially (Graham 2007), and there are rare patches of reef or bioherms primarily formed by strophalosiidine brachiopods (Senowbari-Daryan and Rigby 1996a). Other fossil organisms found in the reefs/bioherms include: corals; brachiopods; bivalves; ammonoids and other cephalopods; trilobites, crinoids and other echinoderms; and fusulinids (Newell et al. 1953; Weidlich and Fagerstrom 1998; Graham 2007). This is the most expansive Permian-aged fossil reef on record and preserves a large diversity of fossil organisms (Graham 2007). Pleistocene/Holocene vertebrate fossils are also found within the caves of this unit as well as those within the Tansill and Yates formation, representing animals that died in the caves after they opened more than 500,000 years ago (Polyak et al. 2006; Morgan and Harris 2015). These remains are commonly buried within bat guano or flowstone. The most common vertebrates are bats, including extinct species, extant species still

found roosting at CAVE today, extant species that no longer live in the region, and extant species not known to roost in caves. Slaughter Canyon Cave preserves thousands of specimens of Constantine's Free Tailed Bat (Morgan 2003a, 2003b), which have turned to apatite and so are likely more than half a million years old (Polyak et al. 2006; Lundberg and McFarlane 2006). Other vertebrates found within the caves include: an extinct vulture; Shasta ground sloth; shrew; marmot; ring-tailed cat; large felids; dire wolf; horse; shrub oxen; pronghorn; and mountain goat (Morgan and Harris 2015).

Fore-Reef Formations

Capitan Limestone (Reef Talus Member) (Pcb)

This unit is exposed at the surface along the escarpment that runs southwest to northwest through CAVE. It is also found in some park caves, most notably down the left fork of Left-Hand Tunnel and near the Jumping Off Point in Lower Cave, both within Carlsbad Cavern, and in the Western Borehole of Lechuguilla Cave (Graham 2007).

A foreslope facies, it is comprised of very light gray to light olive gray fine-to very coarse-grained limestone breccia with rare to common clasts of back-reef sandstone, pisolitic limestone and carbonate sandstone with indistinct to distinct bedding planes inclined 20 to 30 degrees to the southeast (Hayes 1964). It is 250 to 335 m (750 to 1,000 ft) thick and is a highly erosion resistant cliff former (Graham 2007). As the Reef Talus Member represents excess reef material that was pushed/slid into the basin, any fossils found within the Massive Member can be found here as well.

Basin Formations

Castile Formation (Pcs)

The Castile Formation is mapped along the southeastern boundary of CAVE (Graham 2007), and very limited surface exposures may be found at the base of the southeastern escarpment, especially around Rattlesnake Canyon. However, Graham (2007:26) also reports in a table that there are no exposures on CAVE lands.

The Castile Formation's composition varies geospatially. It is primarily white massive gypsum to the east (particularly in the Carlsbad Caverns East 15' Quadrangle outside CAVE) with some interlaminated white gypsum and dark-gray limestone in the lower part (Hayes 1957, 1964). At the southwest corner of this quadrangle it is comprised of thinly laminated light-to dark-gray granular limestone. It alternates very thin laminae of dark-gray limestone and gypsum in the southeast corner of the Carlsbad Caverns West 15' Quadrangle (Hayes and Koogler 1958; Hayes 1964; Graham 2007). It is a massive white gypsum near the mouth of Rattlesnake Canyon (Graham 2007). The Castile formation may include residual gypsum and clastics of the Salado and Rustler formation in the upper 46 m (150 ft).

The Castile Formation is not fossiliferous (Hayes 1964; Graham 2007).

Quaternary Sediments

Gravel (Qg)

Quaternary gravel is mapped at the base of the reef escarpment and stretching across an alluvial plain south of the escarpment, as well as in the bottoms of canyons and at Rattlesnake Springs. The gravel

covers the Castile Formation in most places where this formation would otherwise have been exposed within CAVE, especially north and west of the Black River (Graham 2007).

The gravel is composed of poorly sorted uncemented limestone pebbles and cobbles from the Permian bedrock formations, with associated silt and clay. Caliche or travertine cementing is locally present. The thickness of the gravel deposits reaches 90 m (300 ft) or more in some places, though thickness is highly variable. These deposits erode very easily (Graham 2007).

Alluvium (Qal)

Alluvium is mapped along the banks and valley of the Black River, which flows near Rattlesnake Springs. It is primarily composed of gypsiferous and calcareous sand and silt. The alluvium is minimally resistant to erosion (Graham 2007).

Other Formations

Though not exposed at CAVE's surface or within its caves, the following formations are present in the subsurface, or are present at the surface near CAVE, listed from oldest to youngest:

- Yeso Formation (lower Permian)
- San Andres Limestone (lower–middle Permian)
- Cherry Canyon Formation (middle Permian)
- Grayburg Formation (middle Permian)
- Bell Canyon Formation (middle Permian)
- Salado Formation (middle Permian)
- Rustler Formation (middle Permian)

Taxonomy

See Appendix Table A-1-a through c for a list of Permian fossil taxa from CAVE, or units analogous to CAVE. See Appendix Table A-2 for a list of Pleistocene/Holocene fossil taxa from CAVE.

Plants

In the Permian back-reef facies, especially near the reef margin, the dasyclad green algae genus *Mizzia*, analogous to the extant algae *Cymopolia*, is very abundant and sometimes forms monospecific assemblages (Kirkland George 1992). Three species of *Mizzia* are reported from CAVE (Johnson 1942).

Fossil plant remains from the Quaternary are rare at CAVE, and as a result the Pleistocene flora of the region is usually reconstructed based on the hypothesized environments inhabited by the fossil fauna. However, a palynological study of Lechuguilla Cave, using pollen trapped in guano deposits, was undertaken by Patricia Jablonsky (1994). The study found only pollen of xeric adapted taxa extant in the park today, such as Apiaceae, Cyperaceae, and *Typha*, or pollen from plants such as *Pinus* that disperse widely on the wind. It was later discovered that the deposits which produced the pollen had undergone sediment mixing and were likely of Holocene instead of Pleistocene age, suggesting that the pollen recovered is likewise from the Holocene (Jablonsky 1994, 2004?). Macroremains of xeric-adapted *Celtis* and *Opuntia* were found in Muskox Cave (Logan 1981), but these are again assumed to date to the recent Holocene, especially given that the Pleistocene faunal assemblage from Muskox Cave suggests a boreal or mesic environment (Logan 1979). Only a single packrat midden is reported from within the protection of a karst feature at CAVE, and it is not of sufficient size, age, or stability for paleobotanical/paleoecological analysis (Julio Betancourt, USGS emeritus, pers. comm., November 2019).

Invertebrates

All invertebrates currently confirmed from within CAVE are Permian taxa; however, some Pleistocene and Holocene gastropods have been reported from caves near the park in analogous environments (Metcalf 1977). 209 invertebrate fossil taxa have been confirmed from within the boundaries of CAVE. A general summary follows; more detail on each taxonomic group can be found in the CAVE Permian Paleontology section of this report, and Appendix Tables A-1-a through A-1-c list Permian taxa. Permian fossil taxa vary in the different facies of the Capitan reef complex, though some taxa can be found throughout most units of the park.

The important macro-reef-building organisms are primarily sponges, larger bryozoans, and sometimes specialized coral-imitating brachiopods (Wood 1999); colonial corals were rare and did not play a significant ecological role in the Capitan Reef (Newell et al. 1953; Graham 2007). The sponges can be divided between large, platy species, such as *Gigantospongia discoforma* (the largest Permian sponge) and several species of the genus *Guadalupia*, and smaller taxa such as the notably abundant *Discosiphonella mammosa* (Wood et al. 1994; Rigby et al. 1998). It is currently hypothesized that the larger sponges created sheltered cryptobiotas consisting of the smaller sponges, bryozoans, and other organisms, either by growing progradationally over the fissured slope into the

basin or by falling over (Wood et al. 1994). This is because clusters of these diverse smaller organisms are often found in cavity fills associated with the larger fossil sponges.

Brachiopods are a relatively well-studied group at CAVE, currently the most diverse in terms of number of families, genera, and species. Currently a minimum of 78 species corresponding to 32 families are reported from within CAVE or units at GUMO analogous to those at CAVE (Newell et al. 1953; Cooper and Grant 1976; Senowbari-Daryan and Rigby 1996a). Brachiopods can be found in the reef and reef talus facies of the Capitan Limestone as well as the back-reef facies of the Seven Rivers, Yates, and Tansill formations, though the species present differ. Some bioherms just outside the park consist primarily of coral-imitating richthofenioid brachiopods (Senowbari-Daryan and Rigby 1996a), and it is likely that similar brachiopod bioherm patches exist within CAVE as well.

There is a diverse assemblage of mollusks in all facies at CAVE, with bivalves and gastropods being among the most common organisms found in the back-reef facies after fusulinid foraminifera. Having received comparatively less study than Porifera or Brachiopoda at CAVE, it is highly likely that most of the gastropod taxa at CAVE have yet to be identified, especially given that Girty (1908) and Newell et al. (1953) mostly focused on larger taxa. Fossils of nautiloid and ammonoid cephalopods can be found in both the reef and back-reef facies, and are among the most recognizable fossils present at CAVE.

Two species of trilobite have been reported from the park, but only one, *Anisopyge perannulata*, has been identified (Brezinski 1992; Santucci et al. 2001). The trilobites are found exclusively within the Capitan Limestone, and are present in small numbers at six localities within the park.

Vertebrates

All vertebrates currently confirmed from within CAVE are Pleistocene/Holocene taxa; however, Permian vertebrate taxa have been found elsewhere in the Guadalupe Mountains (Ivanov et al. 2015). Ninety-five vertebrate fossil taxa have been confirmed from within the boundaries of CAVE (see Appendix Table A-2). A brief summary of these taxa follows. More information about Quaternary vertebrate taxa, age dating, and paleoecology is located within the Pleistocene/Holocene Paleontology section of this report. Quaternary vertebrates reported from CAVE include tortoises, lizards, snakes, birds, sloths, shrews, rodents, chiropterans, carnivorans, perissodactyls, and artiodactyls.

The vertebrate assemblage at CAVE documents a changing climate and environment from the late Pleistocene into the Holocene, in which the environment became increasingly arid. Pleistocene deposits contain a large number of boreal, hydrosere, or mesic species. By contrast, Holocene deposits contain more xeric-adapted taxa, and taxa commonly present in the region today.

One notable Pleistocene taxon from CAVE is the Shasta ground sloth, *Nothrotheriops shastensis*. Several specimens of the sloth have been found within Carlsbad Cavern (Hill and Gillette 1987a) and Lechuguilla Cave (Jablonsky 2004?). The specimens recovered are mostly juveniles. Uranium-series age dating on the Carlsbad Cavern specimen revealed it to be about 111,900 years old, indicating the cave was open to the surface at that point in time and greatly increasing the assumed temporal scale

of Pleistocene fossils at the park (previously, most specimens were assumed to be younger than 20,000 years old). Pleistocene bat remains in Slaughter Canyon Cave, belonging to the species *Tadarida constantinei* (the holotype is from the park, and is housed at the Museum of Comparative Zoology at Harvard University), number in the hundreds of thousands of bones and are likely more than half a million years old (Polyak et al. 2006) (Figure 9).



Figure 9. A bat has become incorporated into the tip of this speleothem (NPS).

Carnivorans are somewhat over-represented in the CAVE Quaternary fossil record; 16 species of carnivorans, or their dens/traces, are reported from CAVE in 15 of the 49 localities containing Pleistocene/Holocene fossils. This is possibly owed to the nature of several caves as natural traps, which can also serve as predator traps. The utility of caves as dens or shelters is another possible contributing factor.

Twenty-four rodent species are reported from CAVE, belonging to the families Cricetidae, Erethizontidae, Geomyidae, Heteromyidae, and Sciuridae. Several of these are important biostratigraphic or paleoecological indicators. There are a number of caves with unidentified rodent remains that may correspond to additional species, or where the rodent fossils could help relatively date the fossil deposits within those caves.

Avian fossils have been recovered from several localities at CAVE, but currently most of the avian assemblage is not identified (G. Morgan, pers. obs., December 2019). The only birds identified to species at CAVE are the turkey vulture, *Cathartes aura*, and a Pleistocene black vulture, *Coragyps occidentalis*. A large amount of avian material currently resides, unprepared, at the Smithsonian Institution (G. Morgan, pers. obs., December 2019). Likewise, the herpetological assemblage at CAVE has not been well explored. Only the taxa *Phrynosoma* sp. (horned lizard), *Crotalus* sp. (rattlesnake), and *Gopherus morafkai* (Sonoran Desert tortoise) have been identified to genus or species at CAVE (Morgan and Lucas 2006; NPS Records 2019). The actual assemblage is likely much more diverse, and should be inventoried and studied at some point (G. Morgan, pers. obs., December 2019).

Ichnofossils

Ichnofossils, or trace fossils, are preserved behavioral traces of past organisms, as opposed to preserved portions of their bodies. Ichnofossils include fossilized tracks, feeding traces, burrows, dens, and dung (guano or coprolites), among others. Currently, all ichnofossils observed within CAVE date to the Pleistocene/Holocene except for a single example, and none of these have been identified taxonomically (ichnofossils have their own taxonomy separate from the organisms that created them, as often the organism that made a particular ichnofossil is unknown). The single instance of Permian ichnofossils are worm burrows reported from C-24. This does not mean that Permian ichnofossils do not exist elsewhere within CAVE, only that they have not been reported; further investigation of the back-reef facies is advised in any future searches for Permian ichnofossils.

The most common ichnofossil found at CAVE is bat guano. Fourteen caves had bat guano reported from them (see Appendix D for details), but this is likely not a comprehensive list; further field work and surveys are needed. In some caves, such as Carlsbad Cavern or Slaughter Canyon Cave, guano deposits can be locally several meters thick (Morgan 2002). Bones of small organisms, particularly of the species that produced the guano, are common within guano deposits. For example, the guano deposits in Slaughter Canyon Cave contains hundreds of thousands of bones belonging to the Pleistocene bat *Tadarida constantinei*.

Scratch marks on cave walls and ceilings made by roosting bats are also common in many caves, especially those also containing guano deposits or bat bones (NPS Records 2019). There are areas of polished floor in C-29, and floors with larger claw marks in C-22, that may indicate habitual travel through the twilight zone of the cave by large animals (these are not caves routinely traveled by humans). There is an old rodent nest in C-108, and a small woodrat perch/midden in KF-39 (NPS Records 2019). The latter is subject to occasional hydration and flow, which along with its small size make it unsuitable for dating or paleoecological analysis of its contents (J. Betancourt, pers. comm., November 2019). The midden in KF-39 (Figure 10) is the only one presently confirmed in the subsurface within CAVE, but its presence may indicate the possibility of other, more substantial middens elsewhere within the park.

Other Fossils

In the Capitan Limestone the most prevalent and important fossils belong to the red algae *Archaeolithoporella* and the problematic organism *Tubiphytes*. Together with small bryozoans and a number of other microorganisms, these taxa formed the micro-framework of the reef that covered between 57% and 95% of its areal extent (Weidlich and Fagerstrom 1998). Fossils for these organisms are small, blotchy, and difficult for non-experts to identify, but quite abundant. Fusulinid foraminifera fossils can be found throughout all units of CAVE, some even within the otherwise non-fossiliferous evaporite facies (Graham 2007). These forams are index taxa critical to biostratigraphy within the park.



Figure 10. Woodrat perch/midden in KF-39. This amberrat would not be useful for study or dating, because it is small and has periodically hydrated and flowed. However, it indicates that there is potential for packrat middens in caves at CAVE (NPS).

Paleontology

Permian Paleontology

General Nature of CAVE Permian Paleontological Resources

Permian fossils are exposed within the rock throughout both the surface and the caves. The fossils are most abundant within the Capitan Limestone, both at the surface and in the caves, but the back-reef facies of the Seven Rivers, Yates, and Tansill formations are also fossiliferous, as is the contact zone between these formations and the Capitan (Graham 2007). There are even rare, isolated fossils within the evaporite facies of the Yates and Tansill formations, though these are quite sparse, small, and may be difficult to identify in the field.

The assemblages within each facies (reef complex, reef-back-reef contact, back-reef, evaporite) are distinct from one another, indicating differing communities likely shaped by environmental conditions (Newell et al. 1953; Kirkland George 1992; Graham 2007). The Capitan Limestone's reef complex has the greatest diversity, with a major decrease immediately landward in the contact zone often dominated by the dasyclad algae *Mizzia* (Kirkland George 1992). This is followed by a slower continual decrease in diversity progressively landward, until in the evaporite facies only a few fusulinids and algae can be found with any regularity (Hayes 1957, 1964).

Permian Paleoecology at CAVE

The Reef

The ecosystems of the Delaware Basin changed over time along with the topography, both shaping one another as biogenic carbonate deposition caused the shelf to prograde into the basin (Weidlich and Fagerstrom 1998; Kerans and Kempter 2002; Graham 2007). By the time the Capitan Limestone was deposited, the topography was a reef-rimmed shelf hosting a mesophotic reef on the leading edge of the shelf slope, approximately 45–50 m (150–160 ft) below sea level. This reef complex was not similar to a modern barrier reef, as it did not extend into the surf zone and sunlight-dependent colonial corals were not common. Rather, the primary reef building fauna were broad platy sponges and colonies of bryozoans bound together by encrusting calcareous algae and carbonate cement at the surface (Weidlich and Fagerstrom 1998; Wood 1999). In addition to these major reef-builders, many cryptic taxa likely lived in a pendant manner within the extensive fissures within the slope face protected by larger sheet-like inozoan sponges (Wood et al. 1994; Weidlich and Fagerstrom 1998). The reef complex was also home to many other organisms in smaller numbers, such as corals, brachiopods, gastropods, cephalopods, echinoderms, and foraminifera (especially fusulinids) (Wood 1999). Outside of the park there are a small number of Permian vertebrates reported from the Guadalupe Mountains (Ivanov et al. 2015), but no vertebrate fossils of this age have been reported from CAVE (Newell et al. 1953; NPS Records 2019). In some regions, other organisms replaced sponges and/or bryozoans as the chief macro-reefbuilders, the most common being mounds of richthofenioid brachiopods (Senowbari-Daryan and Rigby 1996a). Fusulinids are found throughout the reef complex, and have a high rate of species turnover, allowing them to be used as index taxa (Newell et al. 1953; Tyrrell 1969; Senowbari-Daryan and Rigby 1996a).

The geometry of the reef's surface was likely highly progradational and vertically oriented given the stratigraphic profile of the rock units and the hypothesized location of the reef complex on the basin slope (Weidlich and Fagerstrom 1998; Kerans and Kempter 2002). Some models suggest that, by the time of the upper Massive Capitan at CAVE, aggradation may have exceeded progradation, but there was still a major progradational component to reef and shelf growth (Weidlich and Fagerstrom 1998). This may have had an effect on the nature of the species present and their relationships as compared to a reef located upon a horizontally planar surface. Possible examples include facilitating the horizontal growth pattern of sponges such as *Gigantospongia discoforma* and *Guadalupia* sp. along with their associated cavity cryptobiotas (Wood et al. 1994; Wood 1999). Much of the carbonate deposition on the reef was not derived from macro-reefbuilders like sponges, solitary corals, and brachiopods, but rather from the encrusting phylloid algae and the problematic organism *Tubiphytes*; 57–95% of the areal cover of the reef consisted of this micro-framework (Weidlich and Fagerstrom 1998). Components of the micro-framework include: *Archaeolithoporella hidensis*, *Tubiphytes* sp., ramose and fenestrate bryozoans, tiny sponges, microbes (indicated by the carbonates they produced), and skeletal debris (Weidlich and Fagerstrom 1998). The relatively small amount of areal cover occupied by macro-reefbuilders was a contributing factor to longstanding debate over whether the Capitan Limestone was a reef, a number of patch reefs, a series of bioherms, etc. Fagerstrom and Weidlich (1999) state that the reef complex was of relatively low diversity for its size, and was likely a single poorly differentiated metazoan community.

Near the end of the Guadalupian the reef complex began disintegrating into patch reefs. First the more diverse sponge and *Archaeolithoporella*/*Tubiphytes*/bryozoan assemblage saw a reduction in sponge diversity, with the large *Gigantospongia* making up the majority of the macro-framework. As the reef continued to fragment there was a stage dominated by *Archaeolithoporella* and *Tubiphytes* (upper Tansill), in which only these encrusting organisms and microbes constructed the reef-framework (Weidlich and Fagerstrom 1998). Still later (uppermost Tansill) the micro-framework progressed to being nearly entirely microbial; this is most evident outside the park in patch reef exposures near Carlsbad, New Mexico (Weidlich and Fagerstrom 1998). These changes in ecology may correspond to the reef shallowing out, and ultimately dying, as the Delaware Basin's connection to the open ocean was cut off (Hill 1996; Kerans and Kempter 2002; J. Hearst, pers. comm., December 2019). The record of this period, or the lead-up to it, recorded within CAVE's fossil assemblages may shed light on how the ecosystem initially responded to such stressors and its ultimate collapse. Given the possible role of climate change in the shallowing, aridification/salinization, and death of the reef (H. DuChene, pers. comm., November 2019), further research into identification of taxa and detailed paleoecology of the reef may be of great utility to conservation paleoecology (Dietl et al. 2015).

The Reef–Back-Reef Margin

Fossil assemblages in the contact zone between the Capitan Limestone and its associated shelf formations (Seven Rivers, Yates, and Tansill) change rapidly in terms of both taxa present and diversity. In the Tansill Formation, in a span of as little as 10 m (33 ft), the assemblage transitions from a diverse reef fauna to back-reef deposits so dominated by the dasyclad algae *Mizzia* that it is nearly monospecific (Kirkland George 1992). The presence of abundant *Mizzia* also indicates a

transition to shallower waters, as dasyclad algae are dependent on photic conditions that preserve a large amount of the red-light end of the visible spectrum. Such conditions are largely limited to 20 m (66 ft) below sea level (Kirkland George 1992). Modern dasyclad algae prefer sub-tropical to tropical climates, and plate tectonic reconstructions placing the Delaware Basin at about 7 degrees north in the late Permian (Graham 2007; H. DuChene, pers. comm., November 2019) support the hypothesis that *Mizzia* was analogous to its modern relatives in this manner.

Most *Mizzia*-dominated regions, both around the contact between the backshelf formation and the Massive Capitan and further shoreward, show little sign of disturbance by wave action. Breakage and abrasion of *Mizzia* fragments is low throughout the Tansill Formation localities studied by Kirkland George (1992), and some localities even contain articulated *Mizzia* fossils. Either the reef complex itself (Kirkland George 1992) or islands and sand bars at the shelf crest (Dunham 1972; Esteban and Pray 1983; Kerans and Kempton 2002) served as barriers to the open sea and served as wave breaks. This barrier to open circulation may have also resulted in the back-reef shelf being hypersaline; this would help explain the sudden loss of diversity and some modern dasyclads are known to be tolerant of extreme salinity (Kirkland George 1992).

The Back-Reef Shelf and Lagoons

This environment is represented by the back-reef facies of the Seven Rivers, Yates, and Tansill formations (Hayes 1964; Graham 2007). This area was low to moderate energy, sandy or silty bottomed, relatively horizontally planar, shallow, warm, and possibly hypersaline (Newell et al. 1953; Kirkland George 1992; Burger 2007; Graham 2007). It progresses from a shallow subtidal environment up to tidal flat, evaporite, and terrigenous redbed facies (Graham 2007). Large portions of it, especially nearer to the reef, are dominated by expansive patches of *Mizzia*, much like near the reef margin; some of these *Mizzia* patches are even found within the Queen Formation within the park (Kirkland George 1992). Despite the relatively low energy, the sediment at the bottom of the back-reef constantly shifted, as reflected by the relative abundance of mobile organisms in these units (outside of *Mizzia* zones) such as bivalves, ammonoids/nautiloids, and gastropods (including bellerophonitids) (Burger 2007; Graham 2007). Fusulinid assemblages found here are transitional between those found in the reef and those found closest to shore, such as in tidal flat facies (Newell et al. 1953; Tyrrell 1969; Senowbari-Daryan and Rigby 1996a; Graham 2007).

The Evaporite Facies

Fossils are very rare in the evaporite facies, and those that are present tend to be small to microscopic and difficult to identify (Hayes 1964; Graham 2007). Those found include some fusulinids, small mollusks, and microbial traces. Some clastic strata found in these facies are essentially non-fossiliferous (Graham 2007). However, because of the facies' low abundance of paleontological resources, those resources that are present within these facies have not received much study, usually being described only in geologic surveys or similar broad scale work. Because of the remote nature of their deposits, any study done on these resources would face severe logistical challenges.

Permian Paleontological Resource Data at CAVE

Only a limited amount of paleontological research has been undertaken into the Permian paleontological resources specifically at CAVE, especially that involving identification of fossil taxa

beyond the phylum or class level. Some older studies included localities from CAVE (Newell et al. 1953), but did not specify the generic- or specific-level taxa that came from CAVE's Capitan Limestone versus the Capitan Limestone in other regions of the Delaware basin such as GUMO. This is an important distinction, because the Capitan Limestone exposed at CAVE, especially at the surface where the most work has been done, is of the latest Capitan and is therefore younger than the deposits exposed throughout most of GUMO and potentially the Glass Mountains (J. Hearst, pers. comm., December 2019). The Capitan reef complex at CAVE represents the reef at its full maturity, just before it began to shallow out and die (Kerans and Kempter 2002; Hill 1996), and therefore may host a fossil assemblage representing a unique ecological community.

More recent studies have usually been undertaken in regard to specific taxa or sites (Kues and DuChene 1990; Kirkland George 1992; Rigby and Senowbari-Daryan 1996; DuChene 2000) or have touched on the broader paleoecology of the reef complex as a whole (Kirkland George 1992; Wood et al. 1994; Weidlich and Fagerstrom 1998; Wood 1999, 2001). Most notably, Kirkland George (1992) studied *Mizzia* dominated back-reef patches just within the boundaries of CAVE and Rigby et al. (1998) produced a large-scale inventory of sponge taxa at both CAVE and GUMO. Yochelson (1960), Cooper and Grant (1972, 1976, 1977), and Batten (1989) identified brachiopods, gastropods, and a monoplacophoran (a limpet-like mollusk) in museum samples originally collected from CAVE. With the exception of the Rigby et al. (1998) sponge study and possibly Cooper and Grant's (1976) work on brachiopods, no large-scale inventory of taxa at CAVE has been undertaken in the last 70–110 years, or ever, as even Newell et al. (1953) and Girty (1908) only used a few localities from the CAVE region and were more focused on localities within GUMO and the Glass Mountains. The specific contents of the subsurface regions intersected by caves are in particular need of study, as especially deep portions of the Massive Member of the Capitan may differ in faunal assemblage and paleoecological relationships compared to the younger exposures on the surface.

Internal NPS surveys of caves are not usually undertaken by paleontologists or paleontological technicians, and rarely identify any fossil taxa past the phylum or class level (NPS Records 2019). Furthermore, these surveys usually record Permian fossils in terms of presence/absence, and make no note of other qualities critical to resource management such as abundance, condition, and stability. Surveys of surface wilderness areas, and corresponding inventory and monitoring of surficial fossils, are even rarer (NPS Records 2019). Thus, there is a critical deficiency of the following information essential to resource management: identifications to the generic, and preferably specific, level (essential to paleoecological understanding, as well as value and associated risk assessment); a definite picture of paleoecology as specific to CAVE (essential to interpretation; current interpretation presents the system as a reef when that is not wholly accurate without qualification); and incomplete locality information, as CAVE has not historically tracked paleontological localities that do not coincide with caves, karst features, archeological sites, springs, etc. (essential for monitoring and law enforcement). Unlike Pleistocene/Holocene vertebrates, Permian taxa are present in nearly every cave and across much of the surface at CAVE while identification of these fossils to the generic level is sparse. Thus, an accounting of the Permian paleontological resources by individual cave is not possible at this time. Exceptions include a few standout specimens from

Carlsbad Cavern and Lechuguilla Cave, but these specimens will be addressed individually within the following taxonomy section for Permian invertebrates.

Because the record for CAVE itself is absent, incomplete, or mixed in with wider reports that include material from elsewhere in the Guadalupe Mountains, any specific identifications provided herein that are not explicitly denoted as originating from a CAVE locality should be regarded as suspect until proven otherwise. While the genera are likely shared between CAVE, GUMO, and possibly the Glass Mountains, assemblages may differ at the species level.

Permian Taxa Present at CAVE

The following briefly outlines the major groups of organisms found within the Permian fossil record at CAVE and some details specific to each that may be of interest to resource managers. Some notable species may be mentioned, but see Appendix Tables A-1-a, b, and c for the complete listing of Permian fossil taxa at CAVE.

Fossil Invertebrates

Phylum Porifera (sponges)

Sponges are sessile, basal, multicellular animals that filter feed by generating a unidirectional water flow into their porous bodies and then direct it through and out a central cavity, stripping bacteria or other sources of food from the water in the process. They are notable for not having true tissues or organs; though they do have cells that fulfill specific purposes, they are not arranged into distinct tissue layers and can transform between cell types. The soft bodies of sponges rarely preserve in the fossil record, but many taxa leave behind mineral spicules that supported jelly-like mesohyl “endoskeleton” in life. These spicules may possess shapes unique to a given taxon, aiding in identification. A few taxa instead possess calcareous exoskeletons, which fossilize relatively easily and preserve an outline of the sponges’ bodies.

Sponges are among the most common fossils present in the Capitan Limestone within CAVE, and were the primary macro-reefbuilders of the Capitan reef complex (Figure 11). The majority of sponge taxa within the park, and those most important to the Permian paleoecology, belong to the polyphyletic (Senowbari-Daryan and García-Bellido 2002) clade Sphinctozoa (chambered sponges) or the suborder Inozoida (Rigby et al. 1998). Within the park and in the greater Guadalupe Mountains, many sponge fossils have preserved the full body profile and some preserve finer details as well. The largest sponge genera present at CAVE, such as *Guadalupia* and *Gigantospongia*, are mushroom- and plate-shaped respectively, and are often found in close association with much smaller sponges, bryozoans, solitary corals, and other organisms (Rigby and Senowbari-Daryan 1996). *Gigantospongia discoforma* specifically is the largest known Permian sponge, being 2.5 m (8.2 ft) wide, though it is only 20 mm (0.8 in) thick (Rigby et al. 1998). The platy shapes have been hypothesized to mean that the large sponges grew horizontally from the reef-front and/or slope wall, providing space and shelter to the smaller organisms that lived in voids behind them, including the abundant sponge *Discosiphonella mammilosa* (Wood et al. 1994; Rigby et al. 1998). However, it is also possible that the large sponges grew tall and upright, making them unstable and prone to collapsing; the debris formed by toppled sponges would also create the cryptic habitats found alongside them in the fossil record (Rigby et al. 1998; Weidlich and Fagerstrom 1998).



Figure 11. Sponge fossils in Carlsbad Cavern. Scale bar with 1-cm-scale black and white squares (NPS/ROD HORROCKS).

Because of their key role as primary builders of the reef complex, sponges are one of the better studied and documented taxonomic groups at CAVE and in the Guadalupe Mountains at large. In addition to the broad studies of Girty (1908) and Newell et al. (1953), Rigby et al. (1998) inventoried and identified the calcareous members of Porifera found within GUMO and CAVE. Rigby et al. (1998) noted the presence of 34 poriferan species, which was considered low diversity compared to Permian deposits of a similar age in Tunisia and China. Some of the taxonomic evaluations in Rigby et al. (1998) have been altered by later work (Rigby and Bell 2006), and Rigby et al. (1998) did not include many still-valid taxa listed in Newell et al. (1953). The latter may imply that those missing taxa were exclusive to the Glass Mountains, which were accounted for in Newell et al. (1953) but not Rigby et al. (1998). The taxa list in Appendix Table A-1-b includes all sponge taxa present in CAVE-analogous units from both sources and a few others, as well as those explicitly found within CAVE's boundaries (Fagerstrom and Weidlich 1999).

Holotypes of two sponge species were collected from CAVE: *Preverticillites parva* and *Lemonea exaulifera*. Both holotypes, UNSM 34701 and UNSM 35215, currently reside in an external repository (the University of Nebraska State Museum, Lincoln, Nebraska). The holotype of *Gigantosporgia discoforma* was found at a locality just outside of the park, and is therefore not an

NPS specimen; it is repositied in the collections of the U.S. National Museum of Natural History, Smithsonian Institution (Rigby et al. 1998).

Phylum Cnidaria (jellyfish and corals)

Corals are relatively rare in the Capitan Limestone, and many of the taxa present are solitary corals. The only colonial coral reported from the area is *Cladochonus* sp., a parasitic tabulate coral that infested the stems of crinoids (Newell et al. 1953; Vinn 2017). The other two corals reported from the Capitan in Newell et al. (1953) are the solitary rugose corals *Lindstroemia cylindrica* and *Lophophyllidium* sp. All three taxa were isolated to the Capitan Reef within the Delaware Basin, and did not occur in the back-reef. Some of the solitary corals are hypothesized to have lived cryptobiotically in void spaces within fissures and behind large, platy sponges such as *Gigantospongia discoforma* (Wood et al. 1994; Rigby et al. 1998), given their spatial relation to such sponges at fossil localities within CAVE and elsewhere (Rigby and Senowbari-Daryan 1996). No fossil evidence of soft-bodied cnidarians is recorded from CAVE.

Phylum Bryozoa (moss animals)

Bryozoans are stationary, epifaunal, filter-feeding animals that live in colonies consisting of clones and are related to brachiopods. The individuals, called zooids, in these colonies behave akin to organs in other animals, and some bryozoan taxa even have specialist zooids that cannot feed themselves. Many types of bryozoans have mineralized skeletons, which aids in fossil preservation and contributes to aquatic carbonate deposition; it is these mineralized taxa that can be found at CAVE. Bryozoans were more diverse and dominant in Paleozoic ecosystems than they are today.

Bryozoans were important reef-building organisms in the Capitan reef complex (Weidlich and Fagerstrom 1998); erect species with larger colonies formed part of the macro-framework in a manner akin to modern soft-corals, whereas encrusting species helped bind the reef framework together. The micro-reef-building bryozoans cover a large portion of the Capitan Limestone's areal extent in some regions, in tandem with algae and *Tubiphytes*. No bryozoans from park localities have been explicitly identified except for *Acanthocladia* sp. (Rigby et al. 1998), though Newell et al. (1953) reported 12 species of bryozoans from the Capitan Limestone of the Guadalupe Mountains. Both fenestrate and ramose bryozoans are present in the Capitan Limestone (Weidlich and Fagerstrom 1998). A full account of bryozoan taxa can be found in Appendix Table A-1-b.

Phylum Brachiopoda (lamp shells)

Brachiopods are a group of filter-feeding animals that have a two-valved shell which is hinged in the rear; their filtering feeding apparatus (lophophore) is a ring of ciliated tentacles around the mouth, a feature shared with bryozoans and several other groups (Figure 12). Although similar in some ways to bivalve mollusk valves, brachiopod valves correspond to the dorsal and ventral sides of the animal rather than the left and right sides, and brachiopod valves are asymmetric in relation to one another, but individually bilaterally symmetric (the opposite is usually true of bivalves). Brachiopods are still extant today, but were much more abundant and diverse in the Paleozoic.



Figure 12. Brachiopod fossils in Lechuguilla Cave. The central brachiopod includes a well preserved lophophore (the structure resembling a pair of wings) (NPS).

Brachiopods are common fossils in both the reef and back-reef facies at CAVE, in varying quality of preservation. Specimens exposed within caves tend to have at least one valve well preserved, but specimens located at the surface can also be of high quality. Because they are relatively easy to recognize as fossils, brachiopods are somewhat more vulnerable to vandalism or theft, though not as much as cephalopods or some gastropods. Exposed clusters of brachiopods along the trail to Slaughter Canyon Cave sometimes show chip marks roughly large and deep enough to have held one or more brachiopods.

Size and morphology among brachiopods is highly variable, though in terms of ecology all present at CAVE were low- to medium-level epifaunal suspension feeders. CAVE brachiopods are diverse, with a minimum of 78 species belonging to 32 families reported from within the park or units at GUMO analogous to those at CAVE (Newell et al. 1953; Cooper and Grant 1976; Senowbari-Daryan and Rigby 1996a). No comprehensive inventory of taxa has been conducted within or involving CAVE since Newell et al. (1953), though Cooper and Grant (1976) inventoried and identified material collected previously. Identification of species exposed within caves is especially lacking, as Newell et al. (1953) restricted their work at CAVE to surface deposits and Cooper and Grant (1976) referenced only a single subsurface locality with two species from Carlsbad Cavern. Newell et al.

(1953) also did not include the brachiopod taxa found with the Seven Rivers, Yates, and Tansill formations, and there are a number of back-reef exposures that include brachiopods.

One group of brachiopods not yet found within CAVE but potentially present, the superfamily Richthofenioidea, mimicked corals and/or reef-building sponges. Conical in shape and tapering down to a pointed pedicle valve that adhered to the substrate, these brachiopods superficially resemble horn corals and are usually found together in large numbers. Entire bioherms predominantly constructed of richthofenioids are present in uppermost Tansill Formation deposits outside the park boundary (Senowbari-Daryan and Rigby 1996a). While no richthofenioid specimens have yet been identified from within CAVE, the taxa most likely to be present are *Cyclacantharia* sp., *Sestropoma cribriferum* (Senowbari-Daryan and Rigby 1996a), and *Prorichthofenia* spp. (Newell et al. 1953).

The holotype of one brachiopod species was collected from CAVE: *Plectelasma planidorsatum* (Cooper and Grant 1976). This holotype resides in external repository at the U.S. National Museum of Natural History, Smithsonian Institution, as specimen USNM 153357.

Phylum Mollusca: Class Bivalvia (clams, oysters, etc.)

Bivalves are shelled mollusks with several key defining features, such as a two-valved shell, no head, and being the only group of mollusks to universally lack the food-processing radula organ. Nearly all bivalves are suspension feeders, but vary in whether they are infaunal or epifaunal and sessile or mobile. Bivalves are critical components of modern ecosystems, but played a more minor role during the Paleozoic. Despite this, Bivalvia is one of the better documented groups in the Delaware Basin stratigraphic units analogous to CAVE; Newell et al. (1953) identified 24 species of bivalves from at least 12 families. Bivalves lived in both the back-reef facies and the reef itself, and both infaunal and epifaunal taxa are present (Newell et al. 1953). No inventory of bivalve taxa has occurred at CAVE since. Bivalves are reported from within many caves, especially those formed with the Yates and Tansill formations (NPS Records 2019), and some specimens are exposed in the Yates Formation within Carlsbad Cavern (Burger 2007). A complete listing of Capitan and Capitan-equivalent bivalve taxa from Newell et al. (1953) can be found in Appendix Table A-1-b.

Phylum Mollusca: Class Cephalopoda (octopuses, squids, nautiloids, etc.)

Cephalopods are a class of mollusks that includes extant taxa such as octopus and squid. Extinct cephalopods (and one living family, the Nautilidae) often had calcareous shells, which fossilize more readily than soft body parts. Most cephalopods are agile nektonic (free swimming) predators and/or scavengers, and their mobility means they can be found in many different types of depositional environments. For example, at CAVE, cephalopod fossils have been found from the shallow subtidal zone of the back-reef facies, in the back-reef to reef margin zone, the main reef, and the talus slope below the reef.

Three species of nautiloid (*Foordiceras* sp., *Metacoceras shumardianum*, and *Orthoceras* sp.) and one species of ammonoid (*Mexicoceras guadalupense*, now under *Waagenoceras*) were identified from the Capitan Limestone of the Guadalupe Mountains by Newell et al. (1953), but these specimens did not come from CAVE localities. Cooper and Grant (1972) noted a second ammonite species, *Strigogoniatites fountaini*, from USNM locality 740n. Known specimens currently exposed

at CAVE, aside from the aforementioned *Strigogoniatites*, do not seem to have been identified to family, genus, or species (NPS Records 2019) (Figure 13). A straight shelled cephalopod, likely a nautiloid, has been reported from Lechuguilla Cave, and is still in situ there (H. DuChene, pers. comm., November 2019; NPS Records 2019).



Figure 13. Coiled cephalopod fossil, probably a nautiloid, in Lechuguilla Cave. Gloved finger for scale (NPS).

Phylum Mollusca: Class Gastropoda (snails)

Gastropods are an incredibly diverse group of mollusks that are well represented in the fossil record due to their ubiquity, wide variety of lifestyles and habitats, and the calcareous shells many taxa possess. Gastropods can be extremely variable in terms of anatomy and behavior, and few conclusions can be drawn from gastropod presence in the fossil record without identifying the specimens at least to family, if not to genus or species.

Gastropods can be found in both back-reef and reef facies at CAVE, though they have a higher relative abundance in the back-reef. Most of the gastropod species at CAVE are likely unidentified, as Newell et al. only recorded three genera as well as two families without identification to genera from the Capitan Limestone of the Delaware Basin. Yochelson (1960) identified an additional gastropod as well as a monoplacophoran (gastropod relative) from locality USNM 3364; Batten (1989) added a further seven species from this locality. Kues and DuChene (1990) later reported a specimen of *Bellerophon* sp. from Lechuguilla Cave that was at the time the largest Permian gastropod; Harvey DuChene (pers. comm., November 2019) claims to have later seen even larger specimens of this genus inside of Lechuguilla Cave (Figure 14). The gastropods that have been identified from CAVE include: *Zygopleura* aff. *rugosa*, the epifaunal *Naticopsis* sp., the sessile

epifaunal suspension feeder *Omphalotrochus* sp. (Newell et al. 1953), the epifaunal grazing species *Apachella glabra*, *Apachella nodosa*, *Apachella pseudostrigillata*, *Apachella translirata*, *Glabrocingulum* (*Stenozone*) *carlsbadensis*, and *Baylea huecoensis*, the epifaunal suspension feeder *Worthenia bialveozona* (Batten 1989), the carnivorous family Pleurotomariidae, the detritus-feeding order Bellerophontida (Newell et al. 1953), the slow-moving detritivore *Knightites* sp. (Yochelson 1960), and the large detritivore *Bellerophon* (Kues and DuChene 1990). Given the very high diversity of gastropods present in the Capitan Limestone and analogous back-reef units at GUMO (J. Hearst, pers. comm., December 2019), it is probable these make up only a small fraction of the overall gastropod assemblage at CAVE.



Figure 14. Bellerophontid gastropods in Lechuguilla Cave in cross section. These gastropods could grow to enormous sizes. Photo by Harvey DuChene(?).

The holotype of one gastropod species was collected from CAVE: *Glabrocingulum* (*Stenozone*) *carlsbadensis* (Batten 1989). This holotype resides in external repository at the U.S. National Museum of Natural History, Smithsonian Institution, as specimen USNM 431537.

Phylum Mollusca: Class Scaphopoda (tusk shells)

Scaphopods are an exclusively infaunal group of mollusks identifiable by their life-habit, elongate slightly curved tusk-like shells, and having their mantle entirely contained inside their shell. They prefer soft substrates that can be easily burrowed through.

Scaphopods are found within the back-reef facies of the Yates and Tansill formations within the park, and it is likely that they could be found within the Seven Rivers Formation too. Girty (1908) and Newell et al. (1953) reported two species of scaphopod from CAVE or analogous units at GUMO, both of the family Prodentaliidae: *Dentalium mexicanum* and *Plagioglypta canna*. Later research concluded that these were both synonyms of *Prodentalium canna* (Yancy 1978).

Phylum Arthropoda: Class Trilobita (trilobites)

Trilobites are an extinct class of three lobed arthropods that lived throughout the Paleozoic. They were diverse and abundant in the Cambrian and Ordovician, filling many different ecological roles. However, trilobites declined heavily after the Ordovician until only a single order, the Proetida, remained by the Carboniferous. This last order of trilobites died out during the End Permian Mass Extinction, about 8 million years after the end of the Capitan Reef.

Two species of trilobites have been found within CAVE: the benthic deposit feeder *Anisopyge perannulata* and an unidentified species (Santucci et al. 2001; Graham 2007; Norr et al. 2016). These trilobites have been observed within Carlsbad Cavern (NPS Records 2019), as well as surface deposits investigated by Newell et al. (1953) and the USNM localities 740n, 750, 750a, and 750b (Brezinski 1992). A prominent example of *Anisopyge* is located near the elevator (Santucci et al. 2001) (Figure 15). Specimens of *Anisopyge* sp. are very rare at CAVE, though this may be an artifact of only relatively well-preserved and complete specimens being positively identified (NPS Records 2019). The identity of the second trilobite species was not recorded in park records or publications (Santucci et al. 2001; NPS Records 2019). Another species of *Anisopyge*, *A. cooperi*, can be found in units within the Glass Mountains that may be analogous to those at CAVE (Brezinski 1992).

A second trilobite genus found in the Guadalupe Mountains is *Delaria* sp. (Brezinski 1992). No specimens of this taxon have been positively identified from CAVE, but they are present in some of the youngest Capitan units at GUMO that should be analogous to those at CAVE.



Figure 15. A tail segment of the trilobite *Anisopyge perannulata*, exposed in Carlsbad Cavern. There was once a metal nameplate pointing out this trilobite to visitors, but it has since been removed to keep the fossil inconspicuous. Scale bar tick marks are millimeters (NPS/ROD HORROCKS).

Phylum Echinodermata (sea stars, brittle stars, sea lilies, sea urchins, etc.)

In the Paleozoic, many of the groups of echinoderms which are abundant today were rarer and played only minor ecological roles. Inversely, crinoids, which are uncommon today, are one of the most common fossils in many Paleozoic deposits. However, in the middle Permian of North America crinoids had already become scarcer. While crinoid columnals and even a few preserved calyxes have been found within CAVE, they were not major reef-builders nor especially common within the Capitan Reef or the back-reef. Crinoid columnals can be found at several CAVE localities within the Capitan Limestone, such as at Slaughter Canyon Cave (Figure 16). Crinoids at CAVE have not been identified to genus or species.

Fossilized echinoid spines have been found within Lechuguilla Cave, and a presence/absence survey of every station within the cave reported echinoids (as well as other echinoderms) from several other localities too (NPS Records 2019) (Figure 17). These specimens do not appear to have been identified any further, if it is even possible to do so; secondary calcite coatings cover some.

Fossil echinoderms have received little study, both at CAVE and in the broader Guadalupe Mountains, in part due to the tendency of the organisms' skeletons to fragment into non-diagnostic pieces after death. Newell et al. (1953) reported only "crinoid columnals" from the Capitan Reef and Girty (1908) reported no identifiable crinoids from the Guadalupe Mountains at large. Girty did identify several echinoid taxa, but most taxa were found in the "black limestone" unit that corresponds to older rocks than are exposed either at the surface or in caves at CAVE. Echinoid fossils are relatively rare in the Paleozoic fossil record, and any new finds may contribute greatly to understanding their evolutionary history; Thompson et al. (2015) published a study that used the species *Eotiaris guadalupensis*, found in the Guadalupe Mountains, to infer the timing of a reorganization of regulatory genes that marked major divergence between two groups of echinoids.



Figure 16. Articulated crinoid columnals from Lechuguilla Cave. These fossils are in raised relief from the bedrock walls due to differential dissolution, and they are frequently superbly preserved (© MAX WISSHAK).



Figure 17. Echinoid spines in Lechuguilla Cave. Echinoid fossils from the Paleozoic in good condition are extremely valuable, as the organisms are relatively rare in units from that time period and are fragile post-mortem (NPS).

Other Fossils (algae, problematic organisms, foraminifera)

Much of the fossiliferous portion of the Capitan Limestone is formed out of sponge-algal stone, with algae making up a significant portion of the rock (Babcock 1974; Babcock and Yurewicz 1989; Weidlich and Fagerstrom 1998) (Figure 18); as a result Capitan Reef is hypothesized to have been primarily formed by a micro-framework of encrusting algae, organisms of problematic classification, and microbes. Though fossils of these organisms are common in the Capitan Limestone, they can be difficult for the untrained to identify. *Archaeolithoporella* is among the most important of the micro-reef-builders; its affinity has previously been the subject of debate, but it is classed as a coralline red alga under current consensus (Wu 1991; Wang et al. 1994). Most of the upper Capitan Limestone contains a very diverse calcareous algal assemblage, but the Seven Rivers-equivalent lower Capitan has only *Archaeolithoporella* and unidentified hemispherical algae (DuChene 2000).

The dasyclad algae *Mizzia* is dominant in much of the back-reef facies at CAVE (Kirkland George 1992), sometimes to the point of mono-specific assemblages. While not prevalent within the reef itself, *Mizzia* rapidly increases in abundance at the reef/back-reef margin and can be found at back-reef facies localities throughout the Seven Rivers, Yates, and Tansill formations (Kirkland George 1992). It is also one of the few fossils in the small surface exposure of the Queen Formation within CAVE (Graham 2007). This genus is critically important to paleoenvironmental and paleoecological reconstruction because it has a modern analog in the tropical dasyclad algae *Cymopolia*. Johnson

(1942) recorded three species of *Mizzia* from CAVE: *Mizzia minuta*, *Mizzia velebitana*, and *Mizzia yabei*.



Figure 18. Layers of algal fossils (darker areas) exposed in the ceiling of Left-Hand Tunnel, Carlsbad Cavern. Algae made up the majority of the reef-framework of the Capitan Reef (NPS/ROD HORROCKS).

Tubiphytes is a problematic encrusting organism (Maslov 1956) that makes up a large portion of the micro-framework of the Capitan Limestone, along with *Archaeolithoporella* and bryozoans (Weidlich and Fagerstrom 1998). Various affinities have been proposed (Riding and Guo 1992), but at present the genus is defined as belonging to the family Nigriporellidae and *incertae sedis* at higher taxonomic level. Riding (1993) claimed that this genus should instead be called *Shamovella obscura*, but Senowbari-Daryan's (2013) paper defining the differences between Paleozoic and Mesozoic species still used *Tubiphytes* as the genus name. It is not currently known which species of *Tubiphytes* occur at CAVE.

Fusulinid foraminifera, single celled amoeba-like organisms that inhabit a calcareous shell, are common fossils in upper Paleozoic marine deposits. Foraminifera have adapted to a variety of lifestyles, but most Guadalupian fusulinids were stationary semi-infaunal omnivores. At least 11 species have been reported from CAVE or from rock units analogous to CAVE (Newell et al. 1953; Tyrrell 1969; Senowbari-Daryan and Rigby 1996a). One species is reportedly present in a deposit in Lechuguilla Cave, and if it could be positively identified may potentially confirm the only known exposure of the Goat Seep Dolomite, the reef unit preceding the Capitan Limestone, within CAVE (H. DuChene, pers. comm., December 2019). A full list of taxa is provided in Appendix Table A-1-c. Fusulinids have a high rate of species turnover and experts can readily identify them to species via test (exoskeleton) shape. Thus, these organisms are excellent late Paleozoic index taxa. Fusulinids are found in every rock unit and facies exposed within the park boundary, though they are very rare in the evaporite facies, and are reported from several caves (e.g., Lechuguilla) (Graham 2007). They are rarely self-evident in the field, however, owing to being about the size and shape of a grain of rice. Weidlich and Fagerstrom (1998) state that most fusulinids at CAVE likely originated on the shelf and any found in the reef or reef talus were transported there, and all fusulinids referred to in Senowbari-Daryan and Rigby (1996a) were from the Seven Rivers, Yates, and Tansill formation, but Newell et al. (1953) reports the species *Leella bellula* and *Staffella fountaini* as exclusively being found in the Capitan Limestone. The current stratigraphy was not established at the time of Newell et al. (1953), and it is possible that this exclusivity could be in error. However, DuChene (2000) lists the reef as being the most common habitat for fusulinids in the Capitan Reef.

Pleistocene–Holocene Paleontology

General Nature of CAVE Quaternary Paleontological Resources

The Quaternary fossils found within CAVE are largely associated with the caves (Morgan and Lucas 2006; Harris 2020), which opened to the surface sometime during the Pleistocene (Lundberg and McFarlane 2006). The exact deposits vary in nature. Several localities have massive assemblages of colonial bats preserved in situ within guano (Baker 1963; Morgan 2002, 2003a, 2003b). These animals roosted seasonally within the cave and died there, though in some cases the bones may have been moved small distances into pits and/or preferentially orientated by water dripping or flowing into the caves (Baker 1963). Other caves with significantly vertical entrances, such as Muskox Cave, acted as natural traps where animals were lured into the depths of the cave by the presence of water, shelter, or prey (Logan 1979, 1981). In these caves the fossils tend to be found near the bottoms of the pits, often in thick rubble piles of debris and talus. Even caves with more gradual entrances, like Carlsbad Cavern, can have animals denning within or trapped animals that venture too far past the twilight zone. These occurrences are evidenced by dying modern individuals, mummies, bones of bats far from the entrance or colonies rooms (Baker 1963), unscattered and unabraded bones of a *Nothrotheriops shastensis* (Hill and Gillette 1987a), and rodent and *Bassariscus astutus* skeletons in caves where living individuals and nests have been sighted (NPS Records 2019). Finally, some fossils may have originated from individuals that died outside the cave, with their remains subsequently being transported into the cave by rainwater, *Neotoma* (woodrats), or cave-denning predators and scavengers (Black 1953; Graham 2007).

Age Dating of Cave Paleontological Resources

The ages of the fossils found within the park's caves vary. For the oldest *Tadarida constantinei* specimens in Slaughter Canyon Cave, exact dates are currently absolute minimums that likely underestimate the age of the fossils by several hundred thousand years (Lundberg and McFarlane 2006). No isotopic dating has been done at Lechuguilla Cave; the *Nothrotheriops* specimen must be of Pleistocene age, but the ages of the bat remains and *Bassariscus astutus* skeleton are unknown. The bat and ringtail remains show little to no diagenetic change (Jablonsky 2004?). The *Nothrotheriops* specimen from Carlsbad Cavern was dated at 111,900 (+13,300, -11,700) years ago via uranium-series dating (Hill and Gillette 1987a), indicating the cavern was open at that time. 2,000-year-old bat mummies have been recovered from Carlsbad Cavern (Jablonsky 1999). The guano from Bat Cave (the most populous modern bat roost in Carlsbad Cavern) dates to about 5,825 ± 200 uncalibrated radiocarbon years before present at oldest (Trautman 1963), or 7,160 to 6,280 calibrated radiocarbon years before present ("present" is 1950; in this document, radiocarbon dates that were not calibrated by the original authors have been calibrated using Calib 7.1 [<http://calib.org/calib/>] where appropriate). Guano recovered from a different site in Carlsbad Cavern was dated to 40,000–50,000 years old by radiocarbon (Jablonsky 2001). Uranium-thorium dating on the flowstone caps above the guano trenches in Slaughter Canyon Cave yielded dates of 66,000 ± 3,000 years old for the younger layer and 212,000 ± 3,000 years old to 209,000 ± 9,000 years old for the older (Lundberg and McFarlane 2006; Polyak et al. 2006), but the bat bones themselves are likely much older (400,000–500,000 years old or more) because they have turned to a greatly diagenetically altered state of apatite (Polyak et al. 2006). The guano layers also contain no nitrogen minerals and have accumulated crystalline apatite (Polyak and Provencio 1998). The chemical environment guano would have created while actively decomposing is corrosive to speleothems, implying the dated speleothems post-date the bat colony (Polyak and Provencio 1998; Polyak et al. 2006).

Caves that have not been assessed by some form of radiometric dating have had their ages estimated based on faunal composition, though this normally results in coarse maximums given the time-averaged nature of many cave deposits and how many specimens belong to taxa still extant in the region (Logan 1979; NPS Records 2019).

Pleistocene / Holocene Climate and Ecological Change in the Guadalupe Mountains

Vertebrate remains found within CAVE have provided substantial evidence for significant climate change in the region since the Pleistocene. Murray (1957) hypothesized that the Guadalupe Mountains, including CAVE, underwent a series of climatic and ecological shifts towards progressively more arid and less woody conditions over the Quaternary. This caused floras and faunas to move latitudinally and altitudinally in response to changing climate bands (Metcalf 1977; Logan 1979). At the time, the primary evidence was a series of successional assemblages preferring different environments found in Burnet Cave and other caves (Schultz and Howard 1935). Murray (1957) specifically referred to the yellow-bellied marmot *Marmota flaviventris* as a species indicating advance of xeric environments to the north and up-altitude across New Mexico upon the retreat of the last glaciation; today within New Mexico, *Marmota flaviventris* is restricted to high elevations on mountains in the northern part of the state. Several other boreal indicator species from Guadalupe Mountains caves are also referred to in Murray (1957), such as white-tailed jackrabbit

Lepus townsendii and long-tailed vole *Microtus longicaudus*, but these taxa have never been found within the boundaries of CAVE.

This hypothesis was later supported by assemblages at CAVE containing extinct or extant taxa adapted for boreal or woodland climates/habitats that no longer live in the Guadalupe Mountains and/or Chihuahuan Desert (Baker 1963; Metcalf 1977; Logan 1979, 1981; Morgan and Lucas 2006). Vertebrate examples include: *Oreamnos harringtoni*, which likely lived in the alpine zone above the timberline (Jass et al. 2000); muskrat *Ondatra zibethicus* and water shrew *Sorex palustris*, which are semi-aquatic (Logan 1979); meadow vole *Microtus pennsylvanicus* and eastern cottontail *Sylvilagus floridanus*, which require or greatly prefer hydrosere environments (Logan 1979); the montane New Mexican shrew *Sorex neomexicanus* (Logan 1979; G. Morgan, pers. obs., December 2019); western red bat *Lasiurus blossevillei*, hoary bat *Aeorestes cinereus* (Baker 1963; Jablonsky 1996; Morgan and Lucas 2006), and red squirrel *Tamiasciurus hudsonicus* (Logan 1979), which need trees and heavily forested regions for the latter; Sonoran Desert tortoise *Gopherus morafkai*, which cannot withstand prolonged periods below freezing (Morgan and Harris 2015); and *Eucatherium collinum*, the Shrub Ox, which is hypothesized to have preferred a cooler and more mesic climate than the modern Guadalupe Mountains (Logan 1979; Morgan and Lucas 2006). Open grasslands, mountain meadows, or wide forest glades must have been present given the presence of highly specialized cursorial animals such as the pronghorns *Capromeryx furcifer* and *Stockoceros conklingi* and the extinct American cheetah *Miracinonyx trumani* (Logan 1979; Van Valkenburgh et al. 1990). These taxa become rarer in the latest Pleistocene and early Holocene cave sediments (Logan 1979; NPS Records 2019), and xeric-adapted or tolerant taxa such as the yellow-faced pocket gopher *Pappogeomys castanops* (Lyman 1983; NPS Records 2019), desert shrew *Notiosorex* (Logan 1979; Carraway 2010), and plants such as the cactus *Opuntia* become more common until the assemblage wholly resembles the recent fauna (Logan 1981).

Examples of Pleistocene invertebrates, mostly land snails, include *Vallonia perspectiva*, *Gastrocopta contracta*, *Pupilla blandii*, *Fossaria modicella*, and *Stagnicola cockerelli* (Metcalf 1977). The latter two are aquatic and the former three prefer more pluvial conditions than exist where their fossils have been recovered today (Metcalf 1977). Furthermore, within Dry Cave (outside of CAVE, but nearby in the same formations), early Holocene sediments cease to include *Pupilla blandii*, *Gastrocopta* and *Vallonia* become rarer, and fossils of xeric-adapted gastropods native to the area today, *Succinea grosvenori* and *Hawaiiia minuscula*, dominate the assemblage. This contrasts with Pleistocene sediments within the same cave that are dominated by the pluvial and aquatic taxa previously mentioned, indicating an onset of more arid conditions in the Holocene (Metcalf 1977).

In general, evidence suggests that during the Pleistocene the area around CAVE was wetter and more grassy or forested than at present depending on ecologic zone (Logan 1979). The boreal to steppe-woodland environments that would have dominated the area at that time have since moved northward and/or to higher altitudes (Harris 1985). While the Chihuahuan Desert at large retains some juniper woodlands and other savanna or woodland type environments at higher elevations, most of it and all of CAVE's lands have transitioned to various desert environmental zones, mostly scrubland, though micro-climate regions created by canyons are also common (Harris 1985; NPS Records 2019).

Where a given taxon's habitat ceased to be found in the northern Chihuahuan Desert it was either locally extirpated (if it migrated to northern refugia) or went extinct (if it was trapped in shrinking montane refugia). It is difficult to differentiate "northern" from "montane" taxa, and it is possible that no real distinction exists; rather, such taxa likely had connected populations in the Pleistocene that became separated as changing climate isolated some relict populations on mountain refugia (Murray 1957; Metcalf 1977; Logan 1979). Fossils corresponding to different types of extirpated environments may indicate the assemblages are time-averaged over the drying trend or that there were adjacent and coexisting environments, probably both given the nature of the depositional environments and visible gradation of environment by altitude and latitude in the modern. Furthermore, the Pleistocene itself had alternating pluvial and inter-pluvial periods, and any significantly time-averaged assemblage will likely contain specimens from multiple types of environment even if wholly of Pleistocene material (Harris 1985). The ecological change brought on by this aridification trend has important implications for modern ecology and biologic resource management, as it may help predict the migration, extirpation, or extinction of species dependent on specific environments and levels of precipitation (Dietl et al. 2015).

Mummified Mammal Remains at CAVE

Bat mummies occur within several different areas of Carlsbad Cavern. One grotto contains several mummified bats (Baker 1963). Most are well preserved and some still hang from the walls, ceilings, and cave formations. Mummified taxa within this room include: *Tadarida brasiliensis mexicana*, *Myotis* sp., *Aeorestes cinereus*, and *Eptesicus fuscus* (Baker 1963). The room's isolated and unusually dry climate are proposed explanations for the mummies (Baker 1963). No estimate on the number of mummies within the room could be found. The individuals within this room appear to have perished at different times, each after becoming trapped within the room because it possesses only a single very narrow exit and entrance (Baker 1963). CAVE staff report that a smaller number of bat mummies can also be found in the other nearby scenic rooms (Ellen Trautner, NPS CAVE Physical Science Technician, December 2019).

Jablonsky (1999) reported 100–150 mummified *Tadarida brasiliensis* within a 6 m by 12 m (20 ft by 40 ft) room in Lower Cave. It is speculated that all of the bats here were part of a colony that died at approximately the same time (Jablonsky 1999). This hypothesis is supported by the taxonomic homogeneity of the assemblage. A leak of hydrogen sulfide (H₂S) or concentration of carbon dioxide (CO₂) are potential causes of the mass death. One specimen collected from this room was carbon-dated to an age of just over 2,000 years old (Jablonsky 1999); it was proposed that the specimen be further chemically tested to help determine cause of death, but the ultimate end location for the specimen is not recorded. Jablonsky (1999) and park staff note that bat mummies have been sighted in other areas of Lower Cave. No further information on these other mummies was provided in Jablonsky (1999).

A mummified *Bassariscus astutus* (ringtail) of unknown age was found in Carlsbad Cavern in 1995. The mummy preserves the skeleton and skin of the animal, as well as some of the hair on the tail; the remains were photographed on March 17, 2020 by Hunter Klein and Ellen Trautner, having not

deteriorated significantly since last observation (Figure 19). Non-mummified bat remains can be found within the same room.



Figure 19. Ringtail mummy in Carlsbad Cavern. Its age is unknown. The camera's lens cap is provided for scale (NPS/HUNTER KLEIN).

No other site within CAVE has confirmed mummies. Specimens of unknown age with remnant skin, fur, or feathers have been observed during surveying trips of several caves (NPS Records 2019). However, it is more likely that these are recent corpses undergoing slow decay in the cave environment than they are to be preserved indefinitely as mummies. None of the other caves within the park possess the same aridity as the site described in Baker (1963), but mummies have been found in other parts of Carlsbad Cavern that are not abnormally dry for the cave. The caves with possible, but unlikely, mummified remains include: C-04 contains a *Cathartes aura* (turkey vulture) specimen with some skin and many feathers (NPS Records 2019); C-93 contains a rodent tentatively identified as *Neotoma* sp. with flesh intact that was either recently dead or a mummy (NPS Records 2019).

Absence of Packrat Middens at CAVE

Middens formed by species of the packrat or woodrat genus *Neotoma* are critical paleontologic resources because the animals bring plant material and other organic material to their nests and middens, where this material can be preserved for tens of thousands of years by crystallized rat urine. The same middens may be used by a series of woodrats for thousands of years, many date back to the late Pleistocene, and the plant matter collected or pollen trapped in the midden is a relatively random sample of the flora in the area immediately around the midden (Borrelli and Holmgren 2016;

Balmaki and Wigand 2019). This forms a relatively high-resolution record of the floral composition of an area, and any changes to it, over time. Many of the oldest middens are found within natural shelters and caves, because they protect the middens from being destroyed by the elements (Dézerald et al. 2019).

Despite the karst landscape of CAVE, there is no record of subsurface packrat middens at the park and no work has been done on such features. According to Betancourt (pers. comm., November 2019), cave systems like those found at CAVE do not usually preserve middens. This is because humidity in such caves is high enough to hydrate the hygroscopic urine, allowing the organic material within the midden to rot. Staff at CAVE have reported sighting *Neotoma* middens hidden under scrub at the surface, but these are unlikely to preserve fossil material because they are routinely exposed to rain and other destructive weather. Cave C-108 had a preliminary report of a rodent nest within it with early speculation that it could be a midden (NPS Records 2019). However, Stan Allison, former CAVE Physical Science Technician and one of the surveyors, has since confirmed that it was not a midden (S. Allison, pers. comm.). It may be worthwhile to check smaller karst features, such as crevices and shelters, for the presence of middens; one such feature, KF-39, has what may be a midden within it (NPS Records 2019). Species of *Neotoma* are common members of both fossil assemblages and the modern fauna at CAVE, but some species, such as the bushy-tailed woodrat *Neotoma cinerea*, are extirpated from the region today, and are now restricted to higher elevations in the northern mountains of New Mexico (Logan 1979; Morgan and Lucas 2006).

Cultural Resource Connections

There are many ways for paleontological resources to have connections to cultural resources. Examples of paleontological resources in cultural contexts include, but are not limited to: fossils used by people for various purposes, such as petrified wood used for tools, spear points, and other artifacts, or fossil shells picked up as charms or simply because they looked interesting; associations of prehistoric humans with paleontological resources, such as kill sites of mammoths, prehistoric bison, and other extinct animals; incorporation of fossils into cultural records, such as fossils in American Indian lore, “tall tales” of mountain men, and emigrant journals; and fossils in building stone. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological resources uncovered in association with an archeological site are considered archeological resources and subject to the Archeological Resources Protection Act (ARPA) and associated policy (16 USC § 470aa) rather than the Paleontological Resources Preservation Act (PRPA) and associated policy (16 USC § 470aaa). As such, an ongoing archeological project does not need to be halted and no further assessment is necessary at the archeological site, though a paleontologist should still be consulted in regard to the fossils. In a similar manner, fossils found in a cultural context or as cultural artifacts are counted as cultural resources and are therefore under the protection of 25 USC § 3001 instead. In either case, experts should try to determine if the paleontological resources are also archeological/cultural resources or if their co-occurrence is merely coincidental.

Conversely, the disturbance of archeological resources and/or cultural artifacts during paleontological management or research requires that the paleontological project cease immediately. The paleontological activity is put indefinitely on hold while management options for the archeological/cultural resources are assessed.

The region around CAVE has had a long history of human inhabitation, and as such contains several coincident paleontological and archeological sites. Descriptions of the paleontological resources found at these sites are provided below, listed by site designation in numerical order. There are also a smaller number of historical sites where fossils can be found related to the development of the public trails within Carlsbad Cavern. Where these sites are not associated with another type of locality, they are listed by common name after other types of site.

CAVE recently completed a Cultural Landscape Inventory (National Park Service 2020), which includes fossils in a cultural resource context. Please refer to that report for more in-depth information about the archeological localities mentioned below and their cultural significance.

A-08: A paleontological locality occurs nearby an archeological site here. There is a possible archaic horizon associated with the faunal assemblage here as well. A single brachiopod fossil was found alongside stone artifacts in a test excavation at the site in 1959. It is unknown if this brachiopod fossil was merely coincident with the artifacts or if it was associated with human occupation (E. Gearty, pers. comm., December 2019).

A-13: The paleontological resources from this site were recovered from within a test pit/trench dug during archeological excavation. The most prominent specimen is a Pleistocene horse (*Equus*) tooth. Remains of unknown age include: porcupine (*Erethizon dorsatum*); tree squirrel (*Sciurus* sp.); cottontail rabbit (*Sylvilagus* sp.); black tailed prairie dog (*Cynomys ludovicianus*); smooth toothed pocket gopher (*Thomomys* sp.); and rock squirrel (*Otospermophilus variegatus*). With the exception of the Pleistocene horse and the tree squirrel, most of these taxa are present in the region today, or were in recent history. The relationship between the fossils and the archeological artifacts is unknown (E. Gearty, pers. comm., December 2019).

A-45: A brachiopod fossil was recovered from a cooking pit at this archeological site (E. Gearty, pers. comm., December 2019).

A-140: Several stone flakes (refuse from making stone tools) were collected from the site that had ovoid fossil inclusions. The fossiliferous material seems to have been chosen because of the inclusions (E. Gearty, pers. comm., December 2019). Park staff have indicated that other archeological sites in the park also include fossiliferous chert flakes (R. Horrocks, pers. obs., 2019).

Natural Entrance: The floor of the room just inside the Natural Entrance of Carlsbad Cavern was previously covered by a pile of sediment and debris, much like many other caves within the park. When the Main Corridor trail was paved in the 1950s, this debris pile was dug out and removed both to clear the trail and to serve as trail fill to level out the path (Black 1953). During this excavation, the debris pile was found to contain a sizable amount of both fossil material and archeological/cultural artifacts. This included bone and fossil beads, likely used as jewelry (Black 1953). Other paleontological resources found within the debris pile included: mammal and reptile teeth; horned-toad (*Phrynosoma* sp.) bones and scales; bones of bats; rodent skulls and postcrania; the ribs and leg bones of many types of mammals, including unspecified large taxa; and the furculae (wishbones) and skulls of birds (Black 1953). Much of this material is likely coincidentally present, the result of natural trapping or remains washed into the cave by rain. However, Black (1953) speculated that some of the bones, especially the larger specimens, were ritualistically tossed into the cave by American Indians after hunts or ceremonies. Erin Gearty (pers. comm., November 2019) thinks it more likely that these remains were left outside of the cave and washed into the cavern later. Black (1953), aside from the bead jewelry, did not elaborate on fossil features, pathologies, or markings that support the hypothesis of human use.

Top of the Cross: The Top of the Cross Amphitheater in the Big Room of Carlsbad Cavern is a seating area carved out so that programs and presentations could be held comfortably within the cavern itself. In 1977, staff concreted a number of Permian fossils of various types together into a conglomerate display at the Top of the Cross (E. Gearty, pers. comm., December 2019; National Park Service 2020) (Figure 20). These fossils include: sponges; brachiopods; nautiloids; ammonoids; and others. It is not recorded if all of these fossils came from within Carlsbad Cavern itself, nor which stratigraphic units they originated from. Oral tradition says they came from trail building efforts in Carlsbad Cavern (R. Horrocks, pers. obs., 2019). This display was intended for use in the interpretive talks held at the amphitheater.



Figure 20. Examples of fossils cemented into a display at the Top of the Cross (NPS/VINCENT SANTUCCI).

Slaughter Canyon Cave (C-02) Guano Mining Trenches: A large mining operation at Slaughter Canyon Cave in the mid-20th century excavated a large volume of bat guano and left behind the present topography of the guano mining trenches. This guano is itself a trace fossil, and is filled with abundant bones of the Pleistocene free-tailed bat *Tadarida constantinei*. Some remnant cultural artifacts from the mining remain within the cave, including wiring, light bulbs, metal fragments, and personal refuse from the miners such as tin cans. Outside the cave, evidence of the pulley system used to move guano downhill can still be seen.

Carlsbad Cavern (C-01; Bat Cave only), Lechuguilla Cave (C-05; entrance pit only), and C-08 were also mined for guano, which contained fossilized bat bones. Relics of the mining operations and infrastructure remain intact within or were collected from these caves.

C-13: An unidentified femur in this cave occurs in a possible cultural resource context.

Fossil Localities

Nearly the entirety of the Permian strata at CAVE are fossiliferous, both above and below ground. Permian fossils may be found in their original bedrock or eroded from the bedrock. Most non-Permian fossils are located within caves and are not encased within stone with the exception of a few Pleistocene/Holocene age fossils found buried in Quaternary sediments or encased in flowstone. Because of the great differences in depositional setting, age, and fauna, the following localities have been split into Permian and Pleistocene/Holocene subsections. Some caves, such as Carlsbad Cavern, contain both types of localities.

There is somewhat of a disjunction between published fossil localities for the Permian, which usually occur at the surface, and those recorded in non-public cave surveys by the park. This is because surface fossil localities such as those collected by Cooper and Grant (1972) or Rigby et al. (1998) do not occur at sites falling under classes routinely monitored by CAVE staff (e.g., cave, karst feature, archeological site, spring, etc.). Furthermore, while these localities mark sites of prior collection of published fossils, fossils can be found throughout entire geologic units (e.g., Capitan, Yates) and not just in those isolated locales, so there can be difficulty distinguishing Permian fossil discoveries as discrete sites. Additionally, most caves in the park likely contain Permian age fossils; however, the resources within these caves are often documented only in passing, if at all (NPS Records 2019).

While this study compiled existing localities published in either publicly available scientific literature or internal NPS reports, it did not discover or document any new localities. It is highly recommended that areas of backcountry wilderness and backcountry caves be resurveyed and inventoried with the intent of documenting and identifying their paleontological resources. Caves located within bedrock units with a high potential for paleontological resources (see Figure 4) would be the recommended focus for this effort.

Some of the information within this section is also summarized in Appendix D. However, that list does not include details about the individual Permian localities within specific caves elaborated on below.

Permian Paleontological Localities at CAVE

Surface

In addition to the localities listed below, Permian-age fossils can be found at the surface along canyon walls and besides several park trails. Exposures of the Capitan Limestone are the most fossiliferous, but fossils are occasionally present in the back-reef facies and rarely present in the evaporite facies of the Seven Rivers, Yates, and Tansill formations (Graham 2007). Most of these surface incidences do not seem to have been officially recorded, marked, or monitored.

Bat Cave Draw: The exposures here are of the uppermost Capitan Limestone (Rigby et al. 1998). This locality was collected from as part of the research eventually published in Senowbari-Daryan (1990), Rigby and Senowbari-Daryan (1996), and Rigby et al. (1998). Most of the fossils here are part of sponge-algal reefs, reef patches, or bioherms. Species found and identified at this locality include: *Cystothalamia guadalupensis*, *Exaulipora permica*, *Girtyocoelia beedei*, *Guadalupia*

zitteliana, *Guadalupia explanata* (now known as *Polyphymaspongia explanata*), *Lemonea polysiphonata*, *Cavusonella caverna*, *Gigantospongia discoforma*, *Preperonidella delicata*, *Bicoelia guadalupensis*, *Virgola neptuna*, *Virgola rigida*, and Unknown Taxon A from Rigby et al. (1998).

Hackberry Draw: The exposures at this locality are within the Massive Member of the Capitan Limestone, and are equivalent to the lower upper Tansill Formation (Rigby et al. 1998). This is the type locality for the sponge species *Preverticillites parva* and *Lemonea exaulifera*. Other species found and identified at this locality include: the sponges *Cystothalamia guadalupensis*, *Tristratocoelia rhythmica*, *Exaulipora permica*, *Parauvanella minima*, *Sollasia ostiolata*, *Gigantospongia discoforma*, *Minispongia* cf. *constricta*, rare *Discosiphonella mammilosa*, the bryozoan *Acanthocladia* sp., and unspecified photosynthetic algae (Rigby et al. 1998). Fagerstrom and Weidlich (1999) also reported *Permosoma* sp. from this locality. This list is not exhaustive; see Rigby et al. (1998) or Fagerstrom and Weidlich (1999) for more details.

Rattlesnake Canyon Traverses: Rigby et al. (1998) did not provide an estimated stratigraphic position, equivalency, or age for the two localities found here. Species found include: *Amblysiphonella* sp. A, *Amblysiphonella* sp. B, *Exaulipora permica*, *Guadalupia zitteliana*, *Guadalupia explanata*, *Preperonidella delicata*, *Bicoelia guadalupensis*, *Heliospongia ramosa*, and *Heliospongia vokesi* (Rigby et al. 1998).

Newell et al. (1953) Locality 51: This locality is located in the back-reef facies of the Yates and Tansill formations within Walnut Canyon (Newell et al. 1953). The assemblage for both formations consisted of bivalves, gastropods, scaphopods, and *Macroporella* algae. Newell et al. (1953) did not further specify the collected organisms to genera or species in their book, but the record for AMNH locality 741 at the American Museum of Natural History may have more detailed information.

Newell et al. (1953) Locality 52: A locality in Walnut Canyon; Newell et al. (1953) did not list what specimens were found at this locality or what unit is exposed there. It is also recorded as AMNH locality 366.

Newell et al. (1953) Locality 53: This locality is a reef escarpment. The reef is analogous to the Tansill Formation, and contains gastropods, scaphopods, *Macroporella* algae, *Mizzia* algae, and other unidentified algae (Newell et al. 1953).

AMNH 725: This locality in the “Yates Formation (probably Capitan)” (Cooper and Grant 1972) contains: *Aneuthelasma amygdalinum* (Cooper and Grant 1976); *Astegosia subquadrata*; *Geyerella americana*; and *Martinia rhomboidalis* (Girty 1908).

USNM 740n: This locality contains: *Anteridocus swalloviaianus*; *Arionthia lamaria*; *Astegosia subquadrata*; *Composita emarginata*; *Dielasma* sp.; *Dielasma sulcatum*; *Eliva inflata* (now known as *Aequalicosta inflata*); *Eliva shumardi* (now known as *Aequalicosta shumardi*); *Heterelasma shumardianum*; *Hustedia* sp.; *Paraspiriferina billingsi*; *Stenoscisma trabeatum*; *Strigirhynchia indentata*; *Tautosia elegans*; *Tautosia shumardiana*; *Timorina attenuata*; *Timorina schuchertensis*; *Tropidelasma gregarium*; *Strigogoniatis fountaini*; and *Anisopyge perannulata* (Cooper and Grant 1972, 1976; Brezinski 1992).

USNM 740o: This Capitan Limestone locality contains: *Anteridocus swallowianus*; *Astegosia subquadrata*; *Eliva inflata*; *Elivina compacta*; *Fascicosta longaeva*; and *Strigirhynchia indentata* (Cooper and Grant 1976, 1977).

USNM 750: This Capitan Limestone locality contains: *Allorhynchus* sp.; *Aneuthelasma amygdalinum*; *Anomaloria anomala*; *Astegosia subquadrata*; *Cleiothyridina pilularis*; *Compressoproductus pinniformis*; *Dielasma* sp.; *Dielasma subcirculare*; *Martinia rhomboidalis*; *Ombonia guadalupensis*; *Paucispinifera latidorsata*; *Plectelasma guadalupense*; *Plectelasma planidorsatum*; *Tropidelasma gregarium* (Cooper and Grant 1972, 1976); and *Anisopyge perannulata* (Brezinski 1992).

USNM 750a: This Capitan Limestone locality contains: *Anteridocus swallowianus*; *Collemataria* sp.; *Composita emarginata*; *Dielasma prolongatum*; *Dyoros* (*Dyoros*) *subliratus*; *Eliva inflata*; *Fascicosta longaeva*; *Grandaurispina* sp. 5; *Hustedia opsia*; *Liosotella popei*; *Paraspiriferina billingsi*; *Paucispinifera* sp.; *Reticulariina* sp.; *Scapharina levis*; *Stenoscisma trabeatum*; *Strigirhynchia transversa*; *Tautosia shumardiana*; *Thamnusia capitanensis* (Cooper and Grant 1972, 1976); and *Anisopyge perannulata* (Brezinski 1992).

USNM 750b: This Capitan Limestone locality contains: *Astegosia subquadrata*; *Composita affinis*; *Compressoproductus pinniformis*; *Elivina compacta*; *Fascicosta longaeva*; *Martinia rhomboidalis*; *Megousia* sp.; *Paraspiriferina billingsi*; *Paucispinifera latidorsata*; *Stenoscisma trabeatum*; *Strigirhynchia transversa*; *Tautosia shumardiana* (Cooper and Grant 1972, 1976); and *Anisopyge perannulata* (Brezinski 1992).

USNM 750e: The brachiopod species *Martinia rhomboidalis* and *Plectelasma planidorsatum* have been found here (Newell et al. 1953), near the contact of the Capitan and Carlsbad formations (Cooper and Grant 1972).

USNM 3364: Yochelson (1960) reported the gastropod *Knightites* sp. 2 from this location, as well as the monoplacophoran *Lepetopsis* sp. Batten (1989) reported the additional gastropod species: *Apachella translirata*; *Apachella pseudostrigillata*; *Apachella glabra*; *Apachella nodosa*; *Baylea huecoensis*; *Glabrocingulum* (*Stenozone*) *carlsbadensis*; and *Worthenia bialveozona*. This is the type locality for *Glabrocingulum carlsbadensis* (Batten 1989).

Sponge Window (non-CAVE): The Sponge Window is an important locality found just outside of the park boundary in private land. It is an analogous site to Bat Cave Draw. The locality is a block of reef, on which the large platy sponge species *Gigantospongia discoforma* grows horizontally outward, protecting cavity spaces behind that host a variety of pendantly growing cryptobiotic organisms (Rigby and Senowbari-Daryan 1996; Rigby et al. 1998). These include unspecified bryozoans, brachiopods, and the small sponges *Amblysiphonella* and *Lemonea*. The exposure is eroded/cut into such that in situ sponge specimens have internal structures revealed. The block is from the upper Massive Member of the Capitan Limestone, and must have been deposited in relatively shallow waters given the presence of abundant dasyclad algae fossils at the locality

(Babcock 1977; Rigby and Senowbari-Daryan 1996). This is the type locality for *Gigantospongia discoforma*.

Caves

It is probable that most caves within CAVE have Permian fossils in them given the origin and nature of the rock units. However, these fossils are usually only noted in a broad and coarse manner as part of more general cave surveys. The caves and localities below are those that have been studied in more detail or have been noted as exceptional by researchers, cavers, or interpreters at the park. Other caves containing Permian fossils include, but are not limited to: C-07, C-08, C-11, C-13, C-20, C-21, C-22, C-24, C-25, C-28, C-29, C-34, C-62, C-87, C-106, and C-108. C-24 is notable for currently being the only Permian-age CAVE locality with trace fossils (worm burrows) reported from it. See Appendix D for more information on these localities.

USNM 750f (Carlsbad Cavern, C-01): The brachiopod species *Astegosia subquadrata* and *Paraspiriferina billingsi* were found here in the Capitan Limestone (Cooper and Grant 1972, 1976).

Devil's Den (Carlsbad Cavern, C-01): A notable nautiloid fossil is exposed near Devil's Den along the Main Corridor Trail, nicknamed "Luke the Spook" by interpreters (David Tise, CAVE Interpreter, pers. comm., December 2019). Devil's Den is within the Yates Formation, and thus this nautiloid was deposited in the back-reef, but it is near the contact with Yates-analogous Capitan Limestone (Burger 2007).

Left-Hand Tunnel (Carlsbad Cavern, C-01): Left-Hand Tunnel is a section of Carlsbad Cavern that branches off from the Big Room at the Lunchroom. It proceeds down a long passage before splitting in two, and from there into further smaller passageways. Guided tours through portions of Left-Hand Tunnel are provided to the public. Both the Massive Member and Reef Talus Member of the Capitan Limestone are exposed within Left-Hand Tunnel, the latter being present in the Left-Fork portion.

Left-Hand Tunnel is extensively fossiliferous, and has several notable exposures along the public trail containing thousands of fossils (Figures 21 and 22). The fossils in Left-Hand Tunnel mostly consist of algae, sponges, bryozoans, brachiopods, gastropods, and fossil hash. The exceptional exposures are often used as an educational stop by interpreters leading public tours (David Brumbaugh, pers. comm., December 2019). There are no records of any scientific studies being performed at the localities within Left-Hand Tunnel, and park staff seem to have only coarsely identified the taxa present.



Figure 21. Mollusk fossils in Left-Hand Tunnel (NPS/ROD HORROCKS).

Elevator and Lunchroom (Carlsbad Cavern, C-01): Fossils are exposed along the walls of the public lunchroom at the base of the elevator in the Big Room of Carlsbad Cavern (Figures 23 and 24). The exposures here are typically not of as high a quality or abundance as Left-Hand Tunnel. However, there are a nautiloid and a trilobite (*Anisopyge perannulata*) (Figure 15) exposed within this room and on the elevator shaft wall respectively (Norr et al. 2016). The latter was previously marked with a nameplate, but the nameplate has since been removed to protect the specimen by keeping it inconspicuous. These two fossils are well preserved, relatively valuable, and located in areas of high public traffic. As such, they are somewhat vulnerable to vandalism, though high NPS staff presence and the hardness of the rock would make theft difficult. They would be good candidate specimens for routine monitoring.

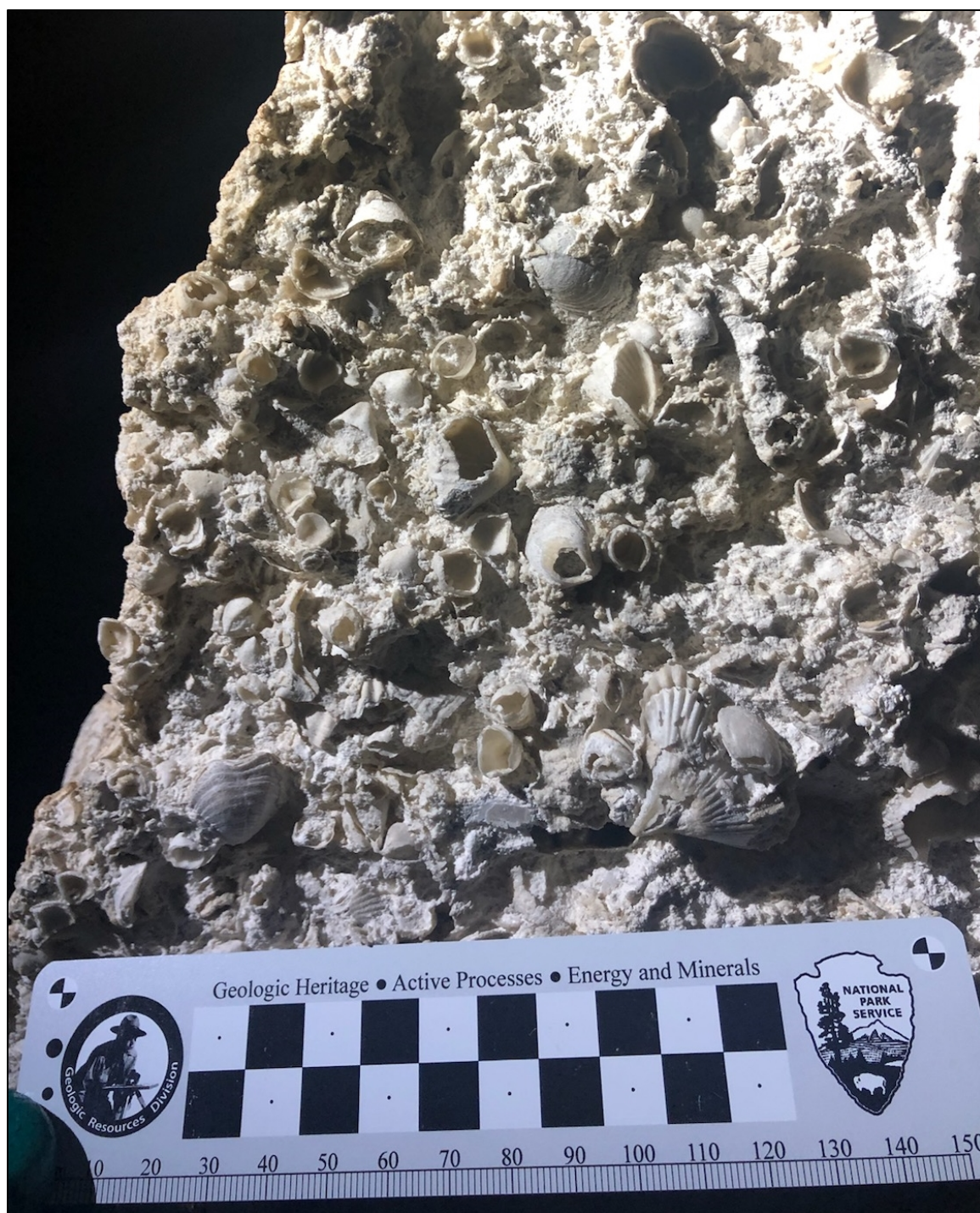


Figure 22. Brachiopod hash in Left-Hand Tunnel, Carlsbad Cavern. Thousands of shells are contained within this deposit (NPS/ROD HORROCKS).



Figure 23. Cephalopod fossil on the ceiling of an alcove in the Big Room lunchroom. Staff hypothesize it is a nautiloid, but identification is difficult given its location (NPS/ROD HORROCKS).



Figure 24. Gastropod fossil from the Big Room, Carlsbad Cavern. Pencil for scale (NPS).

Top of the Cross (Carlsbad Cavern, C-01): A breakdown block near this public seating area has a prominently exposed ammonite in it (Figure 25). The presence of this ammonite was what inspired park staff in 1977 to cement numerous other fossils from elsewhere in Carlsbad Cavern into a display at the Top of the Cross Amphitheater/public seating area (Figure 20).

Lower Cave (Carlsbad Cavern, C-01): Isolated fossils can be found exposed along the walls throughout Lower Cave. Of special note, an unidentified trilobite has been reported from this area. This entire region is located in the Capitan Limestone, mostly in the Massive Member with a small portion in the Reef Talus member. Cave Guided tours of Lower Cave are offered, and fossils are pointed out as part of the tour. The trilobite is off the trail area and not shown to the public.

Tour Stops ‘I’ and ‘K’, Near Iceberg Rock (Carlsbad Cavern, C-01): This area around Iceberg Rock marks a transition between the back-reef facies of the Yates Formation and the equivalent Capitan Limestone. Two signs corresponding to a now out-of-print walking guide to the Main Corridor and Big Room self-guided tour trails denote fossil exposures on each side of this contact. Stop I, in the Yates back-reef, contains an assemblage of gastropods, including bellerophontids, and some bivalves. Stop K, in the Capitan Limestone, consists mostly of brachiopods with a few sponges visible as well (Burger 2007). Other organisms, such as algae, may also be present at these localities. Similar exposures are likely present throughout the Main Corridor and the Big Room.



Figure 25. Ammonite in a large breakdown block at the Top of the Cross, Big Room, Carlsbad Cavern. Unlike most Top of the Cross fossils, which were moved to their present location, this ammonite is in situ (NPS/ROD HORROCKS).

Fossil Avenue (Slaughter Canyon Cave, C-02): Fossil Avenue is a downward-sloping passageway and room in Slaughter Canyon Cave that can be accessed from a south-trending corridor near the guano mining trenches. The passage leads down towards a room about 2 to 2.5 m (6 to 8 ft) high; the passage floor, the walls, and the ceiling of the room are all extensively fossiliferous with brachiopods, crinoid columnals, sponges(?), and algae (Figure 26). The abundance and density of Permian fossils is much higher here than elsewhere in Slaughter Canyon Cave.

This passage and room are not part of the standard guided tour in Slaughter Canyon Cave, but interpreters sometimes take small groups down into the room (Berlin, Brumbaugh, Rocha, Tise, and Walfield, CAVE interpreters, pers. comm., December 2019). No studies seem to have been done on the Permian fossils at this locality, which was named for the Permian fossils.



Figure 26. Permian reef fossils on the ceiling and walls of Fossil Avenue in Slaughter Canyon Cave (NPS).

Lechuguilla Cave (C-05): Harvey DuChene produced a presence/absence paleontological inventory for hundreds of survey stations within Lechuguilla Cave (NPS Records 2020). Every one of these stations had at least one type of fossil present. The inventory marked presence/absence for: algae; sponges; coral; bryozoans; brachiopods; pelecypods (bivalves); cephalopods; gastropods; scaphopods; crinoids; and fusulinids. Specific annotations were made for exceptional localities. Among the highlights are: a fossiliferous neptunian dike (a fissure in the reef that infilled with reef talus and fossils, and was later cemented in by precipitated calcium carbonate) with rare and unusually well-preserved fossils, such as brachiopods with internal structures exposed and preserved, articulated crinoids, and echinoid spines (DuChene 2000); a complete *Leptodus* brachiopod, a genus which readily breaks apart after death (DuChene 2000); fossils coated black by diagenetic processes (DuChene 2000); and locations where the rock that surrounded fossils has dissolved and left fossils such as articulated crinoids exposed in relief or lying out in the open (Figures 16, 17, and 27) (NPS Records 2020). Pleistocene vertebrates were also noted; these are discussed in the Pleistocene/Holocene Cave Paleontology section of this report.



Figure 27. A cephalopod in Lechuguilla Cave (© MAX WISSHAK).

Pleistocene / Holocene Paleontological Resources at CAVE

The following section details the Pleistocene/Holocene paleontological resources found within the 44 caves (though several are dubiously paleontological, see descriptions below) and five non-cave sites known to contain Pleistocene/Holocene vertebrate remains or associated ichnofossils. It is organized by cave number (C-#), an identification system that sorts locations by site type and a number usually corresponding to order of discovery. Non-cave sites are listed after cave sites in the order of karst feature (KF-#), archeological site (A-#), spring (S-#), and other (by name).

For caves open to the public (e.g., Carlsbad Cavern) and those published in publicly accessible scientific journals (e.g., Lechuguilla Cave and Muskox Cave), names are given as well as cave number. For sensitive caves (not open to the public), only the cave number is provided. Regardless of public accessibility of a cave or publication, all paleontological resource information and data herein is considered sensitive. Not all paleontologic resources or sites from public caves have been published, and in fact many are only recorded in internal NPS reports or sensitive records. Much of the information in this section, especially for sensitive caves, comes from sensitive and restricted resource management files at CAVE rather than traditional published sources; these resource management records are cited collectively as “NPS Records 2019.” See Appendix Table A-2 for a listing of Pleistocene/Holocene vertebrate taxa found within CAVE’s paleontological sites, their common names, and their inferred habitats/climate conditions.

Carlsbad Cavern (C-01): The cave for which the park is named, Carlsbad Cavern has four general types of Quaternary fossil deposits: bat guano deposits and associated bones (Baker 1963); remains of animals that sheltered and died in the cave (NPS Records 2019); remains of animals that traveled past the twilight zone and/or were trapped, became lost in the cave, and died (Baker 1963; Hill and Gillette 1987b); and a debris pile below the Natural Entrance containing bones washed into the cave (Black 1953).

Bat guano and remains occur under massive bat colonies that produce thick layers of guano over time, into which dead and dying bats fall and are preserved in situ. Such a deposit occurs beneath the modern *Tadarida brasiliensis mexicana* colony in Bat Cave, and there are smaller similar deposits deeper in the cave within the Big Room representing now abandoned colonies (Santucci et al. 2001). The Bat Cave guano was dated to $5,825 \pm 200$ uncalibrated radiocarbon years old according to Trautman (1963), but later samples by Jablonsky (1999) were dated to only about 100 years before present; this may indicate the older estimate was in error or that the later Jablonsky sample was a fresher sample. Two guano deposits in the Big Room and Lower Cave date to $44,680 \pm 1,200$ and $50,300 \pm 2,200$ years old (Jablonsky 1999, 2001; both dates are beyond the range of calibration), and along with skeletal remains of *Tadarida constantinei* indicate habitation of the cave by bat colonies during the Pleistocene. Bat bones of all types, but especially limbs, are common throughout the guano layers. Most areas of mass chiropteran fossil deposits in Carlsbad Cavern guanos are off-limits to the public. This is either because of coincidence with the modern bat colony in Bat Cave or by being located in hard-to-reach locations away from public trails and tours.

The other types of fossil deposit are the result of animals perishing in the dark zone of the cave, and includes bats and larger mammals. Because many of the bats found are those that currently or historically roosted elsewhere in the cave, certain rooms are hypothesized to have served as “bat traps” where bats flew through narrow openings and could not find their way out (Baker 1963). The presence of *Tadarida brasiliensis mexicana* so deep in the cave is assumed to be the result of waking bats mistakenly flying deeper into the cave via the Main Corridor instead of out the Natural Entrance, as the routes occur next to one another along the same fracture line (Baker 1963). Other species of bats (Cave Myotis) that roost in the Left-Hand Tunnel may have entered the rooms on their way out of the cave (E. Lynch, pers. obs., November 2019). The Bat Mausoleum in Lower Cave contains what is thought to be a prior *Tadarida* colony, and could also explain the presence of that taxon deep in the cave (Jablonsky 1999; E. Lynch, pers. obs., November 2019). Bat bones are abundant in these scenic rooms, and sometimes show preferential orientation from water flow (from percolating groundwater) or have become partially or fully embedded within speleothems. Some unusually dry rooms have preserved bats as mummies (Baker 1963; Jablonsky 1999); some mummies are as much as 2,000 years old (Jablonsky 1999). A small number of the mummies are of non-cave dwelling bats such as *Aeorestes cinereus* and *Lasiurus blossevillei* (Baker 1963; Jablonsky 1993).

A non-bat example of a vertebrate dying within the cave is a juvenile *Nothrotheriops shastensis* specimen (Bretz 1949; Hill and Gillette 1987b; McDonald and Jefferson 2008). Early studies hypothesized the specimen was washed into the cave already dead (Bretz 1949; Gale 1957), but Hill and Gillette (1987a, 1987b) found no evidence of this and instead hypothesized that the animal must

have died near where the fossils were found. To support this hypothesis, Hill and Gillette (1987b) pointed out the lack of stream abrasion or rounding, the lack of scavenger damage to the bones (another way they may have been brought into the cave), and the lack of dispersion of the bones along a stream path. Furthermore, the cleanness of the bones, and the presence of most of them atop a silt layer without any silt packed into the bone, implies that the bones were deposited at the same time as the silt or later, which does not support the hypothesis that they were washed in (Hill and Gillette 1987a). The few bone fragments found within the silt seem to be gravity-sorted and gently washed, in line with a localized and gentle ponding effect (Hill and Gillette 1987b). Uranium-series dating on the *Nothrotheriops* bones indicated an age between 125,200 and 100,200 years before present, making the specimen the oldest found for its genus at that time and the oldest absolutely dated fossil from Carlsbad Cavern (Hill and Gillette 1987a). Specimens of the ringtail *Bassariscus astutus* have also been recovered from several places within Carlsbad Cavern. There are undoubtedly more skeletal specimens of ringtails located throughout Carlsbad Cavern (NPS Records 2020). Other large vertebrates reported from within the cave include Pleistocene jaguar *Panthera onca*, American lion *Panthera atrox*, and Holocene mountain lion *Puma concolor* (Santucci et al. 2001; Graham 2007; NPS Records 2019). Some of the mountain lion finds are so far into the cavern that their presence suggests an alternative, now closed, entrance to Carlsbad Cavern (Santucci et al. 2001). According to Pate (1999) the *Panthera onca* and *Panthera atrox* specimens are actually the same individual. The confusion likely comes from a 1958 letter from the CAVE superintendent that unspecified paleontologists at the Smithsonian Institution had identified the fossils “as those of a Pleistocene jaguar, [*Panthera atrox*].” The size difference between these two species is marked, and the true identity of the felid could be resolved by a cursory overview by an expert; the specimen is currently housed in CAVE’s own collections.

Carlsbad Cavern also has an unusual fossil deposit that also has possible cultural significance. A debris pile and associated sediment layer in the main corridor, just below the Natural Entrance, contains bits of plants, the teeth and bones of *Phrynosoma* sp. (including scales), birds, bats, and rodents, large mammal leg and rib bones, and native cultural artifacts such as beads (Black 1953). Much of this sediment layer was excavated while the current Natural Entrance Route trail was built. It is hypothesized that this debris pile is the result of floodwaters washing material down the Natural Entrance and carrying remains into the cave. Black (1953) also speculates that some of the material, particularly the larger bones, may have been purposefully placed into the cave by American Indians, though a more likely explanation is that they left the remains of hunts and ceremonies outside the cave and such were later washed in by water (E. Gearty, pers. comm., November 2019). With the exception of items retained as cultural resources (e.g., jewelry), most of the material discussed in Black (1953) was likely discarded.

Slaughter Canyon Cave (C-02): Slaughter Canyon Cave, once referred to as New Cave, is one of the richer caverns in terms of Quaternary vertebrate paleontological resources. Its primary resource is a number of guano deposits up to 5 m (16 ft) thick containing hundreds of thousands of bones belonging to the Pleistocene bat species *Tadarida constantinei* (Lawrence 1960; Morgan 2003b; Morgan and Lucas 2006). Like its modern relative *Tadarida brasiliensis mexicana*, *Tadarida constantinei* must have roosted here in massive colonies with dead individuals being preserved in the

guano as in Carlsbad Cavern (Morgan 2002, 2003a, 2004). Though disarticulated, entire skeletons including numerous skulls are common throughout the guano layer (Figure 28). The diagenetically altered bones and mature guano suggest that the remains are significantly older than the $209,000 \pm 9,000$ year (Lundberg and McFarlane 2006) and $212,000 \pm 3,000$ year ages calculated for the lower of two flowstone layers above the guano, likely more than 400,000 years old (Polyak et al. 2006). Current public tours of the cave are directed through the guano trenches where the bones are easily seen (Morgan 2002), introducing possible direct human impacts to the resource, though ranger supervision of tour groups and a gated entrance serve to discourage theft and vandalism. Some *Tadarida brasiliensis* fossils have also been found in the cave along with two species of smaller bats in the genus *Myotis* (Morgan 2003a; Morgan and Harris 2015).

Non-bat vertebrate fossils found within Slaughter Canyon Cave include: *Phrynosoma* sp. (Morgan and Harris 2015); undetermined snake (Serpentes) (Morgan 2003a); *Gopherus morafkai* (Morgan and Lucas 2006); a large raptorial bird (Morgan 2003a); rock squirrel *Otospermophilus variegatus* (Morgan and Harris 2015); pocket mouse *Perognathus* sp. (Morgan 2003a); *Neotoma* sp. (Morgan 2003a); desert cottontail *Sylvilagus audubonii* (Morgan and Lucas 2006); swift fox *Vulpes velox* (Morgan and Lucas 2006); *Canis* sp. (NPS Records 2019); *Puma concolor* (NPS Records 2019); *Bassariscus astutus* (NPS Records 2019); extinct mountain deer *Navahoceros fricki* (Kurten 1975; Morgan and Lucas 2006); dwarf pronghorn *Capromeryx furcifer* (White and Morgan 2011); Stock's pronghorn *Stockoceros conklingi* (Morgan and Harris 2015); extinct camel *Camelops hesternus*; and bighorn sheep *Ovis canadensis* (Morgan and Harris 2015). What was originally thought to be a large carnivore, perhaps *Arctodus simus* (Morgan 2003a; Morgan and Lucas 2006), was re-identified as the pronghorn *Stockoceros conklingi* (Morgan and Harris 2015). A specimen of the porcupine *Erethizon dorsatum* originally from Slaughter Canyon Cave was also found within park museum collections (NPS Records 2019). The overall assemblage fits the Irvingtonian North American Land Mammal Age (1.4–0.25 Ma), which concurs with the estimated age of the guano deposits and bat fossils (Morgan and Harris 2015). The presence of the tortoise *Gopherus morafkai* implies a milder winter climate without prolonged freezing temperatures (Morgan and Harris 2015). How these larger animals entered and died within the cave is not known, but it is likely that the cave has been open nearly 500,000 years. The modern entrance is navigable by humans without equipment, so it is possible animals could easily enter or be dragged in (G. Morgan, pers. obs., November 2019); however, Slaughter Canyon is part of an older truncated cave system, and what sorts of prior entrances existed are also unknown (DuChene and Martinez 2000; Lundberg and McFarlane 2006).



Figure 28. Bones and skulls of Constantine's free-tailed bat, *Tadarida constantinei*, in guano within Slaughter Canyon Cave. These Pleistocene bat bones may be more than half a million years old given their diagenetically altered state (NPS).

C-04: C-04 is a natural trap with a rubble pile containing many bones at the base of the main pit (Figure 29). This rubble pile is 12 m (40 ft) deep, and cave surveyors have speculated that it likely contains fossil resources; however, as expected most of the bones visible on the surface appear to be recent (NPS Records 2019). There are also two other bone localities marked with signs within the cave; one indicates the presence of an unidentified skull that was no longer there as of the last survey in 2017. The bones at these three sites have not been identified. On a ledge in the cave are the remains of a *Cathartes aura*, either recent or mummified given the presence of intact feathers. Elsewhere there are bat guano deposits and associated bat bones, species not identified (NPS Records 2019).



Figure 29. Fossils and/or recent bones at the base of the entrance pit to C-04 (NPS).

Lechuguilla Cave (C-05): Lechuguilla Cave is one of the ten longest caves in the world, and the second deepest in the United States (not counting lava tubes); however, exploration of the cave's true depths has only occurred since 1986, when the cave's rubble-strewn entrance was excavated open (NPS 2019). Though a fantastic location for Permian paleontology, Lechuguilla has not produced as much Quaternary vertebrate material (Morgan and Lucas 2006). A very young juvenile *Nothrotheriops shastensis* has been found inside Lechuguilla (Santucci et al. 2001; Graham 2007; McDonald and Morgan 2011), as well as a complete *Bassariscus astutus* skeleton, *Puma concolor* bones, and brown bear (*Ursus arctos*) bones of Holocene age (Santucci et al. 2001; Jablonsky 2004?; NPS Records 2019). Given the mostly to completely articulated state of the *Nothrotheriops* and *Bassariscus* remains, it would seem they died within Lechuguilla after being trapped in the cave. Skepticism ought to be exercised in regard to the ursid's identification; brown bears have never been

positively identified from any New Mexico Pleistocene cave deposit and most Pleistocene bears are the black bear *Ursus americanus* or the giant short-faced bear *Arctodus simus* (Morgan and Harris 2015).

More abundant within Lechuguilla are bat bones, though the populations do not equal those of Carlsbad Caverns (Jablonsky 2004?). Furthermore, most of the bat remains appear to be recent, some even displaying tissue and blood stains; Jablonsky (2004?) hypothesized that no Pleistocene bats are found within the cave, making the *Nothrotheriops* specimen the only Pleistocene animal fossil from Lechuguilla. A few specimens encapsulated in flowstone may be older, but flowstone encapsulation can occur very quickly as seen nearby in Carlsbad Cavern (Baker 1963; Jablonsky 2004?). Bat taxa found within Lechuguilla Cave include: *Myotis cilliolabrum*; *Myotis velifer*; *Myotis volans*; *Myotis yumanensis*; *Eptesicus fuscus*; *Aeorestes cinereus*; and *Corynorhinus townsendii* (Jablonsky 2004?). All of these species can be found today at or in the vicinity of CAVE.

Lechuguilla Cave is one of the few paleontological sites at CAVE to have its palynology assessed in a paleontological context. Jablonsky (1994) sampled pollen from guano at three sites, two suspected to be Pleistocene and one Holocene. However, it was found that the Pleistocene sites had experienced sediment mixing (Jablonsky 1994), and the later discovery that most fossil bats in the caves were of the recent Holocene (Jablonsky 2004?) shed doubt on whether the sampling areas contained any Pleistocene material to begin with. Most of the pollen recovered corresponded to desert plants extant in the region today, with a small number of riparian forms such as Apiaceae, Cyperaceae, and *Typha* represented (Jablonsky 1994). This would fit with the conclusion that the sampling areas were either Holocene to begin with, or contaminated by Holocene pollen, but does not completely rule out a Pleistocene age because many plants extant today in the area were also extant in the Pleistocene.

C-07: This cave was named for the recent domestic goat (*Capra aegagrus hircus*) bones found within. Small unidentified caprid or cervid bones have been found within C-07 as well. Bat guano of unknown age is also present within the cave (NPS Records 2019).

C-08: C-08 has “notably mature/old” appearing deposits of guano with associated bat bones occurring within it. No study has attempted to formally date the guano or identify the taxa of bats present, however. Living bats roost within the cave, contributing their own guano and remains, but the older deposits are separate from the living bat communities (NPS Records 2019).

Spider Cave (C-09): This cave contained *Erethizon dorsatum* skulls and associated post-crania, *Antilocapra americana* fossils, and recent bones of *Bos taurus* (domestic cow). The ages of fossil specimens are unknown, but both taxa are extant in CAVE (NPS Records 2019). Note that most identifications of *Antilocapra americana* from Pleistocene cave deposits in New Mexico are in error. Most are actually the medium-sized pronghorn *Stockoceros* or some other type of ruminant.

C-10: The primary fossil locality within this cave is a dry pool basin full of large mammal bones. Alison, Provencio, and Polyak speculated that the pool deposit is of Pleistocene age based on the condition of the fossils (NPS Records 2019). Some cave features are also hypothesized to be bear pits/dens, also Pleistocene in age. A complete *Bassariscus astutus* skeleton was found in the cave by

Roemer and Spaul in 1998, though it was thought to be recent; for reasons unknown, this skeleton was no longer present when a later survey team examined the cave. A number of other small bird, rodent, and bat bones are found in various deposits throughout the cave, and are of unknown species (NPS Records 2019). Recent bones of the introduced Barbary sheep, *Ammotragus lervia*, have been found near the entrance of the cave.

C-11: The proximal end of a scapula belonging to an unidentified mammal of uncertain age is the only fossil to have been recorded and collected from this cave (NPS Records 2019). The scapula is stored in the park museum collections.

C-12: This cave contains a number of unidentified small mammal bones, an artiodactyl tibia head, and a fragment of a large mammal's sternum. It also contains bat guano, but this guano is hypothesized to be recent (NPS Records 2019). Recent bones of a burro have also been found within the cave.

C-13: This cave has a number of small rodent bone deposits of unknown age, including an unidentified skull (NPS Records 2019). In the back of the cave there is an unidentified femur with possible cultural resource context.

C-14: Though flagged as a paleontological locality in CAVE's original "paleo sites list" prior to this inventory project, the only recorded bones found here belong to the domestic goat, *Capra aegagrus hircus*, which was introduced to the region at most several hundred years ago. The cave should be resurveyed for Pleistocene/Holocene or Permian fossils; if no such resources are found, this should not be considered a paleontological locality.

C-15: The sole vertebrate fossil from this cave is a bighorn sheep (*Ovis canadensis*) skull of likely Holocene age found relatively close to the entrance (NPS Records 2019). Bighorn sheep were extirpated from the vicinity of CAVE in the early 20th century (Logan 1979).

C-20: Bones of mule deer (*Odocoileus hemionus*) and bighorn sheep of unknown age have been found within this cave. Recent domestic goat bones are also present—the cave acts as a natural trap (NPS Records 2019).

C-21: This cave contains bat and cave swallow guano, age unknown. It is currently home to a small number of *Corynorhinus townsendii*, but no bat bones have been reported. The only vertebrate body remains found within belong to domestic goats (NPS Records 2019).

C-22: This cave contains bat skulls within guano, some of which is marked "old" in survey reports and is associated with flowstone (NPS Records 2019). There are two localities of unidentified large and small mammal bones with calcite encrustation/growth on them, as well as claw traces in flowstone (NPS Records 2019). Reports did not mention the size of the claw traces or the estimated size of the animal that made them. Recent *Capra aegagrus hircus* and *Ammotragus lervia* skulls are also present within the cave.

C-23: This cave was flagged as having paleontological resources in the original and incomplete “paleo sites list” for vertebrate fossils that existed prior to this inventory. However, no record of these supposed paleontological resources could be found in photographs, the cave’s sensitive files, or other materials. The original “paleo sites list” only marked presence/absence, and not nature of content, and included several caves that possessed only recently dead biological resources mistaken for paleontological resources. This cave should be inventoried/surveyed again at some time in the future to record if it actually has paleontological resources, and if so, what their nature is.

C-24: Three unidentified calcified mammal bones have been observed within this cave. *Bassariscus astutus* is known to shelter in this cave today, but one of the photographed bones appears to be too big to be that species. One of the bones was found in a different room far from the other two and therefore is likely a different individual or animal, though scattering of one individual specimen via flooding or scavengers is a possibility. An earlier biology survey also mentioned finding three mammal bones, which were assumed to be canid at the time. Additional chiropteran bones are also present within the cave. All material is of unknown age (NPS Records 2019).

C-25: This cave contains bat and cave swallow guano, age unknown. The skull, vertebrae, and leg bones of an unspecified type of goat identified by Dale Pate have also been found within. If these remains belong to a domestic goat, then they are recent or historic in age (NPS Records 2019).

C-26: This cave is mentioned as containing “mammal fossils,” but no further information about these fossils was provided in the source or could be found elsewhere. This cave needs to be re-examined so that the paleontological resources within can be properly documented.

C-28: This cave contains bat bones and associated bat guano. Several unidentified mid- to large-sized animal bones have been found in a single locality. A capreoline deer skull was recovered from this cave and accessioned into park museum collections; it is not recorded if this was from the same locality as the other large bones. Ringtails are known to make frequent use of the cave. Additional possible fossils include unidentified small bird and rodent bones as well as rodent teeth. These small animal remains are suspected to be recent, however (NPS Records 2019).

C-29: The most common possible fossils here are bat bones, some recent as evidenced by the presence of decaying flesh, and guano. More uniquely, the cave contains a complete, but disarticulated, skeleton of a large carnivoran (NPS Records 2019). Initial surveyors thought it looked canine, but a contacted scientist suggested it was a felid, possibly *Puma concolor* (Figure 30). Gary Morgan (pers. obs. March 2020) thinks it may be a canid based on the shape of the braincase and the atlas vertebra in Figure 30, most likely a coyote (*Canis latrans*) based on its size. There is a large, loose rock hanging over this specimen, and trip reports caution against disturbing the rock while moving through the crawl that leads to the carnivoran. A singular rib that is of a size akin to “a mid-sized dog” was found in a different area of the cave. Polished flooring in some sections may suggest prior or current habitual travel by animals (NPS Records 2019).



Figure 30. A series of photos of a disarticulated carnivore skeleton in C-29. This specimen has been tentatively identified as *Puma concolor* or *Canis latrans*; a definite identification would be desirable (NPS).

C-30: This natural trap contains unidentified cervid skeletons of unknown age and recent remains of domestic goats (NPS Records 2019).

Wen Cave (C-32): This cave functions as a natural trap, as most material is uncovered in the entrance pit or nearby. However, records and the thin sediment layer suggest most of the material is relatively recent. Charlie Peterson and Lloyd Logan collected from this site in 1974, and generated a list of materials and specimens retrieved with identifications (NPS Records 2019). No publication seems to have come from this collection. The specimens are currently housed at Texas Tech University. In interview, Lloyd Logan (pers. comm., February 2020) recalls having found a Pleistocene black vulture (*Coragyps occidentalis*) humerus from the cave; this bone is not mentioned in the faunal list, but would indicate a Pleistocene age for at least some of the material from this cave.

Taxa and specimens present include: *Crotalus* sp. vertebrae; bird bones (may include *Coragyps occidentalis* per interview with Logan); *Neotamias* sp.; unspecified and undated remains of *Canis latrans*; an unidentified carnivore upper P3 or P4 tooth; and unspecified bones and teeth of *Otospermophilus variegatus*, *Peromyscus* sp., Mexican woodrat *Neotoma mexicana*, cotton rat *Sigmodon hispidus*, *Pappogeomys castanops*, *Thomomys bottae*, *Erethizon dorsatum*, *Bassariscus*

astutus, and *Odocoileus hemionus* (NPS Records 2019). All of these taxa live within the boundaries of CAVE today, supporting the hypothesis that the fossil deposit here is Holocene in age. One complete and articulated skeleton of an unidentified rodent has also been found; from photographs it appears to be a rock squirrel, *Otospermophilus variegatus*. This matches an earlier trip report that mentioned the corpse of a rock squirrel near the same location that the articulated skeleton was later discovered, and the skeleton seems to have associated hairs near it in the photograph that match the coloration of a rock squirrel.

Muskox Cave (C-33): Muskox Cave is the richest macro-vertebrate locality at CAVE. It is comprised of a rubble-choked shaft that serves as the modern entrance, becoming wider in size until it terminates in a large, joint-controlled room (Logan 1981). The room contains a 5–10 m (16–33 ft) thick pile of sediment, breakdown blocks, and debris that filled in a Pleistocene sinkhole entrance. Fossil deposits can be found both in the debris pile sealing off the old Pleistocene entrance and nearer to the modern entrance, with the deposits nearer the entrance consisting entirely of Holocene taxa extant in the region today (Logan 1979, 1981). The Pleistocene sinkhole served as a natural trap that quickly killed or disabled most large animals entering, as evidenced by the lack of predation or scavenging marks on bones (Logan 1981). The cave possibly attracted animals into its depths via either the smell of water or dead/dying prey (Logan 1979).

Muskox Cave is a critical resource for paleoecology because nearly half its assemblage (Morgan and Harris 2015) are either extinct Pleistocene taxa or extant taxa extirpated from the Chihuahuan Desert and Guadalupe Mountains (Logan 1979). Many of the taxa found within Muskox Cave's assemblage are (or are hypothesized to have been) dependent on semi-aquatic, boreal, riparian, mild, or mesic environments that no longer exist in the region. Notable examples include the mesic-adapted shrub ox *Euceratherium collinum*, for which the cave is (inaccurately) named (Figures 6 and 31); the muskrat *Ondatra zibethicus*; the montane boreal mountain goat *Oreamnos harringtoni*; and *Sylvilagus floridanus*, now constrained to riparian and montane refugia within New Mexico (Logan 1979; Morgan and Lucas 2006; Morgan and Harris 2015). The masked shrew *Sorex cinereus*, which needs hydrosere environments, can be found in montane settings in central New Mexico and throughout the northern half of North America; this species is emblematic of the extirpated taxa found at Muskox Cave that now exist as separate northern and montane populations (Logan 1979).

Just as importantly, desert-adapted species extant at CAVE today, such as the desert shrews *Notiosorex crawfordi* and *Notiosorex dalquesti* (Carraway 2010), dominate deposits near the modern entrance and therefore suggest a drying trend between when the Pleistocene entrance closed and the modern entrance opened (Logan 1979). The extinct and extirpated species found at the modern entrance show evidence of being moved there by *Neotoma*, and thus are not in situ (Logan 1979).



Figure 31. The *Euceratherium* skull (center left) as it was found in Muskox Cave, with other bones covered with mineralization (NPS/RON KERBO). See Figure 6 for the excavation of this specimen.

Macrofloral samples from within Muskox Cave contain only the modern xeric genera *Celtis* and *Opuntia* (Logan 1981), but the faunal assemblage suggests sub-alpine forests and/or meadows/grasslands (Logan 1979, 1981). Harris (1985) listed the area around Muskox Cave as belonging to the Sagebrush-Steppe woodland zone—forested, but with grasses common, some sagebrush patches, and absence of purely boreal elements. The large cursorial mammals in the assemblage, such as the Mexican horse *Equus conversidens*, *Camelops* (dubious—not found in Morgan’s review of the USNM collection), two species of pronghorn (*Capromeryx furcifer* and *Stockoceros conklingi*), and the American cheetah *Miracinonyx trumani* (Logan 1979; Adams 1979; Van Valkenburgh et al. 1990) are potentially suggestive of a more open environment at some point during deposition of the Pleistocene material (Logan 1981; Morgan and Harris 2015). *Euceratherium* is quite abundant from Muskox Cave, with *Equus conversidens* and both species of pronghorn being fairly common as well. The most common large carnivore is *Canis dirus*; by contrast, *Miracinonyx trumani* is represented by a small number of bones.

C-34: This cave contains an *Otospermophilus variegatus* skeleton, as well as an unidentified rodent skull and bones. All are of unknown age. There are bird bones as well, but these seem to belong to modern juncos; these birds currently nest around the entrance to the cave.

C-49: This cave is divided into two levels, and the fossils are mostly found on the lower level of the cave. Fossil resources are comprised of a large amount of rodent bones, including some complete skeletons, of unknown age. David Ek noted in 1990 that all of the skulls were conspicuously missing from the skeletons in this cave, which is possible evidence of theft (NPS Records 2019). Earlier records indicate the presence of rodent fossils, but did not comment on the presence or absence of skulls.

C-54: This cave contains an articulated skeleton that is tentatively identified as a juvenile *Odocoileus hemionus*. Other remains include unspecified recent bones (NPS Records 2019).

C-56: This cave contains porcupine (*Erethizon dorsatum*) bones and quills of unknown age (NPS Records 2019). An area on the map is marked as the “Deer Beds,” but it was unclear if this means deer bones were found there. Many recent *Capra aegagrus hircus* skulls and bones are found within the cave, usually nearer to the entrance.

C-60: This cave contains a large amount of bird guano, as well as a “fairly fossilized” unidentified rib (NPS Records 2019). It was not specified if this rib was bird, mammal, or reptile, but it is presumed to be mammal.

C-62: Confirmed fossils within the cave include small rodent bones, a mouse jaw among them, of unspecified age. A trip report mentions “possible Pleistocene vertebrate remains” without further detail (NPS Records 2019). Older maps indicate porcupine fossils in the cave, but in a 1990 trip they were no longer present. Black and white photographs from 1977 that showed the possible fossils were mentioned in the corresponding report but were not included in the cave’s file.

C-64: This cave contains bones or fossils of *Erethizon dorsatum* and *Vulpes* sp., in addition to a number of unidentified small mammal bones (NPS Records 2019). Domestic goat remains are also found within this natural trap. Reports suggest that no one has gone to the bottom of the pit since the 1970s, with more recent surveys not undertaking the required vertical climb.

C-77: This cave contains a *Puma concolor* jaw and other unidentified mammal bones. No age estimated (NPS Records 2019).

C-86: Fossils within the cave include: an unidentified rodent incisor; unidentified small bones; a capreoline cervid vertebra; and a *Bassariscus astutus* skeleton (NPS Records 2019). The latter was formerly articulated, but a flooding event disarticulated the skeleton and washed it into another room. No age estimates exist for any of the remains.

C-87: This cave contains bat guano and wall scratches, also likely from bats (NPS Records 2019). In a crevice further into the cave there are a number of unidentified mid-sized mammal bones that appear distinctly procyonid, likely *Bassariscus astutus* or *Procyon lotor*; the former is more common in the area, while the latter seems more likely based on size (Figure 32). The perspective of the photographs makes it difficult to judge despite a pen being used for scale. *Bassariscus* is also more likely to enter caves. Different surveyors have identified these remains as both (NPS Records 2019). The photo is otherwise high quality, and could likely be used by an expert to identify the specimen.

C-89: As with C-23, CAVE’s original “paleo sites list” indicated this cave possesses paleontological resources, but a detailed examination of park records did not confirm this. *Puma concolor* scat has been found in this cave, and the original “paleo sites list” conflated non-living biological and paleontological resources at several other caves, so it is possible that this scat is the reason the cave was included. If a new survey does not turn up evidence for fossil or pre-fossil material in this cave, it should no longer be regarded as a paleontological locality.



Figure 32. Procyonid bones and skull from C-87. Different surveyors have tentatively identified these as either *Procyon lotor* or *Bassariscus astutus* (NPS).

C-90: Photographs from this cave show an abundance of bone (Figure 33), though the age of the remains is uncertain; no written report or cave survey detailing these bones could be found. The bones range in size from small to large, and most are mammalian (NPS Records 2019). Rod Horrocks (pers. obs., January 2020) hypothesizes that this locality/cave was a carnivoran den, and thus many of the bones belong to prey pulled into the cave. The presence of carnivoran scat or claw marks on the bones could confirm this.



Figure 33. Assorted mammalian fossils and/or modern bones in C-90 (NPS).

C-92: This cave contains an unidentified large mammalian limb bone (NPS Records 2019).

C-93: This cave contains a recent or mummified rodent skeleton, still with some flesh. Possibly *Neotoma* sp. If recent, there are no other possible Quaternary fossils reported from this cave (NPS Records 2019).

C-94: This cave contains the unidentified bones of a “ringtail-sized animal” (NPS Records 2019).

C-100: This cave contains an unidentified mammalian scapula of unknown age (NPS Records 2019).

C-106: This cave contains unidentified small rodent bones of unknown age (NPS Records 2019).

C-108: This small, short cave contains several unidentified large mammal bones. Also present is an unidentified mid-sized mammal bone; it appears to be a femur from an unknown taxon. Most importantly, the cave contains what seems to be a large rodent nest of some sort. There was speculation it may be a *Neotoma* midden, but according to surveyor Stan Allison it is not (pers. comm., November 2019).

C-111: This cave includes a rodent skull and associated bones, and a number of unidentified bones belonging to a small- to mid-sized mammal (NPS Records 2019).

KF-39: This karst feature does not meet the definitions for a cave, but may be of great paleoecological importance given the possible presence of packrat middens within. A single small midden, the first packrat midden reported in the subsurface at CAVE, has already been confirmed from this site (NPS Records 2019; S. Allison, pers. comm., November 2019) (Figures 10 and 34). More substantial middens may lie deeper within the feature, or sites like it (J. Betancourt, pers. comm., November 2019).



Figure 34. Close-up of the KF-39 packrat midden. The glossy outer coating suggests it has been periodically hydrated, making it unsuitable for dating or paleoecological study (NPS).

A-13: This site's assemblage includes disarticulated skulls, teeth, and post-crania of several taxa, including: *Erethizon dorsatum*, *Sciurus* sp., *Cynomys ludovicianus*, *Thomomys* sp., *Sylvilagus* sp., and the upper molar of *Equus* sp. (NPS Records 2019).

S-01: Fossils of a species of *Bison*, the first confirmed from within the boundaries of the park, were excavated here from several feet underground (NPS Records 2019).

S-09: The complete skull of an unidentified felid (tentatively *Puma concolor*) in great condition was recovered from the vicinity of this spring (NPS Records 2019).

Garden View Canyon: The partial skull of an *Odocoileus hemionus* was recovered from a site within this canyon (NPS Records 2019). The precise location and nature of the site was not recorded.

Caves with Pleistocene / Holocene Paleontological Resources Near CAVE

The Permian reef complex and associated karst environment present at CAVE extends beyond the park's boundaries. Many of the caves in this region contain fossils and have been extensively studied. The entrance to Big Manhole Cave is just outside the park's boundaries, about 1,200 m (3,900 ft) north of Lechuguilla Cave, and contains a similar Pleistocene/Holocene megafaunal assemblage to Muskox and Slaughter Canyon Cave, as well as a few taxa not confirmed to occur within CAVE such as *Bison* sp. (Harris 1993; Morgan and Lucas 2006).

Other important caves in the area include: Burnet Cave, 25 km (16 mi) northwest of CAVE (Schultz and Howard 1935); Dark Canyon Cave, 23 km (14 mi) northeast of CAVE (Tebedge 1988; Harris 2005); and Dry Cave, 20 km (12 mi) north of CAVE (Harris 1980, 1985, 1997; Metcalf 1977). Beyond these, there are still further paleontological sites throughout the Guadalupe Mountains and Chihuahuan Desert with biostratigraphic and paleoecological implications for CAVE. Further discussion of the content and implications of sites outside of CAVE at a similar level of detail to the preceding section is beyond the scope of this report—for more information, consult Morgan and Lucas (2006) or Morgan and Harris (2015) for a general overview of the region, or Santucci et al. (2001) for cave sites managed by the National Park Service.

Museum Collections and Curation

Paleontological specimens preserved in NPS museum collections or on loan to authorized external repositories are critical tools for understanding, protecting, and preserving natural resources within the parks. These specimens document park resources and scientific studies for the purposes of information, resource protection and management, and future analysis. Systematically collected specimens are the products and subjects of vital research that provide baseline data necessary for continued and effective park management. Museum specimens collected in the past may also provide information that is otherwise no longer obtainable. All collected fossil resources from CAVE must ultimately be stored within CAVE's museum collection, an NPS regional repository, or an approved external repository that has made an agreement with CAVE or the NPS. Director's Order 24: NPS Museum Collections and NPS Museum Handbook, NPS 77, and 36 CFR § 2.5 outline guidance for museum collections, including repository and curatorial obligations.

Park Collections

As of January 2020, the CAVE collection contained 1,348 paleontological specimens (E. Gearty, pers. comm., January 2020) (Figure 35). Aside from educational specimens and those on display in the visitor's center, no museum specimens are stored within the park itself. Instead, CAVE's museum collections are either kept in a collections storage facility at the CAVE Headquarters/Administrative Offices in nearby Carlsbad, New Mexico, or are stored in external, non-NPS repositories. The paleontological specimens at the Carlsbad, New Mexico facility were sorted by size and space convenience as opposed to locality, time period, or taxa (aside from a gross separation of invertebrate and vertebrate specimens). Efforts are underway to reorganize the drawers by locality instead, albeit retaining a separation between invertebrate and vertebrate specimens. There are roughly two cabinets of vertebrate specimens and two cabinets of invertebrate specimens at this facility, with the cabinets being approximately 1 m (3 ft) tall and containing around 8–10 drawers each. At time of writing some vertebrate specimens are inadequately housed, with loose bones, little padding, and a small number of specimen trays that mix several individuals of different taxa. Efforts are underway, in tandem with the reorganization of the drawers, to provide more protective and better fitting housings for these specimens.

Some NPS staff have indicated that portions of the invertebrate collections kept in the Carlsbad, New Mexico collections facility may include donated Mesozoic fossils that likely did not come from within CAVE (J. Hearst, pers. comm., December 2019). If this is found to be the case, unless the specimens have a historical or cultural resources connection to CAVE itself, park staff should consider finding a more appropriate repository for such specimens.

Catalogs and accession files are kept in the same facility as the fossils, and these documents sometimes have more detailed locality, collection, or taxonomic identification than the information recorded on the specimen tags. A significant portion of fossils in the collection storage facility have never been published, either because they come from sensitive caves/sites or because they were salvage collections; examples include the bear bones found in Lechuguilla Cave and the prairie dog fossils found at A-13.



Figure 35. *Camelops* bone from Slaughter Canyon Cave in the CAVE museum collections. *Camelops hesternus* was not previously reported from Slaughter Canyon Cave; this is one of several fossils housed in CAVE's museum collections that have not been documented in publications (NPS).

Field notes, research correspondence, cave survey reports that documented fossils, and similar documents are sometimes accessioned into the collections as part of the park archives. However, these can also be kept in the Resources, Science, and Stewardship (RSS) office files or in administrative records. For example, copies of Pat Jablonsky's field notes are kept in the RSS office, and Harvey DuChene's notes are on loan from him until they can be copied. Items in one type of records storage are sometimes, but not always, duplicated in others. This means there are records pertinent to paleontology that have not been formally entered into the park archives.

Security

Museum security measures are in compliance with NPS policy, as laid out in Director's Order 24: NPS Museum Collections and NPS Museum Handbook, NPS 77 (NPS 2004). Security for records kept at the RSS office is of a similar rigor to that employed for the museum collections proper.

Photographic Archives

The majority of photos taken during cave surveys are digitally stored within various locations on the resources network drive. Fossils are most likely to be photographed during cave surveys if they are especially numerous in an area, of excellent preservation, or are vertebrate remains. While some of these photographs are accessioned into the museum collections via the park archives, not all are. Furthermore, photographs are bulk cataloged when accessioned into the archives. Thus, individual photographs are not individual museum/archive items, and cannot be searched for in isolation from one another within the electronic catalog.

Many photographs of paleontological resources taken within CAVE at the present lack a scale bar, and sometimes lack an object in the photograph to provide scale as well. This is why several of the figures in this report depicting paleontological resources lack a scale. In the future, CAVE staff are strongly encouraged to photograph fossils with a scale bar (preferably one with the NPS logo), or an object whose size is easily understood by viewers if a scale bar is not available.

There are paleontological photos from Harvey DuChene's collections in the RSS office that are not accessioned into the archives and have not been backed up onto physical media; the RSS office seeks funding to scan these photographs.

An interactive photogrammetric model of the MuskoX Cave *Euceratherium* skull (USNM PAL 598576) is available on a website featuring a number of fossil specimens from NPS areas maintained in the Smithsonian collections (Figures 36 and 37). The 3-D model of the skull can be viewed at <https://3d.si.edu/model/fullscreen/p2b-1536596728204-1536762782843-0> (Figure 38).



Figure 36. The *Euceratherium* skull on a stand for photogrammetric documentation (NPS/JACK WOOD).



Figure 37. Creating a photogrammetric model begins with taking multiple photos of a specimen from different but overlapping angles. The photos are then brought together using computer programs (NPS/JACK WOOD).



Figure 38. A 3-D scan of the *Euceratherium* skull from Muskox Cave, resulting from the photogrammetry depicted in Figures 36 and 37. This interactive photogrammetric model can be viewed online by the public on the Smithsonian Institution's website, address given in text. The model is accurate enough to be used for some types of research, removing the need to handle the actual specimen (NPS/JACK WOOD).

Collections in Other Repositories

A substantial number of paleontological specimens from CAVE are kept in non-NPS repositories. The following list documents all known repositories of CAVE paleontological resources (see Appendix B for contact information):

- Carlsbad Caverns National Park Administrative Offices; CAVE
- Museum of Comparative Zoology, Harvard University; MCZ (Lawrence 1960)
- New Mexico Museum of Natural History and Science; NMMNHS (Morgan 2002, 2003a; Morgan and Lucas 2006; Morgan and Harris 2015; E. Gearty, pers. comm., January 2020)
- National Museum of Natural History, Smithsonian Institution; USNM (Cooper and Grant 1976; Logan 1979, 1981; Rigby et al. 1998) (Figures 36–38)
- Texas Tech University; TTU (NPS Records 2019) (this material had long been difficult to find in collections because it had been catalogued using a GUMO accession number)
- University of Nebraska State Museum; UNSM (Rigby et al. 1998)

This list is likely incomplete, because in the past loan paperwork was not always properly filled out and/or documentation is missing/not entered into the database (E. Gearty, pers. comm., 2020). For example, the specimens housed at the Smithsonian from Muskox Cave and other localities are not indicated in the CAVE specimen catalog. While published specimens can likely be tracked, any unpublished specimens that have been loaned out without proper documentation may essentially be lost. It is also worth noting that recent biologic remains were sometimes classified improperly as paleontological resources; e.g., much of the material that was, until recently, stored at Texas A&M falls into this category.

J. Harlan Johnson (1942) documented a number of fossil algae specimens from CAVE and the surrounding region, and reported placing type and figured specimens in his collection at the Colorado School of Mines (Golden, Colorado). At some point prior to 1999, the Johnson collection was transferred to the University of Kansas (Lawrence, Kansas) (correspondence from 2000 in the archives of the International Fossil Algae Association, <http://deptsec.ku.edu/~ifaaku/Archives/Hart-Kaesler.html>). According to the archival correspondence, the Johnson collection proved to be poorly documented, and specimens that were not labeled as type or figured specimens were placed in the teaching collections of the Department of Geology or given to the Department of Ecology. Searching the paleobotany and invertebrate fossil collections databases of the University of Kansas yields no specimens that can be reasonably linked to Johnson (1942), and since there is no indication that any of the specimens from the CAVE locality (#10) were either type or figured specimens, they would presumably have gone to the Department of Geology or Department of Ecology, and would not be recognizable without some other kind of documentation. It is also possible that Johnson did not retain the CAVE specimens to begin with; Johnson (1942) only mentioned retaining type and figured specimens, leaving open the possibilities that some specimens were only documented in the field, or that he discarded some or all of the non-type and figured specimens.

It is possible that fossils were also collected from CAVE prior to its 1923 authorization as a unit of the National Park Service, given herding and guano mining operations were active in the area during

the 1800s and early 1900s. However, such collections do not seem to be recorded if they occurred. There is no positive evidence that any fossils reported in Shumard (1858) or Girty (1908) were collected from the vicinity of CAVE.

Type Specimens

Five type specimens have been named from localities within CAVE's boundaries, including four Permian invertebrates and one Pleistocene vertebrate (Table 2; Figure 39). The collection of the *Tadarida constantinei* holotype in 1960 was from a locality already within the park's boundaries at the time, and CAVE expanded to its present size later that year.

Table 2. Fossil taxa named from specimens found within CAVE.

Taxon	Citation	Age, Formation	Type Specimen	Notes
<i>Glabrocingulum</i> (<i>Stenozone</i>) <i>carlsbadensis</i>	Batten 1989	Permian, Capitan	USNM 431537	Gastropod
<i>Plectelasma</i> <i>planidorsatum</i>	Cooper and Grant 1976	Permian, Capitan	USNM 153357	Brachiopod
<i>Preverticillites parva</i>	Rigby et al. 1998	Permian, Capitan	UNSM 34701	Demosponge
<i>Lemonea exaulifera</i>	Rigby et al. 1998	Permian, Capitan	UNSM 35215	Sclerosponge
<i>Tadarida constantinei</i>	Lawrence 1960	Pleistocene, cave deposits	MCZ 49076	Bat



Figure 39. The holotype of *Plectelasma planidorsatum* at the USNM (USNM 153357). Scale bar increments are centimeters (NPS).

Park Paleontological Research

The following is a list of permitted research at CAVE since 1990. Historic research, and some more in-depth discussion of select research listed below, is covered in the “History of Paleontological Work at CAVE” section of this report.

Research Since 1990

Since 1990, CAVE has issued 40 permits for 24 projects of primarily paleontological interest, or with a significant paleontological component. These numbers do not include projects tangentially related to paleontology, such as other geological projects, or paleoecological projects studying non-paleontological aspects of speleothems. All of the permits were issued between 1991 and 2003. Brief descriptions of the projects follow.

- CAVE1991ACEB, principal investigator Ellen Mackey of University of California Berkeley, project “Preliminary Palynological Investigation for Lechuguilla Cave, Carlsbad, New Mexico”, issued for 1991; same project issued permit CAVE1992AFZY in 1992 and CAVE1993AIKE in 1993.
- CAVE1991ACEJ, principal investigator S. Mazzullo of Wichita State University, project “Paleoecology of Outer-Shelf Back Reef facies of Capitan Reef System”, issued 1991; same project issued permit CAVE1992AFZQ in 1992.
- CAVE1991ACEO, principal investigator Donald McFarlane of the Natural History Museum of Los Angeles County, project “Paleoecological Studies on the Ancient Bat Guano Deposits of [redacted], Carlsbad Caverns National Park”, issued 1991; same project issued permit CAVE1992AFZL in 1992 and CAVE1993AIJV in 1993.
- CAVE1992AGAE, principal investigator Thomas Hobbs of North Harris College, project “Deposition, Preservation and Reconstruction of Bat Remains in [redacted]”, issued 1992.
- CAVE1992AGAG, principal investigator Pat Jablonsky of the Denver Museum of Natural History, project “Chiropteran Collecting and Identification in Carlsbad Cavern”, issued 1992; same project issued permit CAVE1993AIKL in 1993.
- CAVE1992AGAH, principal investigator Pat Jablonsky of the Denver Museum of Natural History, project “Guano Collecting in Lechuguilla Cave, [redacted]”, issued 1992; same project issued permit CAVE1993AIKM in 1993.
- CAVE1992AGAI, principal investigator Pat Jablonsky of the Denver Museum of Natural History, project “Chiropteran Identification (Remains of) in Lechuguilla Cave”, issued 1992; same project issued permit CAVE1993AIKN in 1993.
- CAVE1992AFZV, principal investigator S. Noe of the University of Bremen, project “Development of Reef Mounds in a Stacked-Island Outer Shelf Facies (Tansill Time, Dark Canyon Area, Guadalupe Mountains)”, issued 1992.
- CAVE1992AGAB, principal investigator Bruce Wardlaw of the U.S. Geological Survey, project “Permian Conodont Biostratigraphy of West Texas and New Mexico Guadalupian

Biostratigraphy and the Establishment of the Guadalupian Series of the Permian”, issued 1992; same project issued permit CAVE1993AIKH in 1993.

- CAVE1993AIKA, principal investigator George Brook of the University of Georgia, project “Paleoenvironmental Analysis From Cores of Speleothems in Carlsbad Caverns”, issued 1993.
- CAVE1993AIJU, principal investigator Brenda George of the University of Texas at Austin, project “Distribution and Paleoecology of Dasycladacean Algae in the Capitan and Tansill Formations”, issued 1993.
- CAVE1993AILE, principal investigator Pat Jablonsky of the Carlsbad Museum, project “Salvage Operation for the Removal of Bones Near the Entrance Area in Lechuguilla Cave”, issued 1993.
- CAVE1993AIKU, principal investigator Lloyd Pray of the University of Wisconsin, project “Neptunian Fossil-Rich Dikes in the Capitan-Massive, Permian, Guadalupe Mountains”, issued 1993.
- CAVE1993AILD, principal investigator J. Keith Rigby of Brigham Young University, project “Calcareous Sponges and Depositional Environments of the Upper Capitan Limestone, Guadalupe Mountains, Texas and New Mexico”, issued 1993; same project issued permit CAVE1994ALCF in 1994.
- CAVE1994ALCJ, principal investigator Pat Jablonsky of the Carlsbad Museum, project “Sloth Recovery Project-Lechuguilla Cave”, issued 1994; same project issued permit CAVE1995ANAE in 1995, CAVE1996AQEL in 1996, CAVE1997ASIH in 1997, and CAVE1999J in 1999.
- CAVE1994ALCK, principal investigator Pat Jablonsky of the Carlsbad Museum, project “Guano/Sediment Studies – Entrance Region of Lechuguilla Cave”, issued 1994.
- CAVE1995AMZX, principal investigator Pat Jablonsky, project “Paleoecological Studies of Ancient Guano Deposits of Carlsbad Cavern”, issued 1995; same project issued permit CAVE1996AQED in 1996 and CAVE1997ASHW in 1997.
- CAVE1995ANAF, principal investigator Ronald Johns of Austin Community College, project “Taxonomy and Paleoecology of Sponges in the Lower and Middle Capitan Formation, Guadalupe Mountains, New Mexico and West Texas”, issued 1995.
- CAVE1997ASIG, principal investigator Pat Jablonsky, project “Skeletal Chiropteran Identification for Species Diversity Determination in Carlsbad Cavern, Carlsbad Caverns National Park, New Mexico”, issued 1997.
- CAVE1998vjp, principal investigator Victor James Polyak of Texas Tech University, project “A. Using Stalagmites for Paleoclimate Studies; B. Bat Guano Deposit of Slaughter Canyon Cave; C. Age and Origin of Carlsbad Cavern and Lechuguilla Cave”, issued 1998.
- CAVE1998021, principal investigator Brenda Kirkland George of the University of Texas at Austin, “Documentation of Changes in Paleoecology and Paleoenvironment in the Capitan System”, issued 1998.

- CAVE199911, principal investigator Pat Jablonsky, project “Carbon-14 Analysis of Chiroptera Specimens and Guano Deposits, Carlsbad Cavern”, issued 1999; same project continued in 2000.
- CAVE-2002-SCI-0201, principal investigator Gary Morgan of the New Mexico Museum of Natural History and Science, project “The Extinct Free-Tailed bat *Tadarida constantinei* from Slaughter Canyon Cave, Carlsbad Caverns National Park, New Mexico: A study of its Taxonomy, Age, and Taphonomy”, issued 2002.
- CAVE-2003-SCI-0018, principal investigator Gary Morgan of the New Mexico Museum of Natural History and Science, project “The Extinct Free-Tailed Bat *Tadarida constantinei* and Associated Vertebrates from Pleistocene Guano Deposits in Slaughter Canyon Cave, Carlsbad Caverns National Park, New Mexico”, issued 2003.

Current Research

Besides continued expeditions into Lechuguilla Cave and surveys of caves, archeological sites, and other locales within CAVE, which record fossils found as part of the wider process of surveying, there are currently no dedicated paleontological research projects ongoing at CAVE. Steve Skotnicki is presently working on new stratigraphic columns for the park, which while focused on the geology would be useful to paleontology. In particular, any future biostratigraphic work will benefit from these stratigraphic columns. Work on the microorganisms endemic to the caves is also ongoing, and while the focus is on the extant microbes, these studies also pertain to the nature and age of several types of speleothems assumed to be biogenic in nature (and thus would be ichnofossils).

Paleontological Research Permits

See the National Park Service Natural Resource Management Reference Manual DO-77 section on Paleontological Resource Management, subsection on Scientific Research and Collection (<https://irma.nps.gov/DataStore/Reference/Profile/572379>). NPS Management Policies (NPS 2006a), section 4.8.2.1 on Paleontological Resources, states that

The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit.

Any collection of paleontological resources from an NPS area must be made under an approved research and collecting permit. The NPS maintains an online Research Permit and Reporting System (RPRS) database for researchers to submit applications for research in NPS areas. Applications are reviewed at the park level and either approved or rejected. Current and past paleontological research and collecting permits and the associated Investigator’s Annual Reports (IARs) are available on the RPRS website (<https://irma.nps.gov/rprs/>). Additional information on NPS law and policy can be found in Appendix C.

Interpretation

Importance of Paleontological Resources to Interpretation at CAVE

Though there is currently no Long Range Interpretive Plan for CAVE, the CAVE Foundation Document (2017) states the following interpretive themes:

- 1.) *“The awe-inspiring caves of Carlsbad Caverns National Park began 250 million years ago, when a living reef formed in a Permian sea. Phases in speleogenesis have included uplift of the reef, dissolution of chambers by sulfuric acid, and decoration by the slow drip of calcium carbonate-laden waters.”*
- 2.) *“The continuing discovery and study of organisms in Carlsbad Caverns National Park, such as the ‘microbial forest’ of Lechuguilla Cave and the Brazilian free-tailed bat colony of Carlsbad Cavern, invite greater understanding of how seemingly inconsequential and misunderstood life-forms play significant roles in natural processes that affect our lives.”*
- 3.) *“The natural and cultural resources of the Northern Chihuahuan Desert, as preserved within Carlsbad Caverns National Park and Wilderness, reveal how plants, animals, and people have adapted to an arduous environment.”*
- 4.) *“The relationships between surface and the subsurface environments of Carlsbad Caverns National Park provides unique opportunities to explore the sometimes surprising interactions of these seemingly disparate worlds.”*
- 5.) *“Historical and ongoing discoveries at Carlsbad Caverns National Park exemplify human curiosity and the innate desire to overcome challenges and explore new frontiers.”*
- 6.) *“The ongoing story of providing access to and preserving resources at Carlsbad Caverns National Park reveals how humans value and showcase heritage and continue to learn how to protect it.”*

Paleontological resources possess a varying degree of relevance to all of these interpretive themes. Paleontology is utterly critical to the first theme, as the very rock some of the most spectacular caves occur in was generated by paleobiologic activity. Both carbonate and siliciclastic strata are fossiliferous, ranging from abundantly so in the reef units, to sparsely so in the evaporate facies (Hayes 1964; Graham 2007). The formation and burial of the reef complex, as well as nearby hydrocarbon deposits, was a critical first step in the formation of the caverns (Graham 2007).

Paleontological resources have major utility to the interpretation of the second theme, in that fossils enable the study of extant organisms into the past as well as extinct ones. Fossils record bat inhabitation of the caves for likely the last half-million years (Lundberg and McFarlane 2006; Polyak et al. 2006). There is fossil evidence of microbes within the caves as well (Palmer and Palmer 1990; Provencio and Polyak 2001). Several caves possess abundant insectivore, rodent, and bird fossil assemblages (NPS Records 2019; G. Morgan, pers. obs., December 2019). Extending back into the Permian, future and more detailed research on the Permian reef complex could be greatly informative about how marine reef-like systems operate in the relative absence of hard-bodied reef-builders like modern scleractinian corals.

The Pleistocene/Holocene fossil record is of key importance to the third interpretive theme, as the transition from the Pleistocene into the Holocene marked a substantial increase in aridity and desertification that led to significant changes in the composition of local ecosystems. The fossil record contains evidence that supports hypotheses made by neontologists about xeric-adapted species and evolutionary innovations. The migration/extirpation of some extant montane taxa from the CAVE region after the Pleistocene has important implications for conservation paleobiology going into the future (Logan 1979; Dietl et al. 2015). More detailed research could extend interpretation into the effects of changing climate within the Pleistocene; the oldest fossils dated at Carlsbad Caverns and Slaughter Canyon Cave reveal that CAVE's Pleistocene record must span several Pleistocene pluvial and interpluvial periods (Morgan and Harris 2015). For another example, the assemblage of Muskox Cave indicates that both forested and open environments may have existed in its vicinity during the Pleistocene (Harris 1985).

Natural trap caves and the fossils of cave dwelling or denning taxa play a minor role in supporting the fourth interpretive theme. Furthermore, the ability to observe the Permian stratigraphy both on the surface and underground is of immense scientific value, though a few units are exposed in one environment or the other at CAVE.

Paleontological research, and paleontology's contributions to geologic research, is an integral aspect of the fifth interpretive theme. Likewise, the interpretation, public access, and preservation of paleontological resources at CAVE are integral aspects of the sixth interpretive theme.

Current Status of Interpretation of Paleontological Resources at CAVE

Paleontology and paleontological resources are currently a secondary concern for interpretation at CAVE, but one that is recognized as important and is not ignored by interpreters. The visitor center has a display presenting basic information on the Permian reef complex that includes fossil gastropods, ammonoids, and a *Lemonea* sponge (Figures 40 and 41), but these exhibits are scheduled to be replaced in 2020. Similar information is briefly presented in the park video. All interpreters who responded to a survey of questions about paleontological resources indicated that they are aware of both Permian and Pleistocene/Holocene fossils in the publicly accessible caves. Most interpreters indicated that they draw visitor attention to fossils in Carlsbad Cavern and Slaughter Canyon Cave. Specific examples include: the bat bones in several locations within Carlsbad Caverns and in the guano mining trenches of Slaughter Canyon Cave; Permian fossil deposits in Carlsbad Cavern and Slaughter Canyon Cave; a bat encased in a speleothem in Lower Cave; and two interpreters said that they talk to visitors on the Main Corridor trail about both the Permian shelf taxa present and the Pleistocene mammal fossils collected along that section such as *Nothrotheriops shastensis* and *Panthera atrox*.

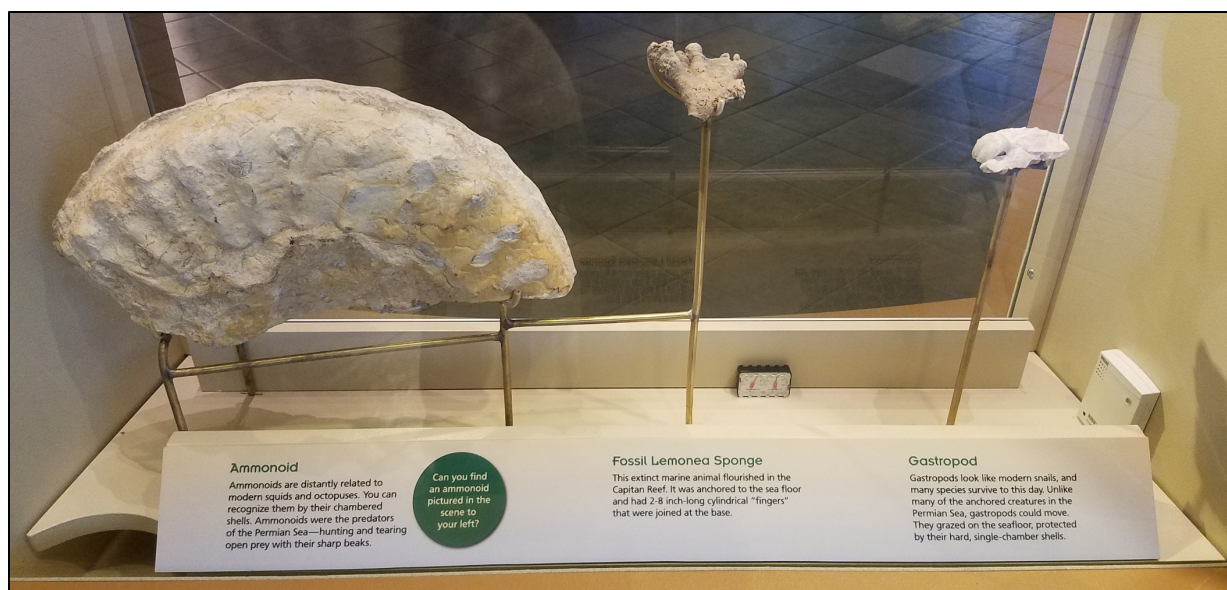


Figure 40. Fossils of an ammonoid, sponge, and gastropod on exhibit in the visitor center (NPS/VINCENT SANTUCCI). Currently (spring 2020), the text from this exhibit is being rewritten to correct mistakes.



Figure 41. A diorama of the Permian life of the CAVE area in the visitor center (NPS/VINCENT SANTUCCI). Currently (spring 2020), these displays are scheduled to be replaced.

Interpreters are asked about fossils by visitors frequently at CAVE. The most common questions relate to the presence of fossils, their age, what animals they are from, where they can be found within the caves, and whether dinosaur fossils have been found within the park. Less common

questions requests include: if the Pleistocene fossils in the caves mean the animals were living inside the caves (most sheltered or denned within, but few were permanent dwellers); whether there was an ocean here during the Mesozoic (there was a seaway, but only in the Cretaceous); whether bats ever come to the Big Room (guano, bones, and mummies prove they did/do); and questions pertaining to the trilobite and the nautiloid next to the Big Room elevator. Interpreters feel that they are well equipped to answer most questions asked of them by visitors; only rarely does a visitor ask a more specialized question pertaining to specific aspects of Permian or Pleistocene paleobiology/paleoecology.

Despite the ability to answer most visitors' questions, the majority of interpreters indicated that they would like to have additional information and/or resources related to paleontological resources. In particular, several mentioned they would like to have more educational specimens that could be easily transported for use in surface programs, scheduled cave tours, and roves of the self-guided trails in Carlsbad Cavern. Others asked for a "more detailed interpretation of specifics for each species that lived and died throughout the Permian Period" and their contribution to the overall Permian paleoecosystem both in the shelf and on the reef. This last request would first require additional scientific study, survey and taxonomic identification within CAVE before it could be done.

Recommendations for Interpretation at CAVE

Improvements to interpretation of paleontological resources at CAVE face several challenges; three are summarized here. The first challenge is the data gap originating from the relative lack of research undertaken with the park regarding Permian taxa and systems. CAVE's Capitan Limestone and associated shelf formations are presently hypothesized to date from the late Guadalupian (265–260 Ma), except for possibly some deep regions of Lechuguilla Cave. While many genera are likely shared with older outcrops in the region, such as at GUMO, the reef complex varied in structure and species both temporally and spatially (Kerans and Kempter 2002). Thus, it may be incorrect to assume a one-to-one correlation between CAVE fossil assemblages and those found elsewhere in analogous units. Furthermore, CAVE records the period preceding the death of the Guadalupian reef, which may significantly alter the taxa found therein compared to other locations and be of significant paleoecological importance. Additional paleontological and paleoecological research undertaken within CAVE itself would be needed to close this gap. Presenting the full story of the reef complex, and how CAVE's deposits may differ from those found elsewhere in the basin, would require collaborative work with repositories of material from other nearby regions (e.g., GUMO). Interpreters can engage the visitors on this data gap by explaining the need for additional research, and this can provide a great opportunity to discuss science in general and paleontology in particular.

The second challenge applies to the Pleistocene/Holocene taxa. Presently a fair amount of research has been done on the paleoecological implications of cave fossil assemblages from CAVE; however, little of this information seems to be integrated into the interpretive program. For example, visitors are shown the bat bones in multiple caves and correctly informed that the deposits prove colonies of bats have roosted in the park for thousands of years (Jablonsky 2001), but the presence of tree-dwelling bat fossils and other taxa suggestive of a more boreal environment in the Pleistocene is

rarely conveyed (Baker 1963). Interpretation at CAVE could benefit from additional elaboration on how discovery of Quaternary cave faunas has informed knowledge about the expansion of the desert, extinction or extirpation of mesic taxa, and the survival or evolution of xeric adapted taxa in the northern Chihuahuan desert and Guadalupe mountains. Further research within CAVE, such as a study of Quaternary invertebrate faunas similar to Metcalf (1977) or identifying the vertebrate microfossil assemblages found in many caves to genera or species, could help further inform interpretation of the Pleistocene and early Holocene at CAVE.

The third challenge regards the sensitive nature of many of the caves where many of the fossils are found. Much of the most detailed inventory and analysis of paleontological resources at CAVE has occurred within restricted access or sensitive caves. Especially for the Pleistocene/Holocene vertebrates, many taxa only occur within sensitive caves. Part of this issue is easily solved, as the partial or entire redaction of detailed locality information from published work is routine in paleontology; the identities and paleoecological implications of the taxa discovered could be presented to the public without mentioning where they were found. The other side of the issue is the amount of analysis that is only recorded in internal park documents. When this analysis concerns caves that are publicly known, such as Muskox Cave and Lechuguilla Cave, and/or the study in question took place long ago, again in the case of Logan's (1979) work in Muskox Cave, the CAVE resource office may want to consider publishing the pertinent report's findings with consent of the original author. The viability of this option is highly dependent on if the results, or the data they stem from, are themselves sensitive; information unfit for public dissemination could always be individually redacted. Logan (1979) and Jablonsky (2004?) are examples of unpublished internal reports containing information of interest to the scientific community that may be appropriate for publicly accessible publications.

Paleontological Resource Management and Protection

National Park Service Policy

Paleontological resources are non-renewable remains of past life preserved in a geologic context. At present, there are 419 units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official tally. As of April 2020, 276 are known to have some form of documented paleontological resources, and paleontological resources are mentioned in the enabling legislation of 18 units. Fossils possess scientific and educational values and are of great interest to the public; therefore, it is exceedingly important that appropriate management attention be placed on protecting, monitoring, collecting, and curating of these paleontological specimens from federal lands. In 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law as part of the Omnibus Public Land Management Act of 2009. The new paleontology-focused legislation includes provisions related to inventory, monitoring, public education, research and collecting permits, curation, and criminal/civil prosecution associated with fossils from designated DOI lands. More information on laws, policies, and authorities governing NPS management of paleontological resources is detailed in Appendix C. Paleontological resource protection training is available for NPS staff through the NPS Geologic Resources Division (GRD). GRD is also available to provide support in investigations of paleontological resource theft or vandalism.

As of the date of this publication, an interagency coordination team including representatives from the Bureau of Land Management (BLM), Bureau of Reclamation (BOR), National Park Service (NPS) and U.S. Fish & Wildlife Service (FWS) is in the processes of developing Department of Interior (DOI) final regulations for PRPA. Draft DOI regulations were published in the Federal Register in December 2016 and were available for 60 days to allow for public comment. The interagency team has reviewed public comments provided for the draft regulation and have drafted the final regulation. The final regulation has completed surnaming by the DOI Solicitor's Office and each of the four bureau directors. The final regulation has been forwarded for final review by DOI Assistant Secretaries. For more information regarding this act, visit <https://www.nps.gov/subjects/fossils/fossil-protection.htm>.

2006 National Park Service Management Policies (section 4.8.2.1) state

... Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).

Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately

documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.

The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the [National Parks Omnibus Management Act of 1998](#).

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

Fossils have scientific, aesthetic, cultural, educational, and tourism value, and impacts to any of these values impairs their usefulness. Effective paleontological resource management protects fossil resources by implementing strategies that mitigate, reduce, or eliminate loss of fossilized materials and their relevant data. Because fossils are representatives of adaptation, evolution, and diversity of life through deep time, they have intrinsic scientific values beyond just the physical objects themselves. Their geological and geospatial contexts provide additional critical data concerning paleoenvironmental, paleogeographic, paleoecologic, and a number of other conditions that together allow for a more complete interpretation of the physical and biological history of the earth. Therefore, paleontological resource management must act to protect not only the fossils themselves, but to collect and maintain other contextual data as well.

In general, losses of paleontological resources result from naturally occurring physical processes, by direct or indirect human activities, or by a combination of both. These processes or activities influence the stability and condition of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). The greatest loss of associated contextual data occurs when fossils are removed from their original geological context without appropriate documentation. Thus, when a fossil weathers and erodes from its surrounding sediments and geologic context, it begins to lose significant ancillary data until, at some point, it becomes more a scientific curiosity than a useful piece of scientific data. A piece of loose fossil “float” can still be of scientific value. However, when a fossil has been completely removed from its original context, such as an unlabeled personal souvenir or a specimen with no provenance information in a collection, it is of very limited scientific utility. Similarly, fossils inadvertently exhumed during roadway construction or a building excavation may result in the loss or impairment of the scientific and educational values associated with those fossils. It is not necessary to list here all of the natural and anthropogenic factors that can lead to the loss of paleontological resources; rather it is sufficient to acknowledge that anything which disturbs native

sediment or original bedrock has potential to result in the loss of the paleontological resources that occur there, or the loss of the associated paleontological resource data.

Unpermitted fossil collecting may be of concern for CAVE, though few records of such activity exist. A single record of attempted theft of a fossil occurred at the Natural Entrance in January 2019. Besides that, there are: chisel marks on or near fossiliferous rocks in Slaughter Canyon; a fossil locality (C-49) with many complete rodent skeletons sans skulls; a porcupine skeleton disappeared from C-62 prior to 1990; and a skull in C-04 that went missing between surveys. In all of these cases, there is no definitive evidence of theft; for example, the missing rodent skulls and the vanished skull in C-04 could be explained by natural causes, such as differential rates/probability of transport by outwash.

Cave localities are in a distinct class for management due to the close connection with archeological resources and unique issues affecting cave resources. CAVE was authorized as a unit of the NPS explicitly for its extensive system of caves exhibiting large rooms, and these caves formed in highly fossiliferous Permian bedrock. Furthermore, many of the caves contain fossils of Pleistocene/Holocene animals, with some of the deposits in guano of former bat colonies or in natural trap caves being highly productive. Overall, the majority of the Pleistocene/Holocene record at CAVE is likely deposited within caves; though the Permian has more non-cave localities, it should be noted that a few caves (Lechuguilla) have paleontological resources that could be considered Lagerstätte quality. Many more caves have not had their Permian-age paleontological resources assessed beyond presence/absence, and some have not been checked for the presence of Permian fossils at all. Several caves and karst features also contain paleontological resources in close association with cultural resources. See Santucci et al. (2001) for additional discussion of paleontological resources in cave settings.

The Federal Cave Resources Protection Act of 1988 (16 USC § 4301–4310) is a second federal law for consideration in the management of cave paleontological resources at CAVE. The law provides a legal authority for the protection of all cave resources on NPS and other federal lands. The definition for “Cave Resource” in the legislation (Section 4302) specifically “includes any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems.”

Management strategies to address any of these conditions and factors could also incorporate the assistance of qualified specialists to collect and document resources rather than relying solely on staff to accomplish this task at CAVE. Active recruitment of paleontological research scientists may also be used as a management strategy.

Law Enforcement Interaction with CAVE Paleontological Resources

The only documented incident of fossil theft or vandalism was at the Natural Entrance to Carlsbad Cavern during the government shutdown in early 2019, when a park ranger caught a visitor trying to chisel an unspecified fossil out of the rock. However, there is evidence of possible theft or vandalism elsewhere in the park. For example, the surface trail through Slaughter Canyon that leads to Slaughter Canyon Cave, and goes past several sensitive caves, has Permian fossils exposed in the

rock along the surface. Though many of these fossils are small and unassuming, larger gastropods and brachiopods are easier to identify. Several locations along the trail, just off the trail, and near the entrance to several caves display chisel or chip marks/gouges large enough to have possibly held fossils. If these markings are evidence of theft or vandalism, it is unknown what was taken. There is also the risk that such chisel marks may attract further attention to the vandalized resources.

Notably, no such marks were immediately evident in Carlsbad Cavern itself aside from the aforementioned one near the natural entrance, though vandalism of speleothems (sometimes accidentally) is a historic and ongoing problem at the park (R. Horrocks, pers. obs., 2019). This is suggestive that real or perceived ranger presence dissuades theft and vandalism. Furthermore, because of how noise carries in caves and the hardness of some of the rock units, it would likely be difficult for thieves to extract fossils unnoticed from a well-staffed and well-visited cave like Carlsbad Cavern. On the reverse, fossils exposed in surface wilderness trails, which are rarely visited, monitored, or maintained, are at unknown risk. It is unknown if the abundant fossilized bat bones present in Carlsbad Cavern or Slaughter Canyon Cave are subject to theft or vandalism; many of the bones are found loose on the floor and could easily be pocketed without the need for excavation, though the bones' great fragility and the guided tour-only nature of the areas where bat bones are most abundant may be deterrents to successful theft.

Sensitive and less visited public caves also show potential signs of theft or vandalism, as recorded by intermittent cave monitoring and surveys. C-04 has several fossil localities marked with signs, and the most recent survey of the cave noted that one sign identified the prior existence of a fossil skull that was no longer present (NPS Records 2019). David Ek noted in 1990 that all the partially to fully articulated rodent skeletons in C-49 were missing skulls, possibly indicating targeted fossil theft in this cave that is within easy walking distance of the visitor center (NPS Records 1990, 2019). However, it is possible that the skulls may be absent because of taphonomic processes, and prior records about C-49 do not mention the presence of skulls either.

Law enforcement protection of paleontological resources could be supported by a number of potential actions, including: a focused assessment of theft and vandalism of fossils (potentially along with an updated study of speleothem vandalism; see Paris and Gianantonio 1983 and Benck et al. 2017); development of a paleontological resource management plan that includes monitoring and protection information; development of protocols for informal monitoring by park staff (not just law enforcement) along surface and wilderness trails; and development of, or participation in, natural resource protection training. Without these steps, CAVE will continue to face problems with identifying, recording, preventing damage to, and enforcing laws protecting its fossil resources.

Baseline Paleontology Resource Data Inventories

A baseline inventory of paleontological resources is critical for implementing effective management strategies, as it provides a baseline of information for decision-making. This inventory report has compiled information on previous paleontological research done in and near CAVE, taxonomic groups that have been reported within CAVE boundaries, and localities that were previously reported. This report can serve as a baseline source of information for future research, inventory reports, monitoring, and paleontological decisions. The Paleontological Resource Inventory and

Monitoring report for the Chihuahuan Desert Network (Santucci et al. 2007) and the references cited within were important baseline paleontological resource data sources for this CAVE-specific report.

Paleontological Resource Monitoring

Paleontological resource monitoring is a significant part of paleontological resource management, and one which usually requires little to implement beyond time and equipment already on hand, such as cameras and GPS units. Monitoring enables the evaluation of the condition and stability of in situ paleontological resources (Santucci and Koch 2003; Santucci et al. 2009). A monitoring program revolves around periodic site visits to assess conditions compared to a baseline for that site, with the periodicity depending on factors such as site productivity, accessibility, and significance of management issues. For example, a highly productive site which is strongly affected by erosion or unauthorized collection, and which can be easily visited by park staff, would be scheduled for more frequent visits than a less productive or less threatened site. CAVE does not currently have a monitoring program for fossil localities; rather, notable paleontological resources are checked during intermittent cave surveys.

A monitoring program is generally implemented after an inventory has been prepared for a park and sites of concern have been identified, with additional sites added as necessary. Because each park is different, with different geology and paleontology among other factors, ideally each park which has in situ fossils or significant accumulations of reworked fossils would have its own monitoring protocol to define its monitoring program. Data accumulated via monitoring is used to inform further management decisions, such as the following questions: Is the site suitable for interpretation and education? Does the site require stabilization from the elements? Is collection warranted? Is there a need for some form of law enforcement presence?

Because the bedrock in many places of the park is pervasively fossiliferous, and because collecting vertebrate fossils from within caves is logistically challenging and with high potential for resource impairment, it is unlikely that CAVE will embark on a systematic collecting regimen. Collection is recommended to be reserved for fossils possessing exceptional value (e.g., rare or high scientific significance) or at immediate risk of major degradation or destruction by human activity and natural processes. Therefore, paleontological resource monitoring is a more feasible potential management tool. The first step in establishment of a monitoring program is identification of localities to be monitored, as discussed previously. Locality condition forms are then used to evaluate factors that could cause loss of paleontological resources, with various conditions at each locality rated as good, fair, or poor. Risks and conditions are categorized as Disturbance, Fragility, Abundance, and Site Access. “Disturbance” evaluates conditions that promote accelerated erosion or mass wasting resulting from human activities. “Fragility” evaluates natural conditions that may influence the degree to which fossil transportation is occurring. Sites with elevated fragility exhibit inherently soft rapidly eroding sediment or mass wasting on steep hillsides. A bedrock outcrop that is strongly lithified has low fragility. “Abundance” judges both the natural condition and number of specimens preserved in the deposits as well as the risk of being easily recognized as a fossil-rich area which could lead to the possibility of unpermitted collecting. “Site Access” assesses the risk of a locality being visited by large numbers of visitors or the potential for easy removal of large quantities of

fossils or fossil-bearing sediments. A locality with high access would be in close proximity to public use areas or other access (along trails, at roadcuts, at beach or river access points, and so on). One security feature that CAVE has implemented for caves that restricts public access is installing locked gates at the entrances to caves (or restricting entry into portions of otherwise public caves). These gates also protect fossil resources within the closed caves.

Each of the factors noted above may be mitigated by management actions. Localities exhibiting a significant degree of disturbance may require either active intervention to slow accelerated erosion, periodic collection and documentation of fossil materials, or both. Localities developed on rocks of high fragility naturally erode at a relatively rapid rate and would require frequent visits to document and/or collect exposed fossils in order to prevent or reduce losses. Localities with abundant or rare fossils, or high rates of erosion, may be considered for periodic monitoring in order to assess the stability and condition of the locality and resources, in regard to both natural processes and human-related activities. Localities that are easily accessible by road or trail would benefit from the same management strategies as those with abundant fossils and by occasional visits by park staff, documentation of in situ specimens, and/or frequent law enforcement patrols. Further information on paleontological resource monitoring can be found in Santucci and Koch (2003) and Santucci et al. (2009).

Foundation Documents and Resource Stewardship Strategies

Foundation documents and Resource Stewardship Strategies are two types of park planning documents that may contain and reference paleontological resource information. The core components of a foundation document include a brief description of the park as well as the park's purpose, significance, fundamental resources and values, other important resources and values, and interpretive themes. The foundation document also includes special mandates and administrative commitments, an assessment of planning and data needs that identifies planning issues, planning products to be developed, and the associated studies and data required for park planning. Along with the core components, the assessment provides a focus for park planning activities and establishes a baseline from which planning documents are developed. The foundation document for CAVE has been published (NPS 2017) and identified the Capitan Reef as a fundamental resource of the park (see "Significance of Paleontological Resources at CAVE" in this report). Fossils also contribute to two of the park's significance statements:

- Carlsbad Caverns National Park protects a portion of the Permian Age Capitan Reef, one of the world's best preserved and accessible reef complexes with unique opportunities to view the reef from the inside.
- Past environments and climates can be understood at Carlsbad Caverns National Park by studying fossil resources and conducting paleoclimate research using speleothems.

A Resource Stewardship Strategy (RSS) is a strategic plan intended to help park managers achieve and maintain desired resource conditions over time. It offers specific information on the current state of resources and planning, management priorities, and management goals over various time frames. CAVE does not currently have an RSS, but is in the pre-draft phase of designing one (E. Lynch, pers. obs., January 2020).

Currently, CAVE's resource management practices are described in the Resource Protection Plan (NPS 2002) and the Cave and Karst Management Plan (NPS 2006b), the latter of which only covers paleontological resources when they occur within or in association with caves or karst features. A paleontological resource management plan was identified as a low priority planning need in the foundation document (NPS 2017) with a note that it may be appended to the cave and karst management plan.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age (see Figure 3) and lowercase letters indicating the formation's name. The American Geosciences Institute website (<https://www.americangeosciences.org/environment/publications/mapping>) provides more information about geologic maps and their uses.

Geologic maps are one of the foundational elements of a paleontological resource management program. Knowing which sedimentary rocks and deposits underlie a park and where they are exposed are essential for understanding the distribution of known or potential paleontological resources.

The ideal scale for resource management in the 48 contiguous states is 1:24,000 (maps for areas in Alaska tend to be coarser). Hayes (1964), which was used for the CAVE map, was published at a smaller scale, 1:62,500. In addition to its smaller scale, it was published more than 50 years ago and utilized field work done more than 70 years ago. Some of the stratigraphic understanding and terminology used by Hayes (1964) is no longer up-to-date. To address these issues, the GRI program is partnering with the New Mexico Bureau of Geology and Mineral Resources to update the geologic map for CAVE and GUMO. The long-term goal of the project is to produce a seamless 1:24,000 updated geologic map covering CAVE, GUMO, and the public lands between. Updated maps for CAVE and GUMO are expected to be delivered in approximately 2022. Currently, 1:12,000 geologic maps are being compiled for most of CAVE. This effort is part of a larger project to provide geologic maps from GUMO to CAVE. The existing digital geologic map for CAVE can be accessed at <https://irma.nps.gov/Datastore/Reference/Profile/1047628>.

In addition to a digital GIS geologic map, the GRI program also produces a park-specific report discussing the geologic setting, distinctive geologic features and processes within the park, highlighting geologic issues facing resource managers, and describing the geologic history leading to the present-day landscape of the park. Graham (2007) is the GRI report for CAVE (at the time the program was known as Geologic Resource Evaluation).

Paleontological Resource Potential Maps

A paleontological resource potential map is included in this report (Figure 4). The map shows the distribution of geologic units within a park that are known to have yielded fossils within the park (green on Figure 4), have not yielded fossils within the park but are fossiliferous elsewhere (yellow), or have not yielded fossils (red). This map gives a quick indication of areas where fossils may be

discovered, which in turn can provide suggestions for areas to survey or monitor, or areas where the discovery of fossils may be of concern during work that disturbs the ground (road work, building construction, etc.). Because the bedrock in CAVE is widely fossiliferous, most bedrock exposures can be reasonably assumed to contain fossils.

NPS Paleontology Archives and Library

All data, references, images, maps and other information used in the development of this report are maintained in the NPS Paleontology Archives and Library. These records consist of both park specific and servicewide information pertaining to paleontological resources documented throughout the NPS. The archives and library are housed and maintained by NPS Senior Paleontologist & Paleontology Program Coordinator Vincent Santucci. If any resources are needed by NPS staff at CAVE, or additional questions arise regarding paleontological resources, contact Vincent Santucci, vincent_santucci@nps.gov. Park staff are also encouraged to communicate new discoveries to the NPS Paleontology Program, not only when support is desired, but in general, so that this information can be incorporated into the archives. A description of the NPS Paleontology Archives and Library can be found in Santucci et al. (2018).

E&R Files

E&R files (from “Examination and Report on Referred Fossils”) are unpublished internal USGS documents. For more than a century, USGS paleontologists identified and prepared informal reports on fossils sent to the survey by other geologists, for example to establish the relative age of a formation or to help correlate beds. The system was eventually formalized as a two-part process including a form sent by the transmitting geologist and a reply by the survey geologist. Sometimes the fossil identifications were incorporated into publications, but in many cases this information is unpublished. These E&R files include documentation of numerous fossil localities within current NPS areas, usually predating the establishment of the NPS unit in question and frequently unpublished or previously unrecognized. Extensive access to the original files was granted to the NPS by the USGS beginning in 2014 (Santucci et al. 2014). At this time no E&R files have been identified from CAVE, although there is the possibility that some exist.

Paleontological Resource Management Recommendations

The paleontological resource inventory at CAVE has documented a variety of fossils, confirming and expanding upon previous reports of paleontological resources from within park boundaries. This report captures the scope, significance, and distribution of fossils at CAVE as well as provides recommendations to support the management and protection of the park's non-renewable paleontological resources.

- CAVE staff are encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, the park can contact GRD or New Mexico Museum of Natural History and Science for guidance or field guides regarding how to recognize common local fossils. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, staff may consider taking advantage of them, as funding and time permit.
- CAVE staff could photo-document and monitor particularly notable or locally abundant invertebrates, vulnerable localities, and for any fossils found during other monitoring activities (e.g., cave surveys). The widespread presence of Permian invertebrate fossils throughout most of CAVE makes photo-documentation and monitoring of every individual fossil within the park impractical. Fossils and their associated geologic context (surrounding rock) should be documented but left in place unless they are subject to imminent degradation. A Geologic Resource Monitoring Manual published by the Geological Society of America and NPS Geologic Resources Division (GRD) includes a chapter on paleontological resource monitoring (Santucci et al. 2009). Santucci and Koch (2003) also present information on paleontological resource monitoring.
- CAVE could consider requesting technical assistance from GRD staff for help with developing a monitoring protocol, and to develop monitoring forms specifically for paleontological resources. A form for designating and recording fossil localities that do not fall under one of the features currently monitored by CAVE (caves, karst features, archeological sites, and springs) could also be designed. There are a small number of productive areas with easy public access or where guided tours are offered that are recommended for monitoring.
- Gary Morgan of the New Mexico Museum of Natural History and Science has expressed interest in publishing Lloyd Logan's 1979 report to the NPS on the paleoecological implications of the Muskox Cave assemblage. This report is much more detailed than the 1981 short paper Logan publicly released. None of the information provided in the report is sensitive. Not only would the information contained within this report be of use to the scientific community, but it may encourage researchers to work on identifying the unanalyzed herpetological and avian components of that collection.
- The fossils stored within CAVE's museum collections storage facility would greatly benefit from additional curatorial work, in order to refit them in appropriate trays, drawers, and cabinets, as well as to reorganize them in a manner that meets NPS standards and is useful to researchers.

- Fossils that remain at the Smithsonian, such as the Permian specimens collected in the 1950s or 1960s by Cooper, could have a loan agreement drawn up for them if one does not exist. They also need to be added to the CAVE museum catalog.
- Park staff may consider designating the park's holotype specimens as considered controlled property. It is recommended that these holotype specimens remain in external repositories to benefit from being housed in museums with large comparative collections.
- If Texas Tech does not plan to work on the Wen Cave collection soon, park staff should consider requesting it be returned to CAVE, especially if a preparator and curator can be hired.
- Park staff are strongly recommended to undertake a paleontological inventory of backcountry caves, where fossils have not been well documented nor the focus of prior surveying.
 - This could also include several reported sightings of bones in Carlsbad Cavern.
 - Any cultural contexts of paleontological materials should also be documented.
 - The exceptional invertebrate localities within Lechuguilla Cave are a high priority for in-depth documentation as well.
- The ~6,000 physical photographs in the RSS office that have yet to be digitized should be scanned and digitally archived.
- There are presently no scheduled interpretive programs that focus on CAVE's paleontological resources at the park; interpretation of fossils is usually done incident to a guided tour or ad hoc as part of informal/roving interpretation. Scheduled programs about both the Permian and Pleistocene/Holocene fossil resources could be developed and offered at the park. CAVE and GUMO are among the best suited sites in the world for discussing middle Permian marine paleontology and paleoecology.
- A document detailing the specimens currently available for use in interpretation could be produced to make the collection more useful. Recommended information in such a document includes: common name, scientific name, age, geologic formation, location of collection, lifestyle (e.g., feeding, movement, and reproductive behaviors), habitat, and closest living relatives (if any). Several interpreters also requested additional educational specimens.
- CAVE staff may consider partnering with other parks containing similar paleontological resources, such as GUMO, in order to design cooperative programs. GUMO is a logical partner for such an effort. For a list of other Permian parks, contact the GRD Paleontology Program.
- Fossil theft is among the greatest threats to the preservation of paleontological resources and any methods to minimize these activities should be utilized by staff. Any occurrence of paleontological resource theft or vandalism should be investigated by a law enforcement ranger. It is highly recommended that records of any incidents be submitted for inclusion in annual law enforcement statistics. There is a single recorded instance of attempted theft and several pieces of anecdotal evidence for unauthorized collection of fossils at CAVE; fossils like trilobites, ammonites, and vertebrate skulls can fetch high commercial value. Even less valuable fossils like brachiopods could be taken as souvenirs.

- Fossils found in a cultural context should be documented like other fossils, but they will also require the input of an archeologist or a cultural resource specialist. Any fossil which has a cultural context may be culturally sensitive as well (e.g., subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.
- Park staff may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Geoscientists-in-the-Parks Program and Mosaics In Science Program are established programs for recruitment of geoscience interns. Contact GRD for additional information or visit <https://www.nps.gov/subjects/geoscientistsinparks/index.htm> and <https://www.nps.gov/subjects/youthprograms/mosaics.htm>.
- For more detailed or academic study and description of fossils, such as those from Muskox Cave, a masters or PhD student could be solicited to study, identify, and analyze the specimens. This would require a long-term commitment on behalf of the student and the park to this project.
- It is recommended that both Permian and Pleistocene/Holocene age fossils be identified to genus or species by an expert where possible. These identifications help flesh out the faunal assemblage and paleoecology of the park, and the types of research that can be conducted without such identifications are limited.
- Park staff are encouraged to ensure that planned infrastructure and facilities development, such as for the waterline, electrical lines, and the sewage line, meet assessment and compliance standards for paleontological resources. Monitoring for paleontological resources at such construction sites is also recommended if excavating units with a high or moderate potential for fossils.
- CAVE staff may consider installing gates at currently ungated caves, or portions thereof, containing particularly abundant, scientifically significant, or valuable fossils. Caves that can be easily found and accessed by the public are a priority.
- Contact the GRD for additional technical assistance with paleontological resource management issues.

If fossil specimens are found by CAVE staff, it is recommended they follow the steps outlined below to ensure proper paleontological resource management.

- Photo-document the specimen without moving it from its location, if it is loose. Include a common item, such as a coin, pen, or pencil, for scale if a ruler or scale bar is not available.
- If a GPS unit is available, record the location of the specimen. If GPS is not available, record the general location within CAVE and position within the rock if applicable. If possible, revisit the site when a GPS unit is available.
- Document associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in CAVE, sketch of the fossil, position within the rock wall or if

it is loose on the ground, any associated fossils, and any other additional information that may be useful for relocating or characterizing the site.

- Removing or collecting fossils is not recommended. Fossils may be embedded within the bedrock or a speleothem, and attempting to remove such fossils may damage cave resources. Loose Pleistocene/Holocene age fossils are a possible exception.
 - However, concealing fossils found in high-traffic areas is appropriate, particularly if further documentation is desired. In such cases it is imperative to record enough locality information to relocate the specimen. Documenting fossils and leaving them in place is the best course of action until natural resource staff is contacted.
- CAVE resource management staff should be alerted to discoveries of fossil resources.

Literature Cited

- Adams, D. B. 1979. The cheetah: native American. *Science* 205(4411):1155–1158.
- Babcock, J. A. 1974. The role of algae in the formation of the Capitan Limestone (Permian, Guadalupian), Guadalupe Mountains, West Texas–New Mexico. Dissertation. University of Wisconsin, Madison, Wisconsin.
- 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. Pages 3–44 *in* M. E. Hileman and S. J. Mazzullo, editors. Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and west Texas. Permian Basin Section SEPM Publication 77–16(1).
- Babcock, J. A., and D. A. Yurewicz. 1989. The massive facies of the Capitan Limestone, Guadalupe Mountains, Texas and New Mexico. Pages 365–371 *in* P. M. Harris and G. A. Grover, editors. Subsurface and outcrop examination of the Capitan shelf margin, northern Delaware Basin. Society of Economic Paleontologists and Mineralogists, San Antonio, Texas. Core Workshop 13.
- Baker, J. K. 1963. Fossilization of bat skeletons in the Carlsbad Caverns. *National Speleological Society Bulletin* 25(1):37–44.
- Balmaki, B., and P. E. Wigand. 2019. Reconstruction of the Late Pleistocene to Late Holocene vegetation transition using packrat midden and pollen evidence from the Central Mojave Desert. *Acta Botanica Brasilica* 33(3):539–547.
- Batten, R. L. 1989. Permian Gastropoda of the southwestern United States. 7. Pleurotomariacea: Eotomariidae, Lophospiriidae, Gosseletinidae. *American Museum Novitates* 2958.
- Benck, K. M., K. Allen, A. J. Nadeau, H. Hutchins, A. M. Davis, and A. Robertson. 2017. Carlsbad Caverns National Park: Natural resource condition assessment. Natural Resource Report NPS/CAVE/NRR—2017/1466. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/Datastore/Reference/Profile/2240877> (accessed 10 April 2020).
- Black, D. M. 1953. Fossil deposits under the entrance of Carlsbad Caverns. *Science* 118(3063):308–309.
- Borrelli, M. P., and C. A. Holmgren. 2016. Dietary modifications of packrats in response to changing plant communities: Evidence from fossil plant cuticles spanning >55,000 years in Sonoran Desert packrat middens. *Journal of Arid Environments* 135:1–8.
- Bretz, J. H. 1949. Carlsbad Caverns and other caves of the Guadalupe Block, New Mexico. *Journal of Geology* 57:447–463.
- Brezinski, D. K. 1992. Permian trilobites from west Texas. *Journal of Paleontology* 66(6):924–943.

- Burger, P. 2007. Walking guide to the geology and Carlsbad Cavern. Carlsbad Caverns and Guadalupe Mountain Association, Carlsbad, New Mexico.
- Carraway, L. N. 2010. Fossil history of *Notiosorex* (Soricomorpha: Soricidae) shrews with descriptions of new fossil species. *Western North American Naturalist* 70(2):144–163.
- Clites, E. C., and V. L. Santucci. 2012. Protocols for paleontological resource site monitoring at Zion National Park. Natural Resource Report NPS/ZION/NRR—2012/595. National Park Service, Fort Collins, Colorado.
- Cooper, G. A., and R. E. Grant. 1969. New brachiopods from west Texas. *Smithsonian Contributions to Paleobiology* 1.
- Cooper, G. A., and R. E. Grant. 1972. Permian brachiopods of west Texas, I. *Smithsonian Contributions to Paleobiology* 14.
- Cooper, G. A., and R. E. Grant. 1974. Permian brachiopods of west Texas, II. *Smithsonian Contributions to Paleobiology* 15.
- Cooper, G. A., and R. E. Grant. 1976. Permian brachiopods of west Texas, V. *Smithsonian Contributions to Paleobiology* 24.
- Cooper, G. A., and R. E. Grant. 1977. Permian brachiopods of west Texas, VI. *Smithsonian Contributions to Paleobiology* 32.
- Cunningham, K. I., D. E. Northup, R. M. Pollastro, W. G. Wright, and E. J. LaRock. 1995. Bacteria, fungi and biokarst in Lechuguilla Cave, Carlsbad Caverns National Park, New Mexico. *Environmental Geology* 25(1):2–8.
- Dézerald, O., C. Latorre, J. L. Betancourt, G. A. B. Vera, and A. L. González. 2019. Ecological fidelity and spatiotemporal resolution of arthropod death assemblages from rodent middens in the central Atacama Desert (northern Chile). *Quaternary Science Reviews* 210:15–25.
- Dietl, G. P., S. M. Kidwell, M. Brenner, D. A. Burney, K. W. Flessa, S. T. Jackson, and P. L. Koch. 2015. Conservation paleobiology: leveraging knowledge of the past to inform conservation and restoration. *Annual Review of Earth and Planetary Sciences* 43:79–103.
- DuChene, H. R. 2000. Bedrock features of Lechuguilla Cave, Guadalupe Mountains, New Mexico. *Journal of Cave and Karst Studies* 62(2):109–119.
- DuChene, H. R., and K. I. Cunningham. 2006. Tectonic influences on speleogenesis in the Guadalupe Mountains, New Mexico and Texas. Pages 211–218 in B. S. Brister, P. W. Bauer, and A. S. Read, editors. *Caves and karst of southeastern New Mexico*. New Mexico Geological Society, Socorro, New Mexico. Guidebook, 57th Field Conference.

- DuChene, H. R., and R. Martinez. 2000. Post-speleogenetic erosion and its effect on caves in the Guadalupe Mountains, New Mexico and West Texas. *Journal of Cave and Karst Studies* 62(2):75–79.
- DuChene, H. R., A. N. Palmer, M. V. Palmer, J. M. Queen, V. J. Polyak, D. D. Decker, C. A. Hill, M. Spilde, P. A. Burger, D. W. Kirkland, and P. Boston. 2017. Hypogene speleogenesis in the Guadalupe Mountains, New Mexico and Texas, USA. Pages 511–530 *in* A. Klimchouk, A. N. Palmer, J. De Waele, A. S. Auler, and P. Audra, editors. *Hypogene karst regions and caves of the world*. Springer, Cham, Switzerland.
- Dunham, R. J. 1972. Capitan Reef, New Mexico and Texas: facts and questions to aid interpretation and group discussion. Society of Economic Paleontologists and Mineralogists, Permian Basin Section, Publication 72–14.
- Esteban, M., and L. C. Pray. 1983. Pisoids and pisolite facies (Permian), Guadalupe Mountains, New Mexico and west Texas. Pages 503–537 *in* T. M. Peryt, editor. *Coated grains*. Springer, Berlin, German.
- Evans, T. J. 2016. General standards for geologic maps. Section 3.1 *in* M. B. Carpenter and C. M. Keane, compilers. *The geoscience handbook 2016*. AGI Data Sheets, 5th Edition. American Geosciences Institute, Alexandria, Virginia.
- Fagerstrom, J. A., and O. Weidlich. 1999. Strengths and weaknesses of the reef guild concept and quantitative data: Application to the Upper Capitan-massive community (Permian), Guadalupe Mountains, New Mexico-Texas. *Facies* 40:131–156.
- Finks, R. M., Reid, R. E. H., and Rigby, J. K. 2004. Porifera (Demospongea, Hexactinellida, Heteractinida, Calcarea). *Treatise on Invertebrate Paleontology Part E, Revised E(3)*.
- Fischer, A. G., and M. Sarnthein. 1988. Airborne silts and dune-derived sands in the Permian of the Delaware Basin. *Journal of Sedimentary Research* 58(4):637–643.
- Gale, B. T. 1957. Geologic development of the Carlsbad Caverns. *In* P. T. Hayes. Geologic map of the Carlsbad Caverns East Quadrangle, New Mexico. U.S. Geologic Survey, Washington D.C. Geologic Quadrangle 98. Scale 1:62,000. Available at: <https://pubs.er.usgs.gov/publication/gq98> (accessed 06 April 2020).
- Garber, R. A., G. A. Grover, and P. M. Harris. 1989. Geology of the Capitan shelf marginsubsurface data from the northern Delaware Basin. Pages 3–269 *in* P. M. Harris and G. A. Grover, editors. *Subsurface and outcrop examination of the Capitan shelf margin, northern Delaware Basin*. Society of Economic Paleontologists and Mineralogists, San Antonio, Texas. Core Workshop 13.
- Girty, G. H. 1908. The Guadalupian fauna. U.S. Geological Survey, Washington, D.C. Professional Paper 58. Available at: <https://pubs.er.usgs.gov/publication/pp58> (accessed 06 April 2020).

- Graham, J. 2007. Carlsbad Caverns National Park Geologic Resource Evaluation Report. Natural Resource Report NPS/NRPC/GRD/NRR—2007/003. National Park Service, Denver, Colorado. Available at: <https://irma.nps.gov/Datastore/Reference/Profile/649168> (accessed 06 April 2020).
- Harris, A. H. 1980. The paleoecology of Dry Cave, New Mexico. National Geographic Society Research Reports 12:331–338.
- Harris, A. H. 1985. Late Pleistocene vertebrate paleoecology of the West. University of Texas Press, Austin, Texas.
- Harris, A. H. 1993. Quaternary vertebrates of New Mexico. New Mexico Museum of Natural History and Science Bulletin 2:179–197.
- Harris, A. H. 1997. Geographic and chronologic patterns in late Pleistocene vertebrate faunas, southern New Mexico. New Mexico Museum of Natural History and Science Bulletin 11:129–134.
- Harris, A. H. 2005. Caves as unique resources for Pleistocene vertebrate faunas. New Mexico Museum of Natural History and Science Bulletin 28:249–253.
- Harris, A. H. 2020. Pleistocene vertebrates of southwestern USA and northwestern Mexico. Available at: <https://www.utep.edu/leb/pleistnm/default.htm> (accessed 06 April 2020).
- Hayes, P. T. 1957. Geology of the Carlsbad Caverns East Quadrangle, New Mexico. U.S. Geological Survey, Washington, D.C. Geologic Quadrangle 98. Scale 1:62,500. Available at: <https://pubs.er.usgs.gov/publication/gq98> (accessed 06 April 2020).
- Hayes, P. T. 1964. Geology of the Guadalupe Mountains, New Mexico. U.S. Geological Survey, Washington, D.C. Professional Paper 446. Available at: <https://pubs.er.usgs.gov/publication/pp446> (accessed 06 April 2020).
- Hayes, P. T., and R. L. Koogle. 1958. Geology of the Carlsbad Caverns West Quadrangle, New Mexico and Texas. U.S. Geological Survey, Washington, D.C. Geologic Quadrangle 112. Scale 1:62,500. Available at: <https://pubs.er.usgs.gov/publication/gq112> (accessed 06 April 2020).
- Helgen, K. M., F. R. Cole, L. E. Helgen, and D. E. Wilson. 2009. Generic revision in the Holarctic ground squirrel genus *Spermophilus*. Journal of Mammalogy 90(2):270–305.
- Henkel, C. J., W. P. Elder, V. L. Santucci, and E. C. Clites. 2015. Golden Gate National Recreation Area: Paleontological Resource Inventory. Natural Resource Report NPS/GOGA/NRR—2015/915. National Park Service, Fort Collins, Colorado.
- Hill, C. A. 1987. Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico and Texas. New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico. Bulletin 117.

- Hill, C. A. 1996. Geology of the Delaware Basin, Guadalupe, Apache, and Glass Mountains New Mexico and West Texas. West Texas Geological Society Bulletin 36(1):5–7.
- Hill, C. A. 1999. Reevaluation of the Hovey Channel in the Delaware Basin, West Texas. AAPG Bulletin 83(2):277–294.
- Hill, C. A. 2000. Overview of the geologic history of cave development in the Guadalupe Mountains, New Mexico. National Speleological Society Bulletin 62:60–71.
- Hill, C. A., and D. D. Gillette. 1985. Bones of the Pleistocene ground sloth, *Nothrotheriops shastensis*, from Carlsbad Cavern, New Mexico. Cave Research Foundation Annual Report 27:23–24.
- Hill, C. A., and D. D. Gillette. 1987a. A uranium series date for the Shasta ground sloth, *Nothrotheriops shastensis*, from Carlsbad Cavern, New Mexico. Journal of Mammalogy 68(3):718–719.
- Hill, C. A., and D. D. Gillette. 1987b. Bones of the Pleistocene ground sloth *Nothrotheriops* in Carlsbad Cavern, New Mexico. National Park Service Unpublished Report. On file at CAVE.
- Hunt, D. W., W. M. Fitchen, and E. Kosa. 2003. Syndepositional deformation of the Permian Capitan reef carbonate platform, Guadalupe Mountains, New Mexico, USA. Sedimentary Geology 154(3–4):89–126.
- International Fossil Algae Association. 2000. Prof. J. Harlan JOHNSON collections: Part II – Museum of Natural History, University of Kansas, Lawrence. Available at: <http://deptsec.ku.edu/~ifaaku/Archives/Hart-Kaesler.html> (accessed 03 April 2020).
- Ivanov, A. O., M. K. Nestell, and G. P. Nestell. 2015. Middle Permian fish microremains from the early Capitanian of the Guadalupe Mountains, west Texas, USA. Micropaleontology 61(4–5):301–312.
- Jablonsky, P. L. 1993. Inventory of bats skulls collected in Carlsbad Cavern under current permit by Pat Jablonsky. National Park Service Unpublished Report. On file at CAVE.
- Jablonsky, P. L. 1994. Pollen analysis of three samples from Lechuguilla Cave, Carlsbad Caverns National Park, Eddy County, New Mexico. National Park Service Unpublished Report. On file at CAVE.
- Jablonsky, P. L. 1996. Lechuguilla Cave – Carlsbad Caverns National Park, Chiroptera Project 1991–1996 faunal list. National Park Service Unpublished Report. On file at CAVE.
- Jablonsky, P. L. 1999. Carbon-14 analysis of Chiroptera specimens and guano deposits, Carlsbad Cavern, Carlsbad Caverns National Park. National Park Service Unpublished Report. On file at CAVE.

- Jablonsky, P. L. 2001. Continuation of Chiroptera guano analysis utilizing carbon-14 dating techniques. National Park Service Unpublished Report. On file at CAVE.
- Jablonsky, P. L. 2004?. Chiropteran studies, Lechuguilla Cave, Carlsbad Caverns National Park. National Park Service Unpublished Report. On file at CAVE.
- Jass, C. N., J. I. Mead, and L. E. Logan. 2000. Harrington's extinct mountain goat (*Oreamnos harringtoni* Stock 1936) from Musko Cave, New Mexico. *Texas Journal of Science* 52:121–132.
- Johnson, J. H. 1942. Permian lime-secreting algae from the Guadalupe Mountains, New Mexico. *Bulletin of the Geological Society of America* 53(2):195–226.
- Jost, A. B., R. Mundil, B. He, S. T. Brown, D. Altiner, Y. Sun, D. J. DePaolo, and J. L. Payne. 2014. Constraining the cause of the end-Guadalupean extinction with coupled records of carbon and calcium isotopes. *Earth and Planetary Science Letters* 396:201–212.
- Kenworthy, J. P., and V. L. Santucci. 2006. A preliminary investigation of National Park Service paleontological resources in cultural context: Part 1, general overview. *New Mexico Museum of Natural History and Science Bulletin* 34:70–76.
- Kerans, C., and K. Kempter. 2002. Hierarchical stratigraphic analysis of a carbonate platform, Permian of the Guadalupe Mountains. *AAPG Datapages Discovery Series* 5.
- King, P. B. 1942. Permian of west Texas and southeastern New Mexico. *AAPG Bulletin* 26(4):535–763.
- King, P. B. 1948. Geology of the southern Guadalupe Mountains, Texas. U.S. Geological Survey, Washington, D.C. Professional Paper 215.
- King, R. H. 1943. New Carboniferous and Permian sponges. *State Geological Survey of Kansas Bulletin* 47.
- Kirkland, B. L., and R. L. Chapman. 1990. The fossil green alga *Mizzia* (Dasycladaceae): a tool for interpretation of paleoenvironment in the Upper Permian Capitan reef complex, southeastern New Mexico. *Journal of Phycology* 26(3):569–576.
- Kirkland, B. L., S. A. Longacre, and E. L. Stoudt. 1999. The dynamic Capitan Reef: An image of an ancient reef and suggestions for future research. Pages 161–173 in A. H. Saller, P. M. Harris, B. L. Kirkland, and S. J. Mazzullo, editors. *Geologic framework of the Capitan Reef*. Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma. Special Publication 65.
- 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). Dissertation. Louisiana State University, Baton Rouge, Louisiana.

- Kluth, C. F., and P. J. Coney. 1981. Plate tectonics of the ancestral Rocky Mountains. *Geology* 9(1):10–15.
- Kues, B. S., and H. R. DuChene. 1990. The largest late Paleozoic bellerophontid gastropod. *Journal of Paleontology* 64(3):478–479.
- Kurtén, B. 1975. A new Pleistocene genus of American mountain deer. *Journal of Mammalogy* 56:507–508.
- Lawrence, B. 1960. Fossil *Tadarida* from New Mexico. *Journal of Mammalogy* 41(3):320–322.
- Logan, L. E. 1979. The mammalian fossils from Musko Cave and their paleoecologic implications. National Park Service Unpublished Report. On file at CAVE.
- Logan, L. E. 1981. The mammalian fossils of Musko Cave, Eddy County, New Mexico. *Proceedings of the Eighth International Congress of Speleology* 1:159–160.
- Lundberg, J., and D. A. McFarlane. 2006. A minimum age for canyon incision and for the extinct molossid bat, *Tadarida constantinei*, from Carlsbad Caverns National Park, New Mexico. *Journal of Cave and Karst Studies* 68(3):115–117.
- Lyman, R. L. 1983. Prehistoric extralimital records for *Pappogeomys castanops* (Geomyidae) in northwestern New Mexico. *Journal of Mammalogy* 64(3):502–505.
- Martin, L. D. 1998. Felidae. Pages 236–242 in C. M. Janis, K. M. Scott, and L. L. Jacobs, editors. *Evolution of Tertiary mammals of North America*, volume 1. Cambridge University Press, Cambridge, United Kingdom.
- Maslov, V. P. 1956. [Fossil calcareous algae of the USSR.] *Trudy Inst. Geol. Nauk Akad. Nauk S.S.S.R.* 160:1–302. [In Russian]
- McDonald, H. G., and G. T. Jefferson. 2008. Distribution of Pleistocene *Nothrotheriops* (Xenarthra, Nothrotheriidae) in North America. *Natural History Museum of Los Angeles County, Science Series* 41:313–331.
- McDonald, H. G., and G. S. Morgan. 2011. Ground sloths of New Mexico: New Mexico Museum of Natural History and Science Bulletin 53:652–663.
- Melim, L. A., K. M. Shingman, P. J. Boston, D. E. Northup, M. N. Spilde, and J. M. Queen. 2001. Evidence for microbial involvement in pool finger precipitation, Hidden Cave, New Mexico. *Geomicrobiology Journal* 18(3):311–329.
- Melim, L. A., M. N. Spilde, B. Jones, P. J. Boston, and R. J. Bixby. 2008. Reticulated filaments in cave pool speleothems: microbe or mineral? *Journal of Cave and Karst Study* 70:135–141.
- Metcalf, A. L. 1977. Some Quaternary molluscan faunas from the northern Chihuahuan Desert and their paleoecological implications. Pages 53–66 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. National Park Service, Washington, D.C. Transactions and Proceedings Series 3.

Morgan, G. S. 2002. Pleistocene vertebrate fossils from Slaughter Canyon Cave, Carlsbad Caverns National Park. *Park Paleontology* 6(3):5.

Morgan, G. S. 2003a. The extinct free-tailed bat *Tadarida constantinei* and associated vertebrates from Pleistocene deposits in Slaughter Canyon Cave, Carlsbad Caverns National Park, southeastern New Mexico. *New Mexico Geology* 25(2):43.

Morgan, G. S. 2003b. The extinct Pleistocene molossid bat *Tadarida constantinei* from Slaughter Canyon Cave, Carlsbad Caverns National Park, New Mexico. *Bat Research News* 44:159–160.

Morgan, G. S. 2004. Pleistocene vertebrate fossils from Slaughter Canyon Cave, Carlsbad Caverns National Park, New Mexico. *Southwestern Cavers* 6:79–80.

Morgan, G. S. 2012. Muskox Cave vertebrate fossils, Carlsbad Caverns National Park, Eddy County, New Mexico: inventory of vertebrate fossils from muskox cave housed in the U. S. National Museum of Natural History, Smithsonian Institution, Washington, DC. Unpublished report. On file at CAVE.

Morgan, G. S., and A. H. Harris. 2015. Pliocene and Pleistocene vertebrates of New Mexico. *New Mexico Museum of Natural History and Science Bulletin* 68:233–427.

Morgan, G. S., and S. G. Lucas. 2006. Pleistocene vertebrates from southeastern New Mexico. Pages 317–336 in B. S. Brister, P. W. Bauer, and A. S. Read, editors. *Caves and karst of southeastern New Mexico*. New Mexico Geological Society, Socorro, New Mexico. Guidebook, 57th Field Conference.

Murray, K. F. 1957. Pleistocene climate and the fauna of Burnet Cave, New Mexico. *Ecology* 38:129–132.

National Park Service (NPS). 2002. Carlsbad Caverns National Park: Carlsbad Cavern Resource Protection Plan. On file at CAVE.

National Park Service (NPS). 2004. Paleontological resource management. In *Natural Resource Management Reference Manual* 77. U.S. National Park Service, Washington, D.C.

National Park Service (NPS). 2006a. *Management Policies 2006*. U.S. Government Printing Office, Washington, D.C.

National Park Service (NPS). 2006b. Carlsbad Caverns National Park: Cave and Karst Management Plan, Environmental Assessment. On file at CAVE.

National Park Service (NPS). 2017. Carlsbad Caverns National Park: Foundation Document. On file at CAVE.

- National Park Service (NPS). 2019. Carlsbad Caverns – Lechuguilla Cave. Available at: https://www.nps.gov/cave/learn/nature/lechuguilla_cave.htm (accessed 13 February 2020).
- National Park Service (NPS). 2020. Carlsbad Caverns National Park Cultural Landscape Inventory. On file at CAVE.
- National Park Service (NPS) Sensitive Records. 2019. Carlsbad Caverns National Park. Accessed November 2019 by Scott Kottkamp.
- National Park Service (NPS) Sensitive Records. 2020. Carlsbad Caverns National Park. Accessed January 2020 by Scott Kottkamp.
- New Mexico Institute of Mining and Geology. 2000. An introduction and virtual geologic field trip to the Permian Reef Complex, Guadalupe and Delaware Mountains New Mexico-West Texas. Available at <https://geoinfo.nmt.edu/staff/scholle/guadalupe.html> (accessed 13 February 2020).
- 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. Hafner Publishing Company, New York, New York.
- Norr, M. R., V. L. Santucci, and J. S. Tweet. 2016. An inventory of trilobites from National Park Service areas. New Mexico Museum of Natural History and Science Bulletin 74: 179–203.
- Palmer, M. V., and A. N. Palmer. 1990. Fossil microorganisms in karst environments. Cave Research Foundation 1990 Annual Report:30–33.
- Paris, S., and D. Gianantonio. 1983. Carlsbad Cavern National Park: Vandalism survey report. National Park Service, Carlsbad, New Mexico. On file at CAVE.
- Pate, D. L. 1999. Jaguars in New Mexico. Canyons & Caves 12:2.
- Polyak, V. J., and P. Provencio. 1998. Bat guano deposit of Slaughter Canyon Cave. National Park Service Unpublished Report. On file at CAVE.
- Polyak, V. J., Y. Asmeron, and J. B. T. Rasmussen. 2006. Old bat guano in Slaughter Canyon Cave. Pages 22–24 in B. S. Brister, P. W. Bauer, and A. S. Read, editors. Caves and karst of southeastern New Mexico. New Mexico Geological Society, Socorro, New Mexico. Guidebook, 57th Field Conference.
- Pray, L. C., and M. Esteban, editors. 1977. Upper Guadalupian Facies, Permian Reef Complex, Guadalupe Mountains, New Mexico and West Texas. Permian Basin Section SEPM Publication 77–16(2).
- Provencio, P., and V. J. Polyak. 2001. Iron oxide-rich filaments: possible fossil bacteria in Lechuguilla Cave, New Mexico. Geomicrobiology Journal 18(3):297–309.

- Queen, J. M. 1994a. Influence of thermal atmospheric convection on the nature and distribution of microbiota in cave environments. Pages 62–64 in I. D. Sasowsky and M. V. Palmer, editors. Breakthroughs in karst geomicrobiology and redox geochemistry. Karst Waters Institute, Charles Town, West Virginia. Special Publication 1.
- Queen, J. M. 1994b. Speleogenesis in the Guadalupe: the unsettled question of the role of mixing, phreatic or vadose sulfide oxidation. Pages 64–65 in I. D. Sasowsky and M. V. Palmer, editors. Breakthroughs in karst geomicrobiology and redox geochemistry. Karst Waters Institute, Charles Town, West Virginia. Special Publication 1.
- Queen, J. M. 2009. Geologic setting, structure, tectonic history and paleokarst as factors in speleogenesis in the Guadalupe Mountains, New Mexico and Texas, USA. Proceedings of the 15th International Congress of Speleology: 952–957.
- Riding, R. 1993. *Shamovella obscura*: the correct name for *Tubiphytes obscurus* (Fossil). Taxon 42:71–73.
- Riding, R., and L. Guo. 1992. Affinity of *Tubiphytes*. Palaeontology 35:37–49.
- Rigby, J. K., and G. L. Bell. 2006. Sponges from the Reef Trail Member of the Upper Guadalupian (Permian) Bell Canyon Formation, Guadalupe Mountains National Park, Texas. Journal of Paleontology 80(s66).
- Rigby, J. K., and B. Senowbari-Daryan. 1996. *Gigantospongia*, new genus, the largest known Permian sponge, Capitan Limestone, Guadalupe Mountains, New Mexico. Journal of Paleontology 70(3):347–355.
- Rigby, J. K., B. Senowbari-Daryan, and 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., and A. Koch. 2003. Paleontological Resource Management Strategies for the National Park Service. Park Science 22(1):22–25.
- Santucci, V. L., J. Kenworthy, and R. Kerbo. 2001. An inventory of paleontological resources associated with National Park Service caves. NPS Geological Resources Division, Denver, Colorado. Technical Report NPS/NRGRD/GRDTR-01/02. TIC# D-2231. Available at: <https://www.nps.gov/subjects/caves/upload/cavepaleo.pdf> (accessed 06 April 2020).
- 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.
- Santucci, V. L., J. P. Kenworthy, and A. L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 in R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. Available at: <https://www.nps.gov/subjects/fossils/upload/geomon-08.pdf> (accessed 06 April 2020).

- Santucci, V. L., J. M. Ghist, and R. B. Blodgett. 2014. Inventory of U.S. Geological Survey paleontology collections to identify fossil localities in National Park Service areas. *Proceedings of the 10th Conference on Fossil Resources*. *Dakoterra* 6:215–218.
- Santucci, V. L., J. S. Tweet, and T. B. Connors. 2018. The Paleontology Synthesis Project and establishing a framework for managing National Park Service paleontological resource archives and data. *New Mexico Museum of Natural History and Science Bulletin* 79:589–601.
- Sarg, J. F. 1981. Petrology of the carbonate-evaporite facies transition of the Seven Rivers Formation (Guadalupean, Permian), southeast New Mexico: *Journal of Sedimentary Petrology* 51:73–95.
- Sarg, J. F. 1985. Permian shelf calcrete, Shattuck Member, Queen Formation (southeast New Mexico) – shelfal expression of Middle Guadalupean fall in sea level. *West Texas Geological Society Bulletin* 24(8):8–16.
- Sarg, J. F. 1986. Facies and stratigraphy of upper San Andres basin margin and lower Grayburg inner shelf. Pages 83–93 in G. E. Moore and G. L. Wilde, editors. *San Andres/Grayburg formations, Guadalupe Mountains, New Mexico and Texas*. Society of Economic Paleontologists and Mineralogists, Permian Basin section, Publication 86–25.
- Schultz, C. B., and E. B. Howard. 1935. The fauna of Burnet Cave, Guadalupe Mountains, New Mexico. *Proceedings of the Academy of Natural Sciences of Philadelphia* 87:273–298.
- Senowbari-Daryan, B. 1990. Die systematische Stellung der thalamiden Schwämme und ihre Bedeutung in der Erdgeschichte, *Munchener geowissenschaftliche Abhandlungen, Reihe A, Geologie und Palaontologie* 21:1–326.
- Senowbari-Daryan, B. 2013. *Tubiphytes* Maslov, 1956 and description of similar organisms from Triassic reefs of the Tethys. *Facies* 59(1):75–112.
- Senowbari-Daryan, B., and D. C. García-Bellido. 2002. Fossil “Sphinctozoa”: chambered sponges (polyphyletic). Pages 1511–1538 in J. N. A. Hooper, R. W. M. Van Soest, and P. Willenz. *Systema porifera*. Springer, Boston, Massachusetts.
- Senowbari-Daryan, B., and J. K. Rigby. 1996a. Brachiopod mounds not sponge reefs, Permian Capitan-Tansill formation, Guadalupe Mountains, New Mexico. *Journal of Paleontology* 70:697–701.
- Senowbari-Daryan, B., and J. K. Rigby. 1996b. First report of *Lercaritubus* in North America, from the Permian Capitan Limestone, Guadalupe Mountains, New Mexico. *Journal of Paleontology* 70:22–26.
- Shumard, B. F. 1858. 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, US Topographic Engineers. *St. Louis Academy of Science Transactions* 1:290–297.

- Shumard, B. F. 1859. Notice of fossils from the Permian strata of Texas and New Mexico, obtained by the United States Expedition under Capt. John Pope, for boring artisan wells along the 32d parallel, with descriptions of new species from these strata and the coal measures of that region. *Transactions of the Academy of Science of St. Louis* 1(3d):387–403.
- Tebedge, S. 1988. Paleontology and paleoecology of the Pleistocene mammalian fauna of Dark Canyon Cave, Eddy County, New Mexico. Dissertation. University of Texas, Austin, Texas.
- Thompson, J. R., E. Petsios, E. H. Davidson, E. M. Erkenbrack, F. Gao, and D. J. Bottjer. 2015. Reorganization of sea urchin gene regulatory networks at least 268 million years ago as revealed by oldest fossil cidaroid echinoid. *Scientific Reports* 5, article 15541.
- Trautman, M. A. 1963. Isotopes, Inc. radiocarbon measures III. *Radiocarbon* 5:62–79.
- Turin, H. J., and M. A. Plummer. 2000. Lechuguilla cave pool chemistry, 1986–1999. *Journal of Cave and Karst Studies* 62(2):135–143.
- Tyrrell, W. W., Jr. 1969. Criteria useful in interpreting environments of unlike but time-equivalent carbonate units (Tansill-Capitan-Lamar), Capitan Reef complex, West Texas and New Mexico. Pages 80–97 in G. M. Freedman, editor. *Depositional environments in carbonate rocks*. Society of Economic Paleontologists and Mineralogists, Tulsa, Oklahoma. Special Publication 14.
- Van Valkenburgh, B., F. Grady, and B. Kurten. 1990. The Plio-Pleistocene cheetah-like cat *Miracinonyx inexpectatus* of North America. *Journal of Vertebrate Paleontology* 10(4):434–454.
- Vinn, O. 2017. Symbiosis in Late Devonian-Mississippian corals: a review. *Palaeobiodiversity and Palaeoenvironments* 97(4):723–729.
- Wang, S., J. Fan, and K. J. Rigby. 1994. *Archaeolithoporella* and *Tubiphytes*: affinities and paleoecology in Permian reefs of South China. *Science in China: Series B, Chemistry, Life Sciences & Earth Sciences* 37(6):723–743.
- Waterhouse, J. B. 2004. Permian and Triassic stratigraphy and fossils of the Himalaya in northern Nepal. *Earthwise* 6:1–259.
- Weidlich, O., and J. A. Fagerstrom. 1998. Evolution of the Upper Capitan-Massive (Permian), Guadalupe Mountains, New Mexico. *Brigham Young University Geology Studies* 43:167–188.
- White, R. S., Jr., and G. S. Morgan. 2011. *Capromeryx* (Artiodactyla: Antilocapridae) from the Rancholabrean Tramperos Creek Fauna, Union County, New Mexico, with a review of the occurrence and paleobiology of *Capromeryx* in the Rancholabrean of New Mexico. *New Mexico Museum of Natural History and Science Bulletin* 53:641–651.
- Wood, R. 1999. Paleoecology of the Capitan reef. Pages 129–137 in A. H. Saller, P. M. Harris, B. L. Kirkland, and S. J. Mazzullo, editors. *Geologic framework of the Capitan Reef*. Society of Economic Paleontologists and Mineralogists, Tulsa, Tulsa, Oklahoma. Special Publication 65.

- Wood, R. 2001. Are reefs and mud mounds really so different? *Sedimentary Geology* 145(3–4):161–171.
- Wood, R., J. A. D. Dickson, and B. Kirkland-George. 1994. Turning the Capitan Reef upside down: a new appraisal of the ecology of the Permian Capitan Reef, Guadalupe Mountains, Texas and New Mexico. *Palaaios* 9:422–427.
- Wu, Y. S. 1991. *Organisms and communities of Permian reef of Xiangbo, China*. International Academic Publishers, Beijing, China.
- Yancey, T. E. 1978. Brachiopods and Mollusca of the Lower Permian Arcturus Group, Nevada and Utah, Part 1: brachiopods, scaphopods, rostroconchs, and bivalves. *Bulletins of American Paleontology* 74(303):257–367.
- Ye, H., L. Royden, C. Burchfiel, and M. Schuepbach. 1996. Late Paleozoic deformation of interior North America: the greater ancestral Rocky Mountains. *AAPG Bulletin* 80(9):1397–1432.
- Yochelson, E. L. 1960. Permian Gastropoda of the southwestern United States. 3. Bellerophontacea and Patellacea. *Bulletin of the American Museum of Natural History* 119(4):208–293.

Appendix A. Paleontological Species Lists

The following tables (Appendix Tables A-1-a, b, and c, and A-2) document the fossil species found at CAVE in stratigraphic context, as reported in the literature, in museum collections, and through personal observations (“pers. obs.”). The Appendix Table A-1 series documents the Permian taxa: Appendix Table A-1-a covers plants, Appendix Table A-1-b covers invertebrates, and Appendix Table A-1-c covers other fossils. Appendix Table A-2 documents the Pleistocene and Holocene taxa. Big Manhole Cave is included due to its proximity to the park. In Appendix Table A-2, extinct species are indicated by a dagger (†) following the name and extralimital species are indicated by an asterisk (*). Species with both went extinct sometime after being extirpated from the vicinity of CAVE. The rows are organized systematically, placing taxa of the same broad groups together. The columns also include the taxon (first column) and references (last column; included in “Literature Cited” above).

It is likely that some of the genera and species cited here are actually examples of different authors identifying the same forms using different names. In addition, because taxonomy constantly changes, some of the species or genera identified here may be identified differently in some references.

Appendix Table A-1-a. Permian fossil plant taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Chlorophyta (green algae)	<i>Mizzia minuta</i>	?	Back-reef dominant; lesser presence in reef	Stationary epifaunal photoautotroph	Johnson (1942)
	<i>Mizzia</i> sp.	All CAVE bedrock except Castile	Back-reef dominant; lesser presence in reef	Stationary epifaunal photoautotroph	George (1992); Kirkland and Chapman (1990)
	<i>Mizzia velebitana</i>	?	Back-reef dominant; lesser presence in reef	Stationary epifaunal photoautotroph	Johnson (1942)
	<i>Mizzia yabei</i>	?	Back-reef dominant; lesser presence in reef	Stationary epifaunal photoautotroph	Johnson (1942)

Appendix Table A-1-b. Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Porifera (sponges)	<i>Amblysiphonella guadalupensis</i>	Capitan (Massive)	Bioherm, some possibly cavity cryptobionts	Stationary epifaunal suspension feeder	Newell et al. (1953); Wood et al. (1994); Rigby et al. (1998)
	<i>Amblysiphonella merlai</i>	Capitan	Bioherm, some possibly cavity cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Amblysiphonella</i> sp. A	Capitan; Goat Seep?	Bioherm, some possibly cavity cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Amblysiphonella</i> sp. B	Capitan	Bioherm, some possibly cavity cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Anthracosycon ficus</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Anthracosycon</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Bicoelia guadalupensis</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Cavusonella caverna</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Rigby et al. (1998)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Porifera (sponges) (continued)	<i>Cystauletes</i> sp.	Capitan (Massive)	Bioherm, some possibly cavity cryptobionts	Stationary epifaunal suspension feeder	Wood et al. (1994)
	<i>Cystothalamia nodulifera</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953); Rigby et al. (1998) as <i>C. guadalupensis</i>
	<i>Discosiphonella mammilosa</i>	Capitan	Bioherm, some possibly cavity cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Exaulipora permica</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Gigantospongia discoforma</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder; projected horizontally outward from cliff face or reef front	Rigby and Senowbari-Daryan (1996); Rigby et al. (1998)
	<i>Girtyocoelia beedei</i>	Capitan	Reef or Bioherm, Shallow Subtidal, Slope	Stationary epifaunal suspension feeder	Girty (1908); Rigby et al. (1998)
	<i>Grossotubenella parallela</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Guadalupia explanata</i>	Capitan	Reef, scaffolding with bryozoan fronds	Stationary epifaunal suspension feeder	Rigby et al. (1998); Finks et al. (2004) as <i>Polyphymaspongia explanata</i>
	<i>Guadalupia</i> sp.	Capitan (Massive)	Bioherm, some possibly cavity cryptobionts	Stationary epifaunal suspension feeder, sheet-like, oriented either as a vertical blade or growing horizontally out of a slope wall or reef front	Wood et al. (1994)
	<i>Guadalupia zitteliana</i>	Capitan (Middle Massive)	Reef, scaffolding with bryozoan fronds	Stationary epifaunal suspension feeder, sheet-like, oriented either as a vertical blade or growing horizontally out of a slope wall or reef front	Rigby et al. (1998)
	<i>Heliospongia ramosa</i>	Capitan	Reef or Bioherm	Stationary intermediate-level epifaunal suspension feeder	Girty 1908; Newell et al. (1953); Rigby et al. (1998)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Porifera (sponges) (continued)	<i>Heliospongia vokesi</i>	Capitan	Reef or Bioherm	Stationary intermediate-level epifaunal suspension feeder	King 1943; Newell et al. (1953); Rigby et al. (1998)
	<i>Laubenfelsia</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Lemonea conica</i>	Capitan	Reef or Bioherm, Slope, possibly cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Lemonea cylindrica</i>	Capitan	Reef or Bioherm, Slope, possibly cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Lemonea digitata</i>	Capitan	Reef or Bioherm, Slope, possibly cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Lemonea exaulifera</i>	Capitan	Reef or Bioherm, Slope, possibly cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Lemonea micra</i>	Capitan	Reef or Bioherm, Slope, possibly cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Lemonea polysiphonata</i>	Capitan	Reef or Bioherm, Slope, possibly cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Lemonea</i> sp.	Capitan (Massive)	Bioherm, possibly cavity cryptobionts	Stationary epifaunal suspension feeder	Senowbari-Daryan (1990); Wood et al. (1994)
	<i>Lercaritubus problematicus</i>	Upper Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Senowbari-Daryan and Rigby (1996b); Rigby and Bell (2006)
	<i>Minispongia constricta</i>	Upper Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Girty (1908); Rigby et al. (1998)
	<i>Neoheliospongia</i> cf. <i>typica</i>	Capitan	Reef or Bioherm	Stationary intermediate-level epifaunal suspension feeder	Rigby et al. (1998)
	<i>Parauvanella minima</i>	Capitan	Reef or Bioherm, Slope, appears in small clusters, possibly cavity cryptobionts	Stationary epifaunal suspension feeder	Rigby et al. (1998)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Porifera (sponges) (continued)	<i>Permosoma</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Fagerstrom and Weidlich (1999)
	<i>Platythalamiella</i> sp.	Capitan	Reef or Bioherm, Shallow Subtidal	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Preperonidella delicata</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Rigby et al. (1998); Rigby and Bell (2006)
	<i>Preperonidella rigbyi</i>	Capitan	Reef or Bioherm, Slope	Stationary epifaunal suspension feeder	Rigby et al. (1998); Rigby and Bell (2006)
	<i>Preverticillites parva</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Pseudovirgula tenuis</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953); Rigby et al. (1998)
	<i>Sollasia ostiolata</i>	Capitan	Reef or Bioherm, Shallow Subtidal, Slope	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Sollasia?</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Steinmannia americanus</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Stellispongiella</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Stylopegma</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Talpospongia</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Tristratocoelia rhythmica</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Rigby et al. (1998)
	<i>Virgola neptuna</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953); Rigby et al. (1998)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Porifera (sponges) (continued)	<i>Virgola rigida</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953); Rigby et al. (1998)
	Unknown Taxa A and B (Rigby et al. 1998)	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Rigby et al. (1998)
Cnidaria: Anthozoa (corals)	<i>Cladochonus</i> sp.	Capitan	Reef	Stationary low-level epifaunal suspension feeder, metazoan	Newell et al. (1953)
	<i>Lindstroemia cylindrica</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Lophophyllidium</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
Bryozoa (moss animals)	<i>Acanthocladia guadalupensis</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Domopora ocellata</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Domopora terminalis</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Fenestrellina capitanensis</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Fenestrellina spinulosa</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Fenestrellina</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Fistulipora</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Goniocladia americana</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Lioclema</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Bryozoa (moss animals) (continued)	<i>Meekopora</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Stenopora polyspinosa</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Triphyllotrypa guadalupensis</i>	Capitan	?	Stationary epifaunal suspension feeder?	Newell et al. (1953)
Brachiopoda (lamp shells)	<i>Aequalicosta inflata</i>	Capitan	Reef or Bioherm, Slope	Epifaunal suspension feeder?	Cooper and Grant (1972, 1976); Waterhouse (2004)
	<i>Aequalicosta shumardi</i>	Capitan	Reef or Bioherm, Slope	Epifaunal suspension feeder?	Cooper and Grant (1972, 1976); Waterhouse (2004)
	<i>Allorhynchus</i> sp.	Capitan	Subtidal; Reef or Bioherm; Slope	Stationary epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Aneuthelasma amygdalinum</i>	Yates?, Capitan?	Open Subtidal	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1976)
	<i>Anomaloria anomala</i>	Capitan	Reef or Bioherm, Slope	Stationary epifaunal suspension feeder	Cooper and Grant (1969, 1972, 1976)
	<i>Anteridocus swallowianus</i>	Capitan	Reef or Bioherm, slope	Stationary epifaunal suspension feeder	Shumard (1858; Cooper and Grant (1972)
	<i>Arionthia lamaria</i>	Capitan	Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1976)
	<i>Astegosia subquadrata</i>	Yates?, Capitan?	Reef or Bioherm, Slope	Stationary epifaunal suspension feeder	Girty (1908); Cooper and Grant (1976)
	<i>Aulosteges guadalupensis</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Aulosteges medicottianus</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Avonia</i> sp.	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Brachiopoda (lamp shells) (continued)	<i>Chonetina hillana</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Cleiothyridina pilularis</i>	Capitan	Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Collemataria</i> sp.	Capitan	Subtidal; Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972, 1974, 1976)
	<i>Composita affinis</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Girty (1908); Cooper and Grant (1972, 1976)
	<i>Composita emarginata</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953); Cooper and Grant (1976)
	<i>Composita gigantea</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Composita mira</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Composita subtilita</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Craspedona limbata</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Crurithyris planoconvexa</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Cyclacantharia</i> sp.	Uppermost Tansill/Capitan	Back-reef/Reef Contact	Stationary low-level epifaunal suspension feeder	Senowbari-Daryan and Rigby (1996a)
	<i>Derbyia</i> sp.	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Dictyoclostus capitanensis</i>	Capitan, Goat Seep?	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Dictyoclostus occidentalis</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Brachiopoda (lamp shells) (continued)	<i>Dielasma prolongatum</i>	Capitan	Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972)
	<i>Dielasma subcirculare</i>	Capitan	Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972)
	<i>Dielasma sulcatum</i>	Capitan	Shallow subtidal, slope	Stationary low-level epifaunal suspension feeder	Girty (1908); Cooper and Grant (1972)
	<i>Dielasma</i> sp.	Capitan	Shallow subtidal, deep subtidal, reef or bioherm, slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972)
	<i>Dyoros subliratus</i>	Capitan	Shallow Open Subtidal; Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Girty (1908); Cooper and Grant (1972)
	<i>Elivina compacta</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Girty (1908); Cooper and Grant (1976)
	<i>Fascicosta longaeva</i>	Capitan	Reef or Bioherm, Slope	Stationary epifaunal suspension feeder	Girty (1908); Cooper and Grant (1976)
	<i>Geyerella americana</i>	Capitan	Talus Slope	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Grandaurispina</i> sp. #5	Capitan	Shallow Subtidal, Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1976)
	<i>Heterelasma shumardianum</i>	Capitan	Reef or Bioherm, slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Hustedia opsia</i>	Capitan	Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972)
	<i>Hustedia</i> sp.	Capitan	Shallow subtidal, deep subtidal, reef or bioherm, slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972)
	<i>Leiorhynchus bisulcatum</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Brachiopoda (lamp shells) (continued)	<i>Leptodus americanus</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953); DuChene (2000)
	<i>Liosotella popei</i>	Capitan	Reef or Bioherm, slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Marginifera opima</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Marginifera popei</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Martinia rhomboidalis</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Megousia</i> sp.	Capitan	Shallow Subtidal, Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1976)
	<i>Neospirifer</i> sp.	?	Shallow subtidal, back-reef, reef	Stationary epifaunal suspension feeder	DuChene (2000)
	<i>Ombonia guadalupensis</i>	Capitan	Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Orthotetes declevis</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Orthotetes distortus</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Orthotetes guadalupensis</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Orthothetina</i> sp.	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Paraspiriferina billingsi</i>	Capitan	Subtidal; Reef or Bioherm; Slope	Stationary low-level epifaunal suspension feeder	Shumard 1858; Cooper and Grant (1972)
	<i>Paucispinifera latidorsata</i>	Capitan	Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Girty (1908); Cooper and Grant (1972)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Brachiopoda (lamp shells) (continued)	<i>Paucispinifera</i> sp.	Capitan	?	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Plectelasma guadalupense</i>	Capitan	Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Girty (1908); Cooper and Grant (1972)
	<i>Plectelasma planidorsatum</i>	Capitan	Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Plicatoderbya</i> sp.	Capitan	?	Epifaunal suspension feeder?	Newell et al. (1953)
	<i>Prorichthofenia</i> spp.	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Pustula</i> sp.?	Capitan	Reef or Bioherm	?	Newell et al. (1953)
	<i>Reticulariina</i> sp.	Capitan	Subtidal, Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1976)
	<i>Scapharina levis</i>	Capitan	Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Sestropoma cribriferum</i>	Uppermost Tansill/Capitan	Back-reef/Reef Contact	Stationary low-level epifaunal suspension feeder	Senowbari-Daryan and Rigby (1996a); Cooper and Grant (1969)
	<i>Squamularia guadalupensis</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Stenoscisma longaeva</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Stenoscisma trabeatum</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Cooper and Grant (1972)
	<i>Stenoscisma venusta</i>	Capitan, Goat Seep?	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Streptorhynchus gregarium</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Girty (1908); Newell et al. (1953); Cooper and Grant (1972, 1976) as <i>Tropidelasma gregarium</i>

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Brachiopoda (lamp shells) (continued)	<i>Striatifera pinniformis</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953); Cooper and Grant (1976)
	<i>Strigirhynchia indentata</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Cooper and Grant (1972)
	<i>Strigirhynchia transversa</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Tautosia elegans</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Tautosia shumardiana</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Thamnosia capitanensis</i>	Capitan	Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Girty (1908); Cooper and Grant (1972)
	<i>Timorina attenuata</i>	Capitan	Reef or Bioherm, Slope	Stationary low-level epifaunal suspension feeder	Cooper and Grant (1972, 1976)
	<i>Timorina schuchertensis</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Girty (1908); Cooper and Grant (1972, 1976)
	<i>Wellerella elegans</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Wellerella indentata</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Wellerella shumardiana</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Wellerella swallowiana</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
Mollusca: Tergomya	<i>Lepetopsis</i> sp.	Capitan?	Subtidal, Reef or Bioherm	Epifaunal grazer	Yochelson (1960)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Mollusca: Bivalvia (clams, oysters, etc.)	<i>Allorisma</i> sp.	Capitan	Reef or Bioherm	Facultatively mobile infaunal suspension feeder	Newell et al. (1953)
	<i>Acanthopecten laqueatus</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Acanthopecten vanvleeti</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Camptonectes asperatus</i>	Capitan	Reef or Bioherm	Facultatively mobile low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Camptonectes papulatus</i> [sic]	Capitan	Reef or Bioherm	Facultatively mobile low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Camptonectes sculptilis</i>	Capitan	Reef or Bioherm	Facultatively mobile low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Cypricardinia contracta</i>	Capitan	Reef or Bioherm	Facultatively mobile infaunal suspension feeder	Newell et al. (1953)
	<i>Edmondia bellula</i>	Capitan	Reef or Bioherm	Facultatively mobile infaunal suspension feeder	Newell et al. (1953)
	<i>Edmondia circularis</i>	Capitan	Reef or Bioherm	Facultatively mobile infaunal suspension feeder	Newell et al. (1953)
	<i>Euchondria</i> sp.	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Girtypecten sublaqueatus</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Lima</i> sp.	Capitan	?	Facultatively mobile low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Limatulina striaticostata</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Myoconcha costulata</i>	Capitan	Reef or Bioherm; Talus Slope	Facultatively mobile infaunal suspension feeder	Newell et al. (1953)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Mollusca: Bivalvia (clams, oysters, etc.) (continued)	<i>Parallelodon multistriatus</i>	Capitan	Reef or Bioherm; Reef Margin, Talus Slope	Facultatively mobile low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Parallelodon politus</i>	Capitan	Reef or Bioherm; Reef Margin, Talus Slope	Facultatively mobile low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Parallelodon</i> sp.	Capitan	Reef or Bioherm; Reef Margin, Talus Slope	Facultatively mobile low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Pernopecten obliquus</i>	Capitan	Reef or Bioherm	?	Newell et al. (1953)
	<i>Plagiostoma deltoideum</i>	Capitan	Reef or Bioherm	Stationary low-level epifaunal suspension feeder	Newell et al. (1953)
	<i>Pleurophorus albequus</i>	Capitan	Reef or Bioherm; Shallow Back-reef?	Facultatively mobile shallow infaunal suspension feeder	Newell et al. (1953)
	<i>Pseudomonotis spinosa</i>	Capitan	Reef or Bioherm	Stationary epifaunal suspension feeder	Newell et al. (1953)
	<i>Schizodus securus</i>	Capitan	Reef or Bioherm; Back-reef?	Facultatively mobile infaunal suspension feeder	Newell et al. (1953)
	<i>Schizodus symmetrica</i>	Capitan	Reef or Bioherm; Back-reef?	Facultatively mobile infaunal suspension feeder	Newell et al. (1953)
	<i>Streblochondria infelix</i>	Capitan	Reef or Bioherm	Nektobenthic suspension feeder	Newell et al. (1953)
Mollusca: Cephalopoda: Nautiloidea	<i>Foordiceras</i> sp.	Capitan; ?	Shallow subtidal to deep slope	Nektobenthic carnivore	Newell et al. (1953)
	<i>Metacoceras shumardianum</i>	Capitan; ?	Shallow subtidal to reef front	Nektobenthic carnivore	Newell et al. (1953)
	<i>Orthoceras</i> sp.	Capitan; ?	Shallow subtidal to reef front	Nektonic carnivore	Newell et al. (1953)
	<i>Waagenoceras guadalupense</i>	Capitan	Reefs to Talus Slope	Fast-moving nektonic carnivore	Newell et al. (1953)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Mollusca: Cephalopoda: Ammonoidea	<i>Strigogoniatites fountaini</i>	Capitan	Reefs to Talus Slope	Fast-moving nektonic carnivore	Cooper and Grant (1972)
Mollusca: Gastropoda (snails)	<i>Apachella glabra</i>	Capitan	Shallow Open Subtidal; Reef or Bioherm	Epifaunal grazer	Batten (1989)
	<i>Apachella nodosa</i>	Capitan	Shallow subtidal; Reef or Bioherm	Epifaunal grazer	Batten (1989)
	<i>Apachella pseudostrigillata</i>	Capitan	Shallow Open Subtidal; Reef or Bioherm	Epifaunal grazer	Batten (1989)
	<i>Apachella translirata</i>	Capitan	Shallow subtidal; Reef or Bioherm; Slope	Epifaunal grazer	Batten (1989)
	<i>Baylea huecoensis</i>	Capitan	Shallow subtidal; Reef or Bioherm	Epifaunal grazer	Batten (1989)
	<i>Bellerophon</i> sp.	Seven Rivers	Lagoonal back-reef, subtidal	Slow-moving low-level epifaunal detritivore	Kues and DuChene (1990)
	Bellerophontida	Capitan, Seven Rivers	?	Slow-moving low-level epifaunal detritivores	Newell et al. (1953)
	<i>Glabrocingulum</i> (<i>Stenozone</i>) <i>carlsbadensis</i>	Capitan	Reef or Bioherm	Epifaunal grazer	Batten (1989)
	<i>Knightites</i> sp.	"Carlsbad Group", Capitan	Delta Front, Shallow Subtidal	Slow-moving low-level epifaunal detritivore	Yochelson (1960)
	<i>Naticopsis</i> sp.	Capitan	Various; shelf to reef to basin	Epifaunal	Newell et al. (1953)
	<i>Omphalotrochus</i> sp.	Capitan?	Shallow subtidal and shelf	Stationary epifaunal suspension feeder	Newell et al. (1953)
	Pleurotomariids	Capitan	?	Benthic carnivore	Newell et al. (1953)

Appendix Table A-1-b (continued). Permian fossil invertebrate taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Mollusca: Gastropoda (snails) (continued)	<i>Wortheria bialveozona</i>	Capitan	Shallow subtidal; Reef or Bioherm	Facultatively mobile epifaunal suspension feeder	Batten (1989)
	<i>Zygopleura</i> aff. <i>rugosa</i>	Capitan?	?	?	Newell et al. (1953)
Mollusca: Scaphopoda (tusk shells)	<i>Dentalium mexicanum</i>	Capitan, Yates, Tansill	Shallow subtidal, deep subtidal, slope	Slow-moving semi-infaunal deposit feeder	Newell et al. (1953)
	<i>Plagioglypta canna</i>	Capitan, Yates, Tansill	Shallow subtidal, deep subtidal, slope	Slow-moving semi-infaunal deposit feeder	Newell et al. (1953)
Arthropoda: Trilobita	<i>Anisopyge perannulata</i>	Capitan	Reef or Bioherm	Fast-moving low-level epifaunal deposit feeder	Newell et al. (1953)
	<i>Delaria</i> sp.	Capitan	Shallow subtidal or Slope	Fast-moving low-level epifaunal deposit feeder	Brezinski (1992); J. Hearst (pers. comm. December 2019)
Echinodermata: Crinoidea (sea lilies)	Crinoid remains	Capitan, Goat Seep?	?	?	Newell et al. (1953)
Echinodermata: Echinoidea (sea urchins)	Echinoid remains	Capitan	?	?	S. Kottkamp (pers. obs.)

Appendix Table A-1-c. Other Permian fossil taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Enigmatic	<i>Tubiphytes</i>	Capitan	Reef?	Encrusting, reef micro-framework builder, ?	Maslov (1956); Riding and Guo (1992); Riding (1993) as <i>Shamovella obscura</i>
Foraminifera	<i>Codonofusiella</i> sp.	Capitan, Unspecified associated back-reef formation	Back-reef; Reef	Stationary semi-infaunal omnivore	Senowbari-Daryan and Rigby (1996a); Tyrrell (1969)
	<i>Leella bellula</i>	Capitan	Reef	Stationary semi-infaunal omnivore	Newell et al. (1953)
	<i>Paraboultonia</i> sp.	Upper Tansill	Back-reef	Stationary semi-infaunal omnivore	Rigby et al. (1998)
	<i>Paradoxiella</i> sp.	Capitan, Unspecified associated back-reef formation	Back-reef; Reef	Stationary semi-infaunal omnivore	Senowbari-Daryan and Rigby (1996a); Tyrrell (1969)
	<i>Parafusulina fountaini</i>	Goat Seep?	Bioherm	Stationary semi-infaunal omnivore	Newell et al. (1953); H. DuChene (pers. comm., 2019?)
	<i>Parafusulina maleyi</i>	Queen	Back-reef	Stationary semi-infaunal omnivore	Newell et al. (1953)
	<i>Polydiexodina capitanensis</i>	Capitan, Seven Rivers, Yates	Reef; Back-reef	Stationary semi-infaunal omnivore	Newell et al. (1953); Senowbari-Daryan and Rigby (1996a); Tyrrell (1969)
	<i>Polydiexodina shumardi</i>	Capitan, Seven Rivers, Yates	Reef; Back-reef	Stationary semi-infaunal omnivore	Newell et al. (1953); Senowbari-Daryan and Rigby (1996a); Tyrrell (1969)
	<i>Rauserella erratica</i>	Queen	Back-reef	Stationary semi-infaunal omnivore	Newell et al. (1953)
	<i>Reichelina</i> sp.	Upper Tansill	Back-reef	Stationary semi-infaunal omnivore	Senowbari-Daryan and Rigby (1996a); Tyrrell (1969)

Appendix Table A-1-c (continued). Other Permian fossil taxa reported from CAVE in stratigraphic context. References are provided where appropriate.

Group	Taxon	Formation	Habitat/Facies	Ecology	Reference
Foraminifera (continued)	<i>Staffella fountaini</i>	Capitan	Reef	Stationary semi-infaunal omnivore	Newell et al. (1953)
	<i>Yabeina</i> sp.	?	Back-reef	Stationary semi-infaunal omnivore	Senowbari-Daryan and Rigby (1996a); Tyrrell (1969)
Rhodophyta (red algae)	<i>Archaeolithoporella hidensis</i>	Capitan	Reef or Bioherm; deep subtidal	Encrusting photosynthetic; reef-binder	Weidlich and Fagerstrom (1998); Fagerstrom and Weidlich (1999)

Appendix Table A-2. Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.

Group	Taxon	Common Name	Family	Reference	Habitat	Cave or Site
Reptilia: Testudines	<i>Gopherus morafkai</i> ?	Sonoran Desert Tortoise	Testudinidae	Morgan and Lucas (2006)	Desert sand hills to rocky foothills, anywhere that provides soft enough soil to burrow into or provides natural shelters	C2
Reptilia: Lacertilia	<i>Phrynosoma</i> sp.	Horned Lizard	Phrynosomatidae	Black (1953); Morgan and Lucas (2006)	Arid to semi-arid	C1; C2
Reptilia: Serpentes	Serpentes	Snake	Unknown	Morgan and Lucas (2006); Morgan (2012)	Highly adaptable in terms of habitat	C2; C33
	<i>Crotalus</i> sp.	Rattlesnake	Viperidae	NPS Records (2019)	Highly adaptable in terms of habitat	C32
Aves	<i>Cathartes aura</i>	Turkey Vulture	Cathartidae	Santucci et al. (2001); NPS Records (2019)	Highly adaptable in terms of habitat	C4
	<i>Coragyps occidentalis</i> (†)	Pleistocene Black Vulture	Cathartidae	Interview with Lloyd Logan (pers. comm. Feb 2020)	Highly adaptable in terms of habitat	C32?
	Cathartidae, unspecified genus (†)	Extinct Vulture	Cathartidae	Graham (2007)	Highly adaptable in terms of habitat	C33
	Unidentified Raptor	Bird of Prey (uncertain taxon)	Unknown	Morgan and Lucas (2006)	Highly adaptable in terms of habitat	C2
	Unidentified	Large sample (~100 bones) of small unidentified bird fossils	Unknown	Morgan (2012)	Highly adaptable in terms of habitat	C33
	Unidentified	Unidentified Birds	Unknown	NPS Records (2019)	Highly adaptable in terms of habitat	C28; C32
Mammalia: Artiodactyla	<i>Antilocapra americana</i>	Extant Pronghorn	Antilocapridae	Logan (1979); NPS Records (2019)	Open country; likely plains	C9; C32; C33

Appendix Table A-2 (continued). Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.

Group	Taxon	Common Name	Family	Reference	Habitat	Cave or Site
Mammalia: Artiodactyla (continued)	<i>Capromeryx furcifer</i> (†)	Dwarf Pronghorn	Antilocapridae	Morgan and Lucas (2006); White and Morgan (2011); G. Morgan (pers. obs., December 2019) for C33	Open country; plains and savanna	C2; C33
	<i>Stockoceros conklingi</i> (†)	Conkling's Pronghorn	Antilocapridae	Logan (1979)	Open country; likely foothills	C33
	<i>Stockoceros</i> sp. (†)	Extinct Pronghorn	Antilocapridae	Harris (1993); Morgan and Lucas (2006)	Open Country	Big Manhole Cave
	<i>Bison</i> sp.	Bison	Bovidae	Morgan and Lucas (2006); NPS Records (2019)	Open country	S1; Big Manhole Cave
	<i>Euceratherium collinum</i> (†)	Shrub Ox	Bovidae	Logan (1979); Morgan and Lucas (2006)	Open country; likely foothills, and likely preferred cooler/more mesic conditions than the modern Guadalupe	C33
	<i>Oreamnos harringtoni</i> (†)	Harrington's Extinct Mountain Goat	Bovidae	Jass et al. (2000)	Alpine zone, above timberline	C33
	<i>Ovis canadensis</i>	Bighorn Sheep	Bovidae	Logan (1979)	Variety of mountain habitats, no change suggested from present	C15; C20; C33
	<i>Camelops hesternus</i> (†)	Yesterday's Camel	Camelidae	Logan (1979); Harris (1993)	Not a good climate indicator	C2; C33; Big Manhole Cave
	<i>Hemiauchenia macrocephala</i> (†)	Large-Headed Llama	Camelidae	Morgan and Lucas (2006)	Not a good climate indicator	Big Manhole Cave
	<i>Navahoceros fricki</i> (†)	American Mountain Deer	Cervidae	Morgan and Lucas (2006); Harris (1993)	?	C2; Big Manhole Cave

Appendix Table A-2 (continued). Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.

Group	Taxon	Common Name	Family	Reference	Habitat	Cave or Site
Mammalia: Artiodactyla (continued)	<i>Odocoileus hemionus</i>	Mule Deer	Cervidae	NPS Records (2019)	Highly adaptable in terms of habitat	C20; C32; C54; Garden Grove Canyon
Mammalia: Carnivora	<i>Canis dirus</i> (†)	Dire Wolf	Canidae	Logan (1979)	Highly adaptable in terms of habitat	C33
	<i>Canis latrans</i>	Coyote	Canidae	NPS Records (2019)	Highly adaptable in terms of habitat	C32
	<i>Canis</i> sp.	Wolf/Dog	Canidae	Logan (1979); NPS Records (2019)	N/A	C2; C33
	<i>Vulpes velox</i>	Swift Fox	Canidae	Morgan and Lucas (2006)	Open country, desert scrubland and grassland steppe. If actually Kit Fox, much more adapted to highly arid conditions	C2
	<i>Vulpes</i> sp.	Fox	Canidae	NPS Records (2019)	Highly adaptable in terms of habitat. Most extant fox species in the region are adapted to xeric environments	C64
	<i>Lynx rufus</i>	Bobcat	Felidae	Logan (1979)	Highly adaptable in terms of habitat	C33; S9?
	<i>Miracinonyx trumani</i> (†)	American Cheetah	Felidae	Logan (1979); Adams (1979); Martin (1998)	Open country; likely savannah, steppe, or other grasslands	C33
	<i>Panthera atrox</i> (†)	American Lion	Felidae	Logan (1979)	Found in varied assemblages	C1; C33
	<i>Panthera onca</i> *	Jaguar	Felidae	Santucci et al. (2001)	Highly adaptable in terms of habitat	C1
	<i>Puma concolor</i>	Cougar	Felidae	Logan (1979)	Highly adaptable in terms of habitat	C1; C2; C5; C29?; C33; C77; S9?
	<i>Conepatus</i> sp.	Hog Nosed Skunk	Mephitidae	Logan (1979)	Desert, brushland, and grassland; can be found in sparse woodlands	C33
	<i>Spilogale gracilis</i>	Western Spotted Skunk	Mephitidae	Logan (1979)	Desert, brushland, and grassland; can be found in sparse woodlands	C33

Appendix Table A-2 (continued). Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.

Group	Taxon	Common Name	Family	Reference	Habitat	Cave or Site
Mammalia: Carnivora (continued)	<i>Mustela frenata</i>	Long-Tailed Weasel	Mustelidae	Logan (1979)	Highly adaptable in terms of habitat	C33
	<i>Bassariscus astutus</i>	Ringtail	Procyonidae	Logan (1979); Morgan and Lucas (2006); NPS Records (2019)	Rocky habitats and deserts, though it has been found in other environs as well	C2; C5; C10; C32; C33; C86; C87?
	<i>Procyon lotor?</i>	Raccoon	Procyonidae	NPS Records (2019)	Highly adaptable in terms of habitat	C87?
	<i>Ursus arctos?</i> *	Brown Bear	Ursidae	NPS Records (2019)	Highly adaptable in terms of habitat?	C5?
Mammalia: Chiroptera	Unidentified Chiroptera	Bat	Unknown	NPS Records (2019)	Highly adaptable in terms of habitat	C4; C8; C10; C22; C28; C29
	<i>Tadarida brasiliensis mexicana</i>	Mexican Free Tailed Bat	Molossidae	Baker (1963)	Colonial, cave rooster. Highly adaptable	C1
	<i>Tadarida constantinei</i> (†)	Constantine's Free Tailed Bat	Molossidae	Lawrence (1960); Baker (1963); Polyak et al. (2006)	Colonial, cave rooster	C1; C2
	<i>Aeorestes cinereus</i>	Hoary bat	Vespertilionidae	Baker (1963); Jablonsky (1996)	Tree-roosting bat	C1; C5
	<i>Antrozous pallidus</i>	Pallid Bat	Vespertilionidae	Logan (1979)	Highly adaptable in terms of habitat	C33
	<i>Corynorhinus townsendi</i>	Townsend's Big Eared Bat	Vespertilionidae	Jablonsky (1993, 1996); Morgan and Lucas (2006)	Cave-roosting bat; otherwise widespread in terms of habitat	C1; C5; C33
	<i>Eptesicus fuscus</i>	Big Brown Bat	Vespertilionidae	Baker (1963); Jablonsky (1993, 1996); Logan (1979)	Highly adaptable in terms of habitat	C1; C5; C33
	<i>Eptesicus fuscus grandis</i>	Big Brown Bat, Pleistocene subspecies	Vespertilionidae	Baker (1963); Logan (1979); Jablonsky (1993)	Highly adaptable in terms of habitat	C1; C33

Appendix Table A-2 (continued). Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.

Group	Taxon	Common Name	Family	Reference	Habitat	Cave or Site
Mammalia: Chiroptera (continued)	<i>Lasiurus blossevillii</i>	Western Red Bat	Vespertilionidae	Morgan and Lucas (2006); G. Morgan (pers. obs., December 2019)	Tree-roosting bat	C1
	<i>Myotis ciliolabrum</i>	Western small-footed bat	Vespertilionidae	Jablonsky (1993, 1996)	Common in arid environments, but may extend into juniper or pine forests at high elevation	C1; C5
	<i>Myotis thysanodes</i>	Fringed Myotis	Vespertilionidae	Logan (1979)	Desert grassland to yellow pine zone	C33
	<i>Myotis velifer</i>	Cave Myotis	Vespertilionidae	Jablonsky (1993, 1996); Logan (1979)	Cave-roosting bat; otherwise widespread in terms of habitat	C1; C5; C33
	<i>Myotis volans</i>	Long-Legged Myotis	Vespertilionidae	Jablonsky (1993, 1996)	Highly adaptable in terms of habitat	C1; C5
	<i>Myotis yumanensis</i>	Yuma Myotis	Vespertilionidae	Jablonsky (1993, 1996)	Prefer proximity to water, but otherwise highly adaptable	C1; C5
	<i>Myotis</i> sp.	Mouse-Eared Bats	Vespertilionidae	Baker (1963)	Highly adaptable in terms of habitat	C1
Mammalia: Eulipotyphla	<i>Cryptotis parva</i>	Least Shrew	Soricidae	Logan (1979)	Grassland steppe, uncommonly found in woodlands	C33
	<i>Notiosorex crawfordi</i>	Crawford's Gray Desert Shrew	Soricidae	Logan (1979)	Commonly found in desert scrubland, but adaptable	C33
	<i>Notiosorex dalquesti</i> (†)	Dalquest's Shrew	Soricidae	Carraway (2010); Harris (1993)	Commonly found in desert scrubland, but adaptable	C33; Big Manhole Cave
	<i>Notiosorex harrisi</i> (†)	Harris' Shrew	Soricidae	Harris (1993); Carraway (2010)	Commonly found in desert scrubland, but adaptable	Big Manhole Cave
	<i>Sorex cinereus</i> *	Masked Shrew	Soricidae	Logan (1979)	Prefers to be near water, but adaptable	C33

Appendix Table A-2 (continued). Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.

Group	Taxon	Common Name	Family	Reference	Habitat	Cave or Site
Mammalia: Eulipotyphla (continued)	<i>Sorex merriami</i> *	Merriam's Shrew	Soricidae	Logan (1979)	Dry woodlands and sagebrush	C33
	<i>Sorex monticolus</i> *	Montane Shrew	Soricidae	Logan (1979) (as <i>S. vagrans</i>)	In montane and hydrosere communities	C33
	<i>Sorex nanus</i> *	Dwarf Shrew	Soricidae	Harris (1993); Morgan and Lucas (2006)	Mountains, but range from the foothills to alpine tundra	Big Manhole Cave
	<i>Sorex neomexicanus</i>	New Mexico Shrew	Soricidae	Logan (1979); G. Morgan (pers. obs., 2019)	Montane communities in SE New Mexico	C33
	<i>Sorex palustris</i> *	Water Shrew	Soricidae	Logan (1979)	Semi-aquatic, requires permanent water	C33
Mammalia: Lagomorpha	<i>Sylvilagus audubonii</i>	Desert Cottontail	Leporidae	Morgan and Lucas (2006)	Desert scrubland	C2
	<i>Sylvilagus floridanus</i>	Eastern Cottontail	Leporidae	Logan (1979)	Either boreal habitats in the mountains (where it exists in NM today) or in riparian environs	C33
	<i>Sylvilagus nuttalli</i> *	Nuttall's Cottontail	Leporidae	Logan (1979); Harris (1993); Morgan and Lucas (2006)	Sagebrush to timber	C33; Big Manhole Cave
	<i>Sylvilagus</i> sp.	Cottontail	Leporidae	NPS Records (2019)	Various	A13
Mammalia: Perissodactyla	<i>Equus conversidens</i> (†)	Mexican Horse	Equidae	Morgan and Lucas (2006); Morgan (2012); NPS Records (2019); Harris (1993)	Various	C33; Big Manhole Cave

Appendix Table A-2 (continued). Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.

Group	Taxon	Common Name	Family	Reference	Habitat	Cave or Site
Mammalia: Perissodactyla (continued)	<i>Equus occidentalis</i> (†)	Western Horse	Equidae	Morgan and Lucas (2006); G. Morgan (pers. obs., December 2019)	Various	Big Manhole Cave; Morgan's Smithsonian Inventory indicates the unidentified <i>Equus</i> in Logan (1979) may be this species
	<i>Equus</i> sp.	Horse	Equidae	Logan (1979)	Prefers open country, but adaptable to other environs and many climates	C33; A13
Mammalia: Rodentia	<i>Lemmys curtatus</i> *	Sagebrush Vole	Cricetidae	Harris (1993); Morgan and Lucas (2006)	Arid brushland; no change from present	Big Manhole Cave
	<i>Microtus mexicana</i>	Mexican Vole	Cricetidae	Logan (1979); Harris (1993); Morgan and Lucas (2006)	Montane grasslands in ponderosa and mixed forests. Only currently extant vole in the Guadalupe Mountains	C33; Big Manhole Cave
	<i>Microtus ochrogaster</i> *	Prairie Vole	Cricetidae	Logan (1979)	Xeric and prairie environs	C33
	<i>Microtus pennsylvanicus</i> *	Meadow Vole	Cricetidae	Logan (1979)	Restricted to hydrosere conditions no longer found in the vicinity of CAVE	C33
	<i>Neotoma albigula</i>	White-Throated Woodrat	Cricetidae	Logan (1979)	Rocky desert brushland	C33
	<i>Neotoma cinerea</i> *	Bushy-tailed Woodrat	Cricetidae	Logan (1979); Harris (1993); Morgan and Lucas (2006)	Highly adaptable in terms of habitat	C33; Big Manhole Cave
	<i>Neotoma mexicana</i>	Mexican Woodrat	Cricetidae	Logan (1979); NPS Records (2019)	Higher elevations in the Guadalupe today, especially like canyons	C33; C32

Appendix Table A-2 (continued). Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.

Group	Taxon	Common Name	Family	Reference	Habitat	Cave or Site
Mammalia: Rodentia (continued)	<i>Neotoma micropus</i>	Southern Plains Woodrat	Cricetidae	Logan (1979)	Desert shrublands	C33
	<i>Neotoma</i> sp.	Woodrat	Cricetidae	Logan (1979); Morgan and Lucas (2006)	Highly adaptable in terms of habitat	C2; C33; C93
	<i>Ondatra zibethicus</i>	Muskrat	Cricetidae	Logan (1979)	Near fluvial and lacustrine systems. Semi-aquatic and needs permanent water	C33
	<i>Onychomys leucogaster</i>	Northern Grasshopper Mouse	Cricetidae	Logan (1979)	Sandy grasslands and mesquite stands; does not indicate change from present	C33
	<i>Onychomys torridus</i>	Southern Grasshopper Mouse	Cricetidae	Logan (1979)	Prefers clay soil and desert pavements in low elevations; does not indicate climate change	C33
	<i>Peromyscus</i> sp.	Deer Mouse	Cricetidae	Logan (1979); NPS Records (2019)	Highly adaptable in terms of habitat	C32; C33
	<i>Reithrodontomys fulvescens</i>	Fulvous Harvest Mouse	Cricetidae	Logan (1979)	Grasslands interspersed with shrubs; does not indicate climatic change, though it is not present in the region today	C33
	<i>Sigmodon hispidus</i>	Hispid Cotton Rat	Cricetidae	NPS Records (2019)	Highly adaptable in terms of habitat	C32
	<i>Erethizon dorsatum</i>	Common Porcupine	Erethizontidae	Logan (1979); NPS Records (2019)	Highly adaptable in terms of habitat	C2; C9; C32; C33; C56; C64; A13
	<i>Pappogeomys castanops</i>	Yellow-faced Pocket Gopher	Geomyidae	Lyman (1983)	Various	C32
	<i>Thomomys bottae</i>	Botta's Pocket Gopher	Geomyidae	Logan (1981); NPS Records (2019)	Mountain valleys and meadows. Found in modern Guadalupe	C32; C33; A13

Appendix Table A-2 (continued). Pleistocene and Holocene taxa reported from CAVE. References are provided where appropriate.

Group	Taxon	Common Name	Family	Reference	Habitat	Cave or Site
Mammalia: Rodentia (continued)	<i>Perognathus merriami</i>	Merriam Pocket Mouse	Heteromyidae	Logan (1979)	Sandy/gravelly soiled arid regions with sparse vegetation, similar to modern	C33
	<i>Perognathus</i> sp.	Pocket Mouse	Heteromyidae	Morgan and Lucas (2006)	Highly adaptable in terms of habitat	C2
	<i>Marmota flaviventris</i> *	Yellow-Bellied Marmot	Sciuridae	Murray (1957); Logan (1979); Harris (1993); Morgan and Lucas (2006)	Meadows in high woodlands; evidence of more mesic conditions than present	C33; Big Manhole Cave
	<i>Neotamias</i> sp.	Chipmunk	Sciuridae	Logan (1979); G. Morgan (pers. obs., December 2019)	Highly adaptable in terms of habitat	C32; C33
	<i>Otospermophilus variegatus</i>	Rock Squirrel	Sciuridae	Logan (1979); Helgen et al. (2009); NPS Records (2019)	Prefers environs similar to modern, from arid scrublands to rocky foothills	C32; C33; C34; A13
	<i>Tamiasciurus hudsonicus</i> *	Red Squirrel	Sciuridae	Logan (1979)	Mixed coniferous, spruce-fir forests, and associated montane regions; presence indicates past spruce-fir forests in region	C33
Mammalia: Xenarthra	<i>Nothrotheriops shastensis</i> (†)	Shasta Ground Sloth	Nothrotheriidae (†)	Hill and Gillette (1987a, 1987b) for CC; Jablonsky (2004?) for Lechuguilla; McDonald and Jefferson (2008) and McDonald and Morgan (2011) for both	Various	C1; C5

Appendix B. Outside Repositories of CAVE Fossils

MUSEUM OF COMPARATIVE ZOOLOGY, HARVARD UNIVERSITY

26 Oxford Street

Cambridge, MA 02138

(617) 495-2460

<https://mcz.harvard.edu/>

Museum of Comparative Zoology CAVE holdings: The holotype and an additional 19 paratypes of the Pleistocene bat *Tadarida constantinei* are held here.

NEW MEXICO MUSEUM OF NATURAL HISTORY AND SCIENCE

1801 Mountain Road NW

Albuquerque, NM 87104

(505) 841-2800

<http://www.nmnaturalhistory.org/>

nmmnhs.info@state.nm.us

New Mexico Museum of Natural History and Science CAVE holdings: Pleistocene vertebrates from Slaughter Canyon Cave, including a large sample of *Tadarida constantinei*, and smaller samples of four other species of bats, two rodents, desert tortoise, and two extinct pronghorns.

There are also other holdings of Quaternary fossil vertebrates, often transferred to the museum from other sources (e.g., McFarlane's bat specimens).

SMITHSONIAN INSTITUTION, NATIONAL MUSEUM OF NATURAL HISTORY

Department of Paleobiology

P.O. Box 37012

NHB MRC 121

Washington, D.C. 20013

<https://naturalhistory.si.edu/research/paleobiology>

paleodept@si.edu

Smithsonian CAVE holdings: Numerous specimens of both Permian and Pleistocene age from the park. The most notable include the 1976 collection from Musko Cave and the holotypes of *Glabrocingulum (Stenozone) carlsbadensis* and *Plectelasma planidorsatum*.

TEXAS TECH UNIVERSITY

2500 Broadway

Lubbock, TX 79409

(806) 742-2011

<https://www.ttu.edu/>

Texas Tech CAVE holdings: Holocene vertebrates and plants from Wen Cave, including: a coyote *Canis latrans*; an unidentified carnivoran upper P3 or P4 tooth; bones and teeth of eight rodent taxa;

bones of the ringtail *Bassariscus astutus*; bones of the mule deer *Odocoileus hemionus*; rattlesnake vertebrae (*Crotalus* sp.); and bird bones. These remains were cataloged under a GUMO accession number.

UNIVERSITY OF NEBRASKA STATE MUSEUM

Morrill Hall

645 North 14th Street

Lincoln, NE 68588

(402) 472-2637

<https://museum.unl.edu/>

University of Nebraska holdings: Permian sponge fossils, including the holotypes of *Lemonea exaulifera* and *Preverticillites parva*, as well as two skeletons of the extinct mountain deer *Navahoceros fricki*, one mounted and on display in the UNSM, and a small sample of *Tadarida constantinei*.

Appendix C. Paleontological Resource Law and Policy

The following material is reproduced in large part from Henkel et al. (2015):

In March 2009, the Paleontological Resources Preservation Act (PRPA) (16 USC 460aaa) was signed into law (Public Law 111–11). This act defines paleontological resources as

...any fossilized remains, traces, or imprints of organisms, preserved in or on the earth's crust, that are of paleontological interest and that provide information about the history of life on earth.

The law stipulates that the Secretary of the Interior should manage and protect paleontological resources using scientific principles. The Secretary should also develop plans for

...inventory, monitoring, and the scientific and educational use of paleontological resources.

Paleontological resources are considered park resources and values that are subject to the “no impairment” standard in the National Park Service Organic Act (1916). In addition to the Organic Act, PRPA will serve as a primary authority for the management, protection and interpretation of paleontological resources. The proper management and preservation of these non-renewable resources should be considered by park resource managers whether or not fossil resources are specifically identified in the park’s enabling legislation.

The Paleontological Resources Management section of NPS Reference Manual 77 provides guidance on the implementation and continuation of paleontological resource management programs. Administrative options include those listed below and a park management program will probably incorporate multiple options depending on specific circumstances:

- **No action**—no action would be taken to collect the fossils as they erode from the strata. The fossils would be left to erode naturally and over time crumble away, or possibly be vandalized by visitors, either intentionally or unintentionally.
- **Surveys**—will be set up to document potential fossil localities. All sites will be documented with the use of GPS and will be entered into the park GIS database. Associated stratigraphic and depositional environment information will be collected for each locality. A preliminary faunal list will be developed. Any evidence of poaching activity will be recorded. Rates of erosion will be estimated for the site and a monitoring schedule will be developed based upon this information. An NPS Paleontological Locality Database Form will also be completed for each locality. A standard version of this form will be provided by the Paleontology Program of the Geologic Resources Division upon request and can be modified to account for local conditions and needs.
- **Monitoring**—fossil-rich areas would be examined periodically to determine if conditions have changed to such an extent that additional management actions are warranted. Photographic records should be kept so that changes can be more easily ascertained.

- **Cyclic monitoring**—areas of high erosion which also have a high potential for producing significant specimens would be examined periodically for new sites. The periodicity of such cyclic prospecting will depend on locality-specific characteristics such as rates of sediment erosion, abundance or rarity of fossils, and proximity to visitor use areas.
- **Stabilization and reburial**—significant specimens which cannot be immediately collected may be stabilized using appropriate consolidants and reburied. Reburial slows down but does not stop the destruction of a fossil by erosion. Therefore, this method would be used only as an interim and temporary stop-gap measure. In some situations, stabilization of a locality may require the consideration of vegetation. For example, roots can destroy in situ fossils, but can also protect against slope erosion, while plant growth can effectively obscure localities, which can be positive or negative depending on how park staff want to manage a locality.
- **Shelter construction**—it may be appropriate to exhibit certain fossil sites or specimens in situ, which would require the construction of protective shelters to protect them from the natural forces of erosion. The use of shelters draws attention to the fossils and increases the risk of vandalism or theft, but also provides opportunities for interpretation and education.
- **Excavation**—partial or complete removal of any or all fossils present on the surface and potentially the removal of specimens still beneath the surface which have not been exposed by erosion.
- **Closure**—the area containing fossils may be temporarily or permanently closed to the public to protect the fossil resources. Fossil-rich areas may be closed to the public unless accompanied by an interpretive ranger on a guided hike.
- **Patrols**—may be increased in areas of known fossil resources. Patrols can prevent and/or reduce theft and vandalism. The scientific community and the public expect the NPS to protect its paleontological resources from vandalism and theft. In some situations, a volunteer site stewardship program may be appropriate (for example, the “Paleo Protectors” at Chesapeake & Ohio Canal National Historical Park).
- **Alarm systems/electronic surveillance**—seismic monitoring systems can be installed to alert rangers of disturbances to sensitive paleontological sites. Once the alarm is engaged, a ranger can be dispatched to investigate. Motion-activated cameras may also be mounted to visually document human activity in areas of vulnerable paleontological sites.

National Park Service Management Policies (2006a; Section 4.8.2.1) also require that paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. In 2010, the National Park Service established National Fossil Day as a celebration and partnership organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value (<https://www.nps.gov/subjects/fossilday/index.htm>). National Fossil Day occurs annually on Wednesday of the second full week in each October in conjunction with Earth Science Week.

Related Laws, Legislation, and Management Guidelines

National Park Service Organic Act

The NPS Organic Act directs the NPS to manage units

...to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner as will leave them unimpaired for the enjoyment of future generations. (16 U.S.C. § 1).

Congress reiterated this mandate in the Redwood National Park Expansion Act of 1978 by stating that the NPS must conduct its actions in a manner that will ensure no

...derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress. (16 U.S.C. § 1 a-1).

The Organic Act prohibits actions that permanently impair park resources unless a law directly and specifically allows for the acts. An action constitutes an impairment when its impacts

...harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources and values. (Management Policies 2006 1.4.3).

Paleontological Resources Protection Act (P.L. 111-011, Omnibus Public Land Management Act of 2009, Subtitle D)

Section 6302 states

The Secretary (of the Interior) shall manage and protect paleontological resources on Federal land using scientific principles and expertise. The Secretary shall develop appropriate plans for inventory, monitoring, and the scientific and educational use of paleontological resources, in accordance with applicable agency laws, regulations, and policies. These plans shall emphasize interagency coordination and collaborative efforts where possible with non-Federal partners, the scientific community, and the general public.

Federal Cave Resources Protection Act of 1988 (16 USC 4301)

This law provides a legal authority for the protection of all cave resources on NPS and other federal lands. The definition for “Cave Resource” in Section 4302 states

Cave resources include any material or substance occurring naturally in caves on Federal lands, such as animal life, plant life, paleontological deposits, sediments, minerals, speleogens, and speleothems.

NPS Management Policies 2006

NPS Management Policies 2006 include direction for preserving and protecting cultural resources, natural resources, processes, systems, and values (NPS 2006). It is the goal of the NPS to avoid or minimize potential impacts to resources to the greatest extent practicable consistent with the

management policies. The following is taken from section 4.8.2.1 of the NPS Management Policies 2006, “Paleontological Resources and Their Contexts”:

Paleontological resources, including both organic and mineralized remains in body or trace form, will be protected, preserved, and managed for public education, interpretation, and scientific research. The Service will study and manage paleontological resources in their paleoecological context (that is, in terms of the geologic data associated with a particular fossil that provides information about the ancient environment).

Superintendents will establish programs to inventory paleontological resources and systematically monitor for newly exposed fossils, especially in areas of rapid erosion. Scientifically significant resources will be protected by collection or by on-site protection and stabilization. The Service will encourage and help the academic community to conduct paleontological field research in accordance with the terms of a scientific research and collecting permit. Fossil localities and associated geologic data will be adequately documented when specimens are collected. Paleontological resources found in an archeological context are also subject to the policies for archeological resources. Paleontological specimens that are to be retained permanently are subject to the policies for museum objects.

The Service will take appropriate action to prevent damage to and unauthorized collection of fossils. To protect paleontological resources from harm, theft, or destruction, the Service will ensure, where necessary, that information about the nature and specific location of these resources remains confidential, in accordance with the National Parks Omnibus Management Act of 1998.

Parks will exchange fossil specimens only with other museums and public institutions that are dedicated to the preservation and interpretation of natural heritage and qualified to manage museum collections. Fossils to be deaccessioned in an exchange must fall outside the park’s scope of collection statement. Systematically collected fossils in an NPS museum collection in compliance with 36 CFR 2.5 cannot be outside the scope of collection statement. Exchanges must follow deaccession procedures in the Museum Handbook, Part II, chapter 6.

The sale of original paleontological specimens is prohibited in parks.

The Service generally will avoid purchasing fossil specimens. Casts or replicas should be acquired instead. A park may purchase fossil specimens for the park museum collection only after making a written determination that

- *The specimens are scientifically significant and accompanied by detailed locality data and pertinent contextual data;*
- *The specimens were legally removed from their site of origin, and all transfers of ownership have been legal;*
- *The preparation of the specimens meets professional standards;*

- *The alternatives for making these specimens available to science and the public are unlikely;*
- *Acquisition is consistent with the park's enabling legislation and scope of collection statement, and acquisition will ensure the specimens' availability in perpetuity for public education and scientific research.*

All NPS construction projects in areas with potential paleontological resources must be preceded by a preconstruction surface assessment prior to disturbance. For any occurrences noted, or when the site may yield paleontological resources, the site will be avoided or the resources will, if necessary, be collected and properly cared for before construction begins. Areas with potential paleontological resources must also be monitored during construction projects.

(See [Natural Resource Information 4.1.2](#); [Studies and Collections 4.2](#); [Independent Research 5.1.2](#); [Artifacts and Specimens 10.2.4.6](#). Also see [36 CFR 2.5](#).)

NPS Director's Order-77, Paleontological Resources Management

DO-77 describes fossils as non-renewable resources and identifies the two major types, body fossils and trace fossils. It describes the need for managers to identify potential paleontological resources using literature and collection surveys, identify areas with potential for significant paleontological resources, and conduct paleontological surveys (inventory). It also describes appropriate actions for managing paleontological resources including: no action, monitoring, cyclic monitoring, stabilization and reburial, construction of protective structures, excavation, area closures, patrols, and the need to maintain confidentiality of sensitive location information.

Excerpt from Clites and Santucci (2012)

Monitoring

An important aspect of paleontological resource management is establishing a long-term paleontological resource monitoring program. National Park Service paleontological resource monitoring strategies were developed by Santucci et al. (2009). The park's monitoring program should incorporate the measurement and evaluation of the factors stated below.

Climatological Data Assessments

These assessments include measurements of factors such as annual and storm precipitation, freeze/thaw index (number of 24-hour periods per year where temperature fluctuates above and below 32 degrees Fahrenheit), relative humidity, and peak hourly wind speeds.

Rates of Erosion Studies

These studies require evaluation of lithology, slope degree, percent vegetation cover, and rates of denudation around established benchmarks. If a park does not have this information, there may be opportunities to set up joint projects, because erosion affects more than just paleontological resources.

Assessment of Human Activities, Behaviors, and Other Variables

These assessments involve determining access/proximity of paleontological resources to visitor use areas, annual visitor use, documented cases of theft/vandalism, commercial market value of the fossils, and amount of published material on the fossils.

Condition Assessment and Cyclic Prospecting

These monitoring methods entail visits to the locality to observe physical changes in the rocks and fossils, including the number of specimens lost and gained at the surface exposure. Paleontological prospecting would be especially beneficial during construction projects or road repair.

Periodic Photographic Monitoring

Maintaining photographic archives and continuing to photo-document fossil localities from established photo-points enables visual comparison of long-term changes in site variables.

Appendix D. CAVE Paleontological Locality Summary

This table does not include a full listing of Permian-age surface localities, because they do not fall under the types of sites that would receive a designated number at CAVE (rather, they are referred to by the locality number given by the collecting institution). Additional details about those localities and their paleontological resources can be found in the Fossil Localities section.

Appendix Table D-1. Paleontological localities of CAVE.

Site	Type of Locality	Vertebrates	Invertebrates	Plants	Age of Fossils
Carlsbad Cavern (C-01)	Vertebrate; Invertebrate; Ichnofossil	Reptiles, Mammals: <i>Phrynosoma</i> scales and bones; many types of bat (see faunal list); bat guano; <i>Nothrotheriops shastensis</i> ; <i>Panthera atrox</i> ; <i>Panthera onca</i> ; <i>Puma concolor</i>	Many, including algae, sponges, brachiopods, bivalves, cephalopods, crinoids, etc.; notably trilobites	None recorded	Permian; Pleistocene; Holocene
Slaughter Canyon Cave (C-02)	Vertebrate; Invertebrate; Ichnofossil	Reptiles, Birds, Mammals: <i>Gopherus</i> sp. (desert tortoise); unidentified snake; unidentified raptorial bird; <i>Tadarida constantinei</i> ; many other mammals (see faunal list)	Algae, brachiopods, crinoids, more?	None recorded	Permian; Pleistocene
C-04	Vertebrate; Ichnofossil	Birds, Mammals: <i>Cathartes aura</i> (recent); bat bones; bat guano; unidentified bones	None recorded	None recorded	Quaternary; Holocene (recent)
Lechuguilla Cave (C-05)	Vertebrate; Invertebrate; Ichnofossil; Plant	Mammals: many types of bat (see faunal list); bat guano; <i>Nothrotheriops shastensis</i> ; <i>Bassariscus astutus</i> ; <i>Puma concolor</i> ; <i>Ursus arctos</i>	Many forms	Pollen of many plants (Jablonsky 1993)	Permian; Pleistocene; Holocene
C-07	Vertebrate; Invertebrate; Ichnofossil	Mammals: bat guano; small cervid or caprine bones (age unknown); <i>Capra aegagrus hircus</i> (recent)	Unidentified spiral; very small brachiopod	None recorded	Permian; Quaternary; Holocene (Recent)
C-08	Vertebrate; Invertebrate; Ichnofossil	Mammals: bat bones; bat guano (notably mature/old in appearance)	Algae, Sponges	None recorded	Permian; Pleistocene? (old guano, associated bones); Holocene (recent guano and bat bones)

Appendix Table D-1 (continued). Paleontological localities of CAVE.

Site	Type of Locality	Vertebrates	Invertebrates	Plants	Age of Fossils
Spider Cave (C-09)	Vertebrate	Mammals: <i>Erethizon dorsatum</i> skull and post-crania; <i>Antilocapra americana</i> bones; <i>Bos taurus</i> bones (recent)	?	None recorded	Holocene; Holocene (Recent)
C-10	Vertebrate	Birds, Mammals: Pleistocene bones and bone fragments of large mammal; hypothesized cave bear pits/dens; complete <i>Bassariscus astutus</i> skeleton (recent?); <i>Ammotragus lervia</i> skeleton (recent); bird, bat, and rodent bones of unspecified age	There is a comment that the cave must lie at the contact between Capitan Reef and the back-reef, but no fossils are mentioned.	None recorded	Pleistocene; Holocene (Recent)
C-11	Vertebrate; Invertebrate	Mammals: Proximal end of a scapula	Algae, Sponges	None recorded	Permian; Quaternary
C-12	Vertebrate	Mammals: unidentified bones, bat guano (recent)	None recorded	None recorded	Holocene (Recent), possibly some older Quaternary
C-13	Vertebrate; Invertebrate	Mammals: unidentified femur; small rodent bones; unidentified small mammal skull	Back-Reef–Massive Capitan contact; algae; sponges, brachiopods, bivalves, gastropods	None recorded	Permian; Quaternary
C-14	Vertebrate	Mammals: <i>Capra aegagrus hircus</i> (recent)	None recorded	None recorded	Holocene (Recent)
C-15	Vertebrate	Mammals: <i>Ovis canadensis</i> (Bighorn Sheep) Skull	None recorded	None recorded	Quaternary
C-20	Vertebrate; Invertebrate?	Mammals: <i>Odocoileus hemionus</i> (recent?); <i>Capra aegagrus hircus</i> skull (recent); <i>Ovis canadensis</i>	Capitan Reef facies, no further record	None recorded	Permian; Quaternary; Holocene (Recent)
C-21	Vertebrate; Invertebrate; Ichnofossil	Mammals: bat guano (likely recent, cave home to <i>Corynorhinus townsendii</i>); <i>Capra aegagrus hircus</i> (recent)	Seven Rivers Formation, back-reef facies. Several large ammonoid fossils.	None recorded	Permian; Holocene (Recent)

Appendix Table D-1 (continued). Paleontological localities of CAVE.

Site	Type of Locality	Vertebrates	Invertebrates	Plants	Age of Fossils
C-22	Vertebrate; Invertebrate; Ichnofossil	Mammals: bat skulls and guano (some marked “old” and associated w/ flowstone), claw traces in flowstone, <i>Capra aegagrus hircus</i> (recent), <i>Ammotragus lervia</i> skulls (recent), two localities of unidentified large calcified and small mammal bones	Sponges, corals, bryozoans, brachiopods, bivalve, ammonoids, bellerophontid gastropod and other snails, crinoids, fusulinids	None recorded	Permian; Pleistocene?; Holocene; Holocene (Recent)
C-23	Vertebrate	Mammals	No record	None recorded	NO FILE
C-24	Vertebrate; Invertebrate; Ichnofossil	Mammals: three unidentified, calcified mammal bones; additional chiropteran bones	Fore-reef Capitan talus. Corals, bryozoans, brachiopods, nautiloids, gastropods, worm burrow traces	None recorded	Permian; Quaternary
C-25	Vertebrate; Invertebrate; Ichnofossil	Mammals: bat guano; goat (<i>Capra aegagrus hircus</i> ?) bones	Sponges/sponge hash, bivalves, a nautiloid, crinoids. Massive reef facies, predominantly sponges.	None recorded	Permian; Holocene
C-26	Vertebrate	Mammals; no further information in file	None recorded	None recorded	Quaternary?
C-28	Vertebrate	Birds, Mammals: unidentified small bird bones; bat bones; bat guano; unidentified large animal bones; rodent bones and teeth (likely recent)	“Outstanding” sponges, brachiopods, a crinoid	None recorded	Permian; Quaternary; Holocene (Recent)
C-29	Vertebrate; Invertebrate; Possible Ichnofossil	Mammals: bat bones (some recent—decaying bodies); bat guano; complete disarticulated skeleton of a large carnivore. Initial surveyors thought it looked canine, but a contacted scientist suggested it was a felid, possibly <i>Puma</i> ; a single rib of a size akin to “a mid-sized dog” was found in a different area of the cave; polished flooring in some sections may suggest habitual travel by animals	Algae, sponges, corals, brachiopods, bivalves, cephalopods, gastropods, crinoids, possible trilobite	None recorded	Permian; Quaternary; Holocene (Recent)
C-30	Vertebrate	Mammals: capreoline skeletons; <i>Capra aegagrus hircus</i> (recent) skeletons	None recorded	None recorded	Quaternary; Holocene (recent)

Appendix Table D-1 (continued). Paleontological localities of CAVE.

Site	Type of Locality	Vertebrates	Invertebrates	Plants	Age of Fossils
Wen Cave (C-32)	Vertebrate	Reptiles, Birds, Mammals: <i>Crotalus</i> sp. vertebrae; humerus of <i>Coragyps occidentalis</i> ; unidentified bird bones; small skeleton of unidentified mammal— presumed rodent, possibly <i>Otospermophilus variegatus</i> ; <i>Canis latrans</i> , unspecified remains; unidentified carnivoran upper P3 or P4; many other mammals (see faunal list)	None recorded	None recorded	Pleistocene; Holocene
Musk Ox Cave (C-33)	Vertebrate; Plant	Mammals: many (see faunal list)	None recorded	<i>Celtis</i> , <i>Opuntia</i>	Pleistocene; Holocene
C-34	Vertebrate; Invertebrate	Birds, Mammals: <i>Otospermophilus variegatus</i> skeleton; unidentified rodent skull and bones	Algae, sponges, corals, brachiopods, bivalves, gastropods, crinoids	None recorded	Permian; Quaternary; Holocene (Recent)
C-49	Vertebrate	Mammals: large amount of rodent bones, some complete skeletons. Skulls uniformly missing?	None recorded	None recorded	Quaternary
C-54	Vertebrate	Mammals: unspecified “recent” bones; articulated skeleton tentatively identified as a juvenile <i>Odocoileus hemionus</i>	None recorded	None recorded	Holocene (Recent)
C-56	Vertebrate	Mammals: many <i>Capra aegagrus hircus</i> skulls and bones; <i>Erethizon dorsatum</i> bones; an area on the map is marked as the “deer beds,” but it was unclear if this means deer bones were found here.	None recorded	None recorded	Holocene (Recent)
C-60	Vertebrate; Ichnofossil	Birds, Mammals?: bird guano; “fairly fossilized” unidentified rib	None recorded	None recorded	Pleistocene; Holocene (Recent)
C-62	Vertebrate; Invertebrate	Mammals: “possible Pleistocene vertebrate remains” without further detail; older maps indicate porcupine fossils in the cave, but in a 1990 trip they were gone; small rodent bones including a mouse jaw	Ammonite	None recorded	Permian; Quaternary; Pleistocene?
C-64	Vertebrate	Mammals: <i>Capra aegagrus hircus</i> (recent); <i>Erethizon dorsatum</i> ; <i>Vulpes</i> sp.; small mammal bones	None recorded	None recorded	Quaternary; Holocene (recent)
C-77	Vertebrate	Mammals: <i>Puma concolor</i> jaw; unidentified bones;	None recorded	None recorded	Quaternary
C-86	Vertebrate	Mammals: unidentified rodent incisor; unidentified small bones; capreoline vertebra; <i>Bassariscus astutus</i> skeleton	None recorded	None recorded	Quaternary

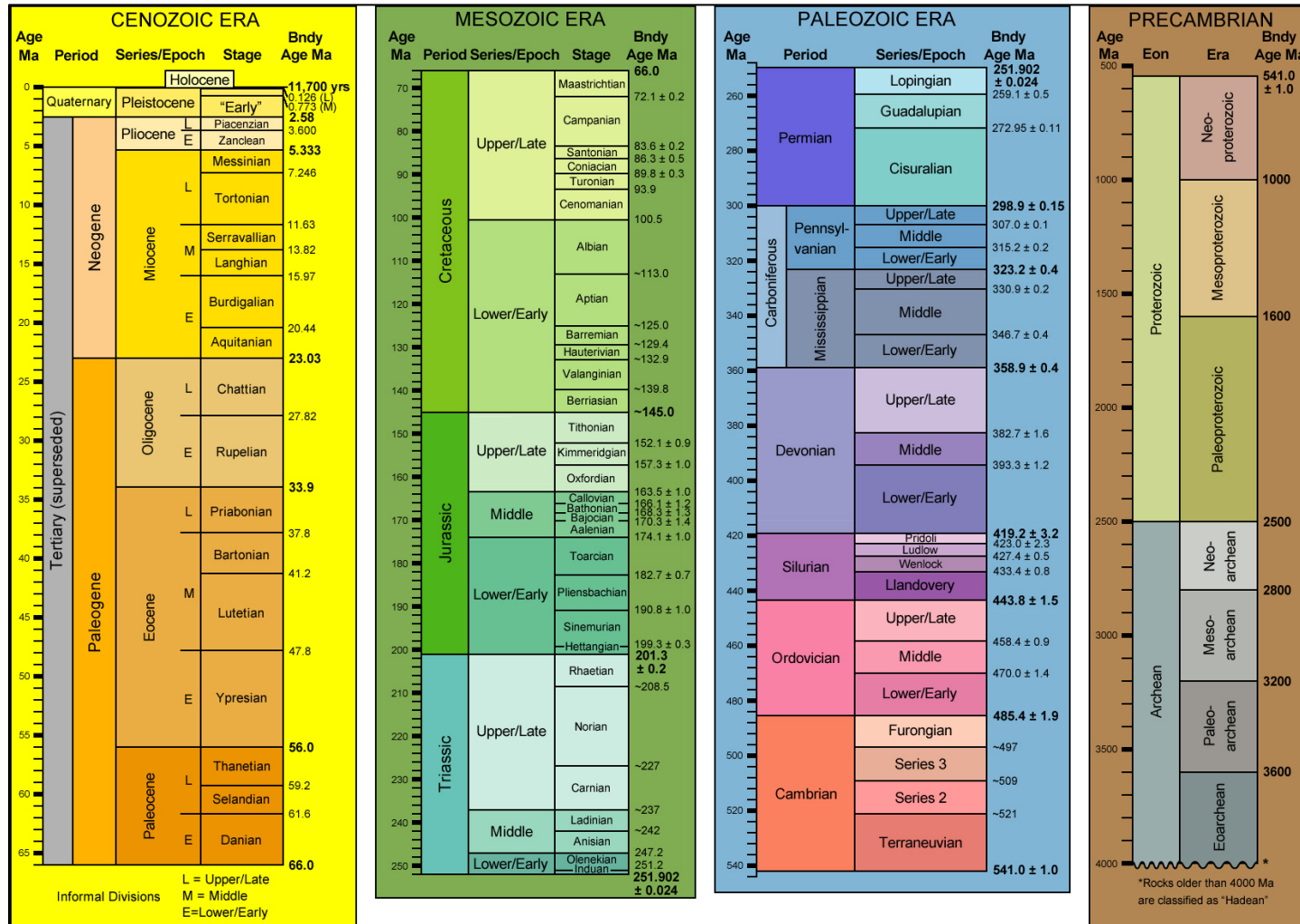
Appendix Table D-1 (continued). Paleontological localities of CAVE.

Site	Type of Locality	Vertebrates	Invertebrates	Plants	Age of Fossils
C-87	Vertebrate; Invertebrate; Ichnofossil	Mammals: bat guano; wall scratches; unidentified bones—appear distinctly procyonid. Likely <i>Bassariscus astutus</i> or <i>Procyon lotor</i> .	Algae, sponges, brachiopods, gastropods, unidentified invertebrates. One seems to be an ammonite?	None recorded	Permian; Quaternary
C-89	Vertebrate	None indicated in record? May have been erroneously included in paleo list because of presence of mountain lion scat?	None recorded	None recorded	No fossils?
C-90	Vertebrate	Mammals: extensive amount of bones of varying sizes from small to large. Current hypothesis by park staff is that this was a carnivoran den.	None recorded	None recorded	Quaternary
C-92	Vertebrate	Mammals: unidentified large mammal limb bone	None recorded	None recorded	Quaternary, likely Holocene (Recent)
C-93	Vertebrate	Mammals: rodent skeleton, possibly <i>Neotoma</i> sp.?	None recorded	None recorded	Holocene (Recent)
C-94	Vertebrate	Mammals: unidentified bones of a “ringtail-sized animal”	Explicitly recorded as “none observed”	None recorded	Quaternary
C-100	Vertebrate	Mammals: unidentified scapula	None recorded	None recorded	Quaternary
C-106	Vertebrate; Invertebrate	Mammals: unidentified small rodent bones	Algae, sponges, brachiopods	None recorded	Permian; Quaternary
C-108	Vertebrate; Invertebrate; Ichnofossil	Mammals: rodent nest; unidentified mid-sized bone (femur?); unidentified large mammal bones	Brachiopods; other unidentified invertebrates	None recorded	Permian; Quaternary
C-111	Vertebrate	Mammals: rodent skull and bones; small- to mid-sized unidentified mammal bones.	None recorded	None recorded	Quaternary
KF-39	Ichnofossil, Plant?	Mammals: crystallized woodrat urine—likely not of significant value according to Julio Betancourt (pers. comm., November 2019), but indicates possible presence of more substantial middens nearby	None recorded	Any plants preserved in the amberat	Quaternary; Likely Holocene (Recent)

Appendix Table D-1 (continued). Paleontological localities of CAVE.

Site	Type of Locality	Vertebrates	Invertebrates	Plants	Age of Fossils
Garden Grove Canyon	Vertebrate	Mammals: <i>Odocoileus hemionus</i> skull (recent?)	None recorded	None recorded	Quaternary
S-01	Vertebrate	Mammals: <i>Bison</i> sp.	None recorded	None recorded	Quaternary
S-09	Vertebrate	Mammals: complete, well preserved mid-sized felid skull. Cf. <i>Puma concolor</i>	None recorded	None recorded	Quaternary
A-13	Vertebrate	Mammals: various bones of <i>Erethizon dorsatum</i> , <i>Sciurus</i> sp., <i>Sylvilagus</i> sp., <i>Cynomys ludoviciana</i> , <i>Thomomys</i> sp., <i>Otospermophilus variegatus</i> ; <i>Equus</i> molar	None recorded	None recorded	Quaternary

Appendix E. Geologic Time Scale



Ma=Millions of years old. Bndy Age=Boundary Age. Colors are standard USGS colors for geologic maps. Modified from 1999 Geological Society of America Time Scale (<https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf>). Dates and additional information from International Commission on Stratigraphy update 2018/08 (<https://stratigraphy.org/chart>) and USGS Fact Sheet 2007-3015 (<https://pubs.usgs.gov/fs/2007/3015/>).

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 130/170768, June 2020

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525