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Natural Resource Stewardship and Science

Grand Canyon-Parashant National Monument

Paleontological Resource Inventory (Public Version)

Natural Resource Report NPS/PARA/NRR—2021/2338



ON THE COVER

Large, well-preserved invertebrate trace fossils (*Psammichnites* isp.) in the Supai Group (Wescogame Formation?) of Grand Canyon-Parashant National Monument. Scale bar is in cm. Photo by Rose Weeks (NPS).

Grand Canyon-Parashant National Monument

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Natural Resource Report NPS/PARA/NRR—2021/2338

Justin S. Tweet,[1] Holley Flora,[2] Summer Rose Weeks,[2] Eathan McIntyre,[2] and Vincent L. Santucci[3]

[1] National Park Service
9149 79th St. S.
Cottage Grove, MN 55016

[2] National Park Service
Grand Canyon-Parashant National Monument
345 East Riverside Drive
St. George, UT 84790

[3] National Park Service
Geologic Resources Division
1849 "C" Street, NW
Washington, D.C. 20240

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Contents

Page

Figures ix

Tables xv

Photographs xvii

Appendices xvii

Executive Summary xix

Acknowledgments xxi

Dedication xxiii

Introduction 1

Significance of Paleontological Resources at PARA 4

Purpose and Need 4

Project Objectives 5

History of Paleontological Work at PARA 7

Summary of 2020 Paleontological Survey 11

Geology 13

Geologic History 13

Geologic Formations 14

Geologic Maps and Stratigraphic Units Present Within PARA 14

Tonto Group: Bright Angel Shale (middle Cambrian) (PARA-NPS Only) 26

Tonto Group: Muav Formation (middle Cambrian) 26

Tonto Group: Frenchman Mountain Dolostone (middle–upper Cambrian) 27

Nopah Formation (upper Cambrian) (PARA-BLM Only) 28

Temple Butte Formation (Middle–Upper Devonian) 28

Redwall Limestone (Lower–Middle Mississippian) 29

Surprise Canyon Formation (Upper Mississippian) 32

Callville/Supai interval (Upper Mississippian–Pennsylvanian) 33

Contents (continued)

Page

Supai Group: Watahomigi Formation (Upper Mississippian–Middle Pennsylvanian) 35

Supai Group: Manakacha Formation (Middle Pennsylvanian) 36

Supai Group: Wescogame Formation (Upper Pennsylvanian) 37

Pakoon Limestone (lower Permian) 38

Supai Group: Esplanade Sandstone (lower Permian) 39

Hermit Formation (lower Permian) 41

Coconino Sandstone (lower Permian) 42

Toroweap Formation (lower Permian) 44

Kaibab Formation (lower Permian) 46

Moenkopi Formation (Lower–Middle Triassic) 51

Chinle Formation (Upper Triassic) (PARA-BLM Only) 54

Glen Canyon Group: Moenave Formation and Kayenta Formation, undivided (Upper Triassic–Lower Jurassic) (PARA-BLM Only) 57

Glen Canyon Group: Navajo Sandstone (Lower Jurassic) (PARA-BLM Only) 59

Willow Tank Formation (Upper Cretaceous) (PARA-BLM Only) 61

Rainbow Gardens Formation (upper Oligocene–lower Miocene) 62

Rocks of the Grand Wash Trough (middle–upper Miocene) 63

Upper Cenozoic igneous rocks (upper Miocene–Holocene) 64

Pliocene and Quaternary surficial sediments (Pliocene–Holocene) 68

Taxonomy 71

Fossil Plants 71

Fossil Invertebrates 72

Phylum Porifera (sponges) 72

Phylum Cnidaria (jellyfish and corals) 73

Phylum Bryozoa (moss animals) 77

Contents (continued)

Page

Phylum Brachiopoda (lamp shells) 80
Phylum Mollusca: Class Bivalvia (clams, oysters, scallops, etc.) 83
Phylum Mollusca: Class Cephalopoda (octopuses, squids, nautiloids, etc.) 86
Phylum Mollusca: Class Gastropoda (snails) 86
Phylum Mollusca: Class Scaphopoda (tusk shells) 87
Phylum Echinodermata (sea stars, brittle stars, sea lilies, sea urchins, etc.) 88
Other Invertebrates 91
Fossil Vertebrates 92
Ichnofossils 93
Other Fossils 97
Paleontological Localities 99
Paleontological Localities Within PARA 99
Redwall Limestone 100
Supai Group, Undifferentiated 103
Pakoon Limestone 108
Hermit Formation 109
Toroweap Formation 110
Kaibab Formation 114
Moenkopi Formation 117
Chinle Formation (PARA-BLM Only) 118
Moenave/Kayenta Formations, Undivided (PARA-BLM Only) 118
Rainbow Gardens Formation 119
Other Cenozoic Localities 119
Quaternary Caves and Rock Shelters 119
Paleontological Localities Near PARA 120
Cultural Resource Connections 121

Contents (continued)

Page

Museum Collections and Paleontological Archives 123
Museum Collections and Curation 123
Monument Collections 123
Collections in Other Repositories 124
Type Specimens 124
Archives 125
NPS Paleontology Archives 125
E&R Files 125
Photographic Archives 126
PARA Paleontological Research 127
Current and Recent Research 127
Paleontological Research Permits 127
Recommended Research 128
Interpretation 129
Current Long Range Interpretive Plan 129
Recommended Interpretive Themes 129
I. General Paleontological Information 129
II. Fossils of PARA 130
III. Caves and Fossil Resources 130
IV. Further Interpretation Themes 130
Other Recommendations for Interpretation and Education 130
Paleontological Resource Management and Protection 133
National Park Service Policy 133
Baseline Paleontology Resource Data Inventories 136
Paleontological Resource Monitoring 136
Foundation Documents and Resource Stewardship Strategies 138

Contents (continued)

Page

Geologic Maps 138

Paleontological Resource Potential Maps 139

Paleontological Resource Management Recommendations 141

Literature Cited 145

Figures

Page

Figure 1. Geography of PARA and eastern LAKE (NPS map, cropped). The NPS areas of PARA are also part of LAKE. 2

Figure 2. Land management jurisdictions in PARA. Map courtesy of Jennifer Fox (PARA). 3

Figure 3. Geologic map of the Grand Wash parcel of PARA-NPS (see Figure 4 for full legend), derived from Beard et al. (in press) and Billingsley and Wellmeyer (2003), digitized by the NPS Geologic Resources Inventory (GRI). 21

Figure 4. Full legend for Figures 3 and 5 22

Figure 5. Geologic map of the Parashant Canyon parcel of PARA-NPS (see Figure 4 for full legend), derived from Billingsley and Wellmeyer (2003) and Billingsley et al. (2006), digitized by the NPS GRI. 23

Figure 6. Geologic overview map of PARA (see Figure 7 for full legend), derived from Billingsley and Wellmeyer (2003) and Billingsley et al. (2006), digitized by the NPS GRI. 24

Figure 7. Full legend for Figure 6. The Mesozoic Chinle Formation, undivided Moenave and Kayenta Formations, Navajo Sandstone, and Willow Tank Formation referenced in the text are mostly exposed in far northern PARA, outside of the map's extent. 25

Figure 8. An outcrop of gray Redwall Limestone, with a large chert lens near the center of the image indicating this is the Thunder Springs Member; PARA-NPS (NPS/2020 FIELD INVENTORY). 30

Figure 9. An example of limestone (light-colored, lower in section) meeting cross-bedded sandstone (orange-brown, higher in section) in the undivided Supai Group, PARA-BLM (NPS/2020 FIELD INVENTORY). 34

Figure 10. Boulders of eroded Pakoon Limestone with Stephanie Wallace for scale, PARA-NPS (NPS/2020 FIELD INVENTORY). 38

Figure 11. Esplanade Sandstone on the left transitions into the dark red recessive beds of the Hermit Formation (center) below a more resistant ridge of Permian carbonates on the right, PARA-NPS (NPS/2020 FIELD INVENTORY). 40

Figure 12. An outcrop of the Esplanade Sandstone, PARA-NPS (NPS/2020 FIELD INVENTORY). 40

Figure 13. A ledge of Coconino Sandstone, PARA-BLM (NPS/2020 FIELD INVENTORY). 43

Figures (continued)

Page

Figure 14. GRCA 6541, described as a piece of limestone from the Coconino Sandstone (NPS/KIM BESOM). 44

Figure 15. A cliff-forming outcrop of the Brady Canyon Member of the Toroweap Formation with Holley Flora for scale, PARA-BLM (NPS/2020 FIELD INVENTORY). 45

Figure 16. A Kaibab Formation cliff (Fossil Mountain Member), PARA-NPS (NPS/2020 FIELD INVENTORY). 47

Figure 17. Invertebrate fossils in this block have been replaced by red mineralization. Kaibab Formation, Harrisburg Member, PARA-BLM (NPS/2020 FIELD INVENTORY). 49

Figure 18. Examples of fossil replacement in the Kaibab Formation, PARA-BLM. 50

Figure 19. Replacement mineralization does not necessarily replicate original surface texture, as shown by the "woven" appearance of this bivalve. Kaibab Formation, PARA-BLM (NPS/2020 FIELD INVENTORY). 50

Figure 20. The contact of the lower red member and overlying Virgin Limestone Member, PARA-BLM (NPS/2020 FIELD INVENTORY). 52

Figure 21. The Virgin Limestone Member, exposed as both a flaggy "floor" and a low bluff, PARA-BLM (NPS/2020 FIELD INVENTORY). 52

Figure 22. The heterogenous Shnabkaib Member, PARA-BLM (NPS/2020 FIELD INVENTORY). 53

Figure 23. A Chinle Formation (Petrified Forest Member) site showing more resistant and less resistant intervals, PARA-BLM (NPS/2020 FIELD INVENTORY). 55

Figure 24. An area of Moenave–Kayenta exposures with Holley Flora for scale, PARA-BLM (NPS/2020 FIELD INVENTORY). 58

Figure 25. Weathered knobs of Navajo Sandstone, PARA-STATE (NPS/2020 FIELD INVENTORY). 59

Figure 26. Outcrops of the heterogeneous Rainbow Gardens Formation, PARA-NPS (NPS/2020 FIELD INVENTORY). 62

Figure 27. The gypsum-rich facies of the rocks of the Grand Wash Trough, PARA-BLM (NPS/2020 FIELD INVENTORY). 64

Figure 28. Pyroclastic deposits in PARA (NPS/2020 FIELD INVENTORY). 65

Figure 29. Limestone over sandstone within a maar, with Holley Flora for scale, PARA-BLM (NPS/2020 FIELD INVENTORY). 66

Figures (continued)

Page

Figure 30. Organic or inorganic laminations, PARA-BLM (NPS/2020 FIELD INVENTORY).. 67

Figure 31. Several large pieces of petrified wood, Chinle Formation, Petrified Forest Member, PARA-BLM (NPS/2020 FIELD INVENTORY). 71

Figure 32. The sponge *Actinocoelia maeandrina*, Kaibab Formation, PARA-BLM. 72

Figure 33. A probable chaetetid-type sponge in cross-section from the Pakoon Limestone, PARA-NPS (NPS/2020 FIELD INVENTORY). 73

Figure 34. A weathered example of the tabulate *Syringopora*, Redwall Limestone, PARA-NPS (NPS/2020 FIELD INVENTORY). 74

Figure 35. Several examples of *Vesiculophyllum* weathering on a Redwall Limestone surface, PARA-NPS (NPS/2020 FIELD INVENTORY). 75

Figure 36. Corallites of a colonial rugose coral, Pakoon Limestone, PARA-BLM (NPS/2020 FIELD INVENTORY). 76

Figure 37. A colonial rugose coral in cross-section, Pakoon Limestone, PARA-BLM (NPS/2020 FIELD INVENTORY). 77

Figure 38. Two examples of typical fenestrate bryozoan fossils (NPS/2020 FIELD INVENTORY). 78

Figure 39. A colony of branching bryozoans exposed in relief, Pakoon Limestone, PARA-NPS (NPS/2020 FIELD INVENTORY). 78

Figure 40. Most of the fossils visible here are cross-sections of bryozoan fronds (the streak-like features). 79

Figure 41. These cross-sections represent branching bryozoans, Kaibab Formation, PARA-NPS (NPS/2020 FIELD INVENTORY). 79

Figure 42. A brachiopod fossil in cross-section with internal structures representing the brachidium. Pakoon Limestone, PARA-BLM (NPS/2020 FIELD INVENTORY). 80

Figure 43. Various common Permian brachiopods (NPS/2020 FIELD INVENTORY). 82

Figure 44. A productid brachiopod partially exposed from rock, showing the characteristic bulbous lobed shape and knobby ribbing. 83

Figure 45. Pectinids, PARA-BLM, Kaibab Formation except D (Toroweap Formation) (NPS/2020 FIELD INVENTORY). 84

Figures (continued)

Page

Figure 46. A loose stone crowded with diminutive bivalves. Kaibab Formation, PARA-BLM (NPS/2020 FIELD INVENTORY). 85

Figure 47. Moenkopi Formation bivalves, PARA-BLM (NPS/2020 FIELD INVENTORY).. 85

Figure 48. Various gastropods (NPS/2020 FIELD INVENTORY)..... 87

Figure 49. Two examples of scaphopods, Kaibab Formation, PARA-BLM. 88

Figure 50. Star-shaped crinoid columnals typical of *Holocrinus*. 89

Figure 51. Various crinoid columnals (NPS/2020 FIELD INVENTORY). 90

Figure 52. Echinoids (NPS/2020 FIELD INVENTORY)..... 91

Figure 53. Examples of unidentified fossils (NPS/2020 FIELD INVENTORY). 92

Figure 54. A bat jaw from a cave deposit, PARA-BLM (NPS/2020 FIELD INVENTORY). 92

Figure 55. A consolidated packrat midden, PARA-BLM (NPS/2020 FIELD INVENTORY). 93

Figure 56. An unconsolidated midden, PARA-STATE (NPS/2020 FIELD INVENTORY). 94

Figure 57. A heavily burrowed block from the Chinle Formation, Petrified Forest Member, PARA-BLM (NPS/2020 FIELD INVENTORY)..... 95

Figure 58. A burrow in the Toroweap Formation, PARA-BLM (NPS/2020 FIELD INVENTORY). 95

Figure 59. *Psammichnites* isp. trace fossils from the Wescogame? Formation, PARA-BLM (NPS/ ROSE WEEKS). 96

Figure 60. Detail of part of the *Psammichnites* trails, PARA-BLM (NPS/ ROSE WEEKS). 96

Figure 61. A stromatolite found at a Redwall Limestone locality, PARA-NPS (NPS/2020 FIELD INVENTORY)..... 97

Figure 62. Several fusulinid foraminifera are visible in this photo, the most characteristic being the example below the light-colored echinoid spine near the center. 98

Figures (continued)

Page

Figure 63. A fossiliferous Redwall Limestone "bench" at PARA PAL 0006 (PARA-NPS) with numerous rugose corals (*Vesiculophyllum*) eroding in relief (NPS/2020 FIELD INVENTORY). 101

Figure 64. Differing preservation in the Redwall Limestone (NPS/2020 FIELD INVENTORY). 102

Figure 65. Undivided Supai Group outcrop exhibiting planar bedding, undulations, and a silicified rugose coral below the scale bar, Grand Wash, PARA PAL 0027, PARA-BLM (NPS/2020 FIELD INVENTORY). 105

Figure 66. An unidentified silicified fossil fragment seen in rocks of the undivided Supai Group, PARA PAL 0027, PARA-BLM (NPS/2020 FIELD INVENTORY). 105

Figure 67. An example of a large red chert lens in gray Supai Group limestone, PARA PAL 0034, PARA-BLM (NPS/2020 FIELD INVENTORY). 106

Figure 68. Extensive burrowing by large invertebrates in Supai Group sandstone at PARA PAL 0034, PARA-BLM (NPS/2020 FIELD INVENTORY). 107

Figure 69. Marine invertebrates in limestone at PARA PAL 0038, PARA-BLM, crowded with large and small crinoid fragments (NPS/2020 FIELD INVENTORY). 108

Figure 70. Burrows in the Hermit Formation, PARA PAL 0037, PARA-NPS (NPS/2020 FIELD INVENTORY) 109

Figure 71. A horn coral preserved as mold and cast in a Toroweap Formation float cobble in Quaternary channel deposits, PARA PAL 0010, PARA-BLM (NPS/2020 FIELD INVENTORY) 111

Figure 72. Pseudofossils (pieces of stylolites) with wood-like texture among Toroweap Formation float, PARA PAL 0010, PARA-BLM (NPS/2020 FIELD INVENTORY). 111

Figure 73. Two views of in situ stylolites in the Toroweap Formation (NPS/2020 FIELD INVENTORY). 112

Figure 74. LAKE 33391, an apparent piece of petrified wood from PARA PAL 0017, PARA-BLM (NPS/2020 FIELD INVENTORY). 113

Figure 75. A Kaibab Formation brachiopod with desert varnish, PARA PAL 0031, PARA-NPS (NPS/2020 FIELD INVENTORY) 115

Figure 76. A weathered Kaibab Formation sponge with desert varnish, PARA PAL 0031, PARA-NPS (NPS/2020 FIELD INVENTORY) 115

Figures (continued)

Page

Figure 77. Fossil appearance is affected by weathering; PARA PAL 0016, PARA-BLM (NPS/2020 FIELD INVENTORY) 116

Figure 78. Moenkopi Formation trace fossils, PARA PAL 0028, PARA-BLM (NPS/2020 FIELD INVENTORY). 117

Figure 79. Color variations enhance Chinle Formation cross-bedding at PARA PAL 0022, PARA-BLM (NPS/2020 FIELD INVENTORY). 118

Figure 80. A spar-covered mammal skeleton (NPS/KYLE VOYLES). 120

Figure 81. A coyote skull and atlas vertebra, PARA-BLM (NPS/2020 FIELD INVENTORY). 122

Figure 82. A photo of LAKE/PARA-NPS specimens in LAKE collections, collected by Schenk in the 1930s (NPS/JUSTIN TWEET). 123

Figure 83. Paleontological potential map of PARA 140

Tables

Page

Table 1. Summary of PARA stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. 15

Table 2. Capsule information for 2020 localities. 99

Table 3. Fossil taxa named from specimens found within PARA-BLM. 125

Table 4. Paleontological decisions from the PARA Resource Management Plan (U.S. Department of the Interior 2008: Table 2.2 [table structure has been adapted for this document]). 135

Appendix Table A-1. Paleobotanical taxa reported from PARA in stratigraphic context. 179

Appendix Table A-2. Pre-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. 180

Appendix Table A-3. Fossil invertebrate taxa reported from the Supai Group and associated units of PARA in stratigraphic context. 182

Appendix Table A-4. Post-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. 190

Appendix Table A-5. Fossil vertebrate taxa reported from PARA in stratigraphic context. 196

Appendix Table A-6. Supai and older ichnofossils reported from PARA in stratigraphic context. 197

Appendix Table A-7. Post-Supai ichnofossils reported from PARA in stratigraphic context. 198

Appendix Table A-8. Foraminifera taxa reported from PARA in stratigraphic context. 199

Appendix Table A-9. Other fossils reported from PARA in stratigraphic context. 202

Appendix Table B-1. Specimens collected during the 2020 paleontological inventory. 204

Appendix Table B-2. Pre-2020 specimens from PARA localities in LAKE collections (after Bonde et al. 2018). 206

Appendix Table B-3. Parashant Canyon specimens in GRCA collections. 207

Appendix Table D-1. Basic information for localities recorded during 2020 paleontological inventory. 227

Photographs

Page

Jeff Bradybaugh xxiii

Field team members, left to right: Rose Weeks, Stephanie Wallace, and Holley Flora (NPS/2020 FIELD INVENTORY). 12

Appendices

Page

Appendix A: Paleontological Species 175

Appendix B: Museum Collections Data 203

Appendix C: Repository Contact Information 219

Appendix D: Selected Paleontological Locality Data 221

Appendix E: Glossary 243

Appendix F: Paleontological Resource Law and Policy 253

Appendix G: Geologic Time Scale 259

Executive Summary

Grand Canyon-Parashant National Monument (PARA) in northwestern Arizona has significant paleontological resources, which are recognized in the establishing presidential proclamation. Because of the challenges of working in this remote area, there has been little documentation of these resources over the years. PARA also has an unusual management situation which complicates resource management. The majority of PARA is administered by the Bureau of Land Management (BLM; this land is described here as PARA-BLM), while about 20% of the monument is administered by the National Park Service (NPS; this land is described here as PARA-NPS) in conjunction with Lake Mead National Recreation Area (LAKE). Parcels of state and private land are scattered throughout the monument.

Reports of fossils within what is now PARA go back to at least 1914. Geologic and paleontologic reports have been sporadic over the past century. Much of what was known of the paleontology before the 2020 field inventory was documented by geologists focused on nearby Grand Canyon National Park (GRCA) and LAKE, or by students working on graduate projects; in either case, paleontology was a secondary topic of interest. The historical record of fossil discoveries in PARA is dominated by Edwin McKee, who reported fossils from localities in PARA-NPS and PARA-BLM as part of larger regional projects published from the 1930s to the 1980s. The U.S. Geological Survey (USGS) has mapped the geology of PARA in a series of publications since the early 1980s. Unpublished reports by researchers from regional institutions have documented paleontological resources in Quaternary caves and rock shelters.

From September to December 2020, a field inventory was conducted to better understand the scope and distribution of paleontological resources at PARA. Thirty-eight localities distributed across the monument and throughout its numerous geologic units were documented extensively, including more than 420 GPS points and 1,300 photos, and a small number of fossil specimens were collected and catalogued under 38 numbers. In addition, interviews were conducted with staff to document the status of paleontology at PARA, and potential directions for future management, research, protection, and interpretation.

In geologic terms, PARA is located on the boundary of the Colorado Plateau and the Basin and Range provinces. Before the uplift of the Colorado Plateau near the end of the Cretaceous 66 million years ago, this area was much lower in elevation and subject to flooding by shallow continental seas. This led to prolonged episodes of marine deposition as well as complex stratigraphic intervals of alternating terrestrial and marine strata. Most of the rock formations that are exposed in the monument belong to the Paleozoic part of the Grand Canyon section, deposited between approximately 510 and 270 million years ago in mostly shallow marine settings. These rocks have abundant fossils of marine invertebrates such as sponges, corals, bryozoans, brachiopods, bivalves, gastropods, crinoids, and echinoids. The Cambrian–Devonian portion of the Grand Canyon Paleozoic section is represented in only a few areas of PARA. The bulk of the Paleozoic rocks at PARA are Mississippian to Permian in age, approximately 360 to 270 million years old, and belong to the Redwall Limestone through the Kaibab Formation. While the Grand Canyon section has only small

remnants of younger Mesozoic rocks, several Mesozoic formations are exposed within PARA, mostly ranging in age from the Early Triassic to the Early Jurassic (approximately 252 to 175 million years ago), as well as some middle Cretaceous rocks deposited approximately 100 million years ago. Mesozoic fossils in PARA include marine fossils in the Moenkopi Formation and petrified wood and invertebrate trace fossils in the Chinle Formation and undivided Moenave and Kayenta Formations.

The succeeding Cenozoic Era is represented by localized terrestrial deposition beginning about 25 million years ago. Fossils so far have been sparse in these mid–late Cenozoic deposits, with the exception of vertebrate and plant material preserved within caves and rock shelters probably representing the past few tens of thousands of years. Western PARA was influenced by the beginning of Basin and Range extension around 17 million years ago, and volcanic activity has occurred throughout the monument over the past 9 million years. Faulting, volcanism, and the evolution of the Colorado River drainage system have combined to sculpt the monument's landforms and expose, erode, or conceal the fossiliferous bedrock formations.

Most of the fossils collected from PARA are reposited in LAKE collections. Other specimens have been held in four other institutions, including GRCA's museum, the Museum of Northern Arizona (Flagstaff, Arizona), the National Museum of Natural History (Washington, D.C.), and the University of Nevada, Las Vegas. Two fossil species of foraminifera have been named from specimens collected within PARA-BLM. Paleontological resource management at PARA is complicated by divided land management and the monument's logistical challenges, but this inventory should provide a foundation for future efforts. Recommendations for management, research, protection, and interpretation have been provided based on interviews with PARA staff.

Acknowledgments

We first acknowledge Ken and Stephanie Wallace for their volunteer hours spent in the field assisting Holley and Rose, and providing experiential knowledge of the terrain and geologic setting of the paleontological localities. They have played an important role in the success of the field component of this inventory.

PARA staff provided a great deal of assistance and additional information, including participation in interviews concerning paleontological resources at PARA and associated interpretation and management issues. Particular thanks are extended to Amber Franklin, Jennifer Fox, Greg Page, Marty Sims, Brenda Todd, Mark Wimmer, and Greg Woodall. We also credit the monument staff, interns, and firefighters who took the time to document fossils and interesting features they encountered while doing various activities within the monument. Some areas of this monument are so remote that very few people will ever see them. Without curious individuals reporting their observations, many fascinating discoveries would likely never have been made.

Staff at other nearby NPS units have made additional contributions. We wish to recognize Kim Besom and Colleen Hyde (GRCA) for assistance with Edwin McKee's collections, Anne Miller (GRCA) for discussion of the Supai trace fossil block, Jessica Bitter (LAKE) for assistance with curation, and Erin Eichenberg (Tule Springs Fossil Beds National Monument; TUSK) for many contributions going back to 2015. Allen Calvert (Mojave Desert Inventory and Monitoring Network; MOJN) served as peer review coordinator. Tim Connors of the NPS Geologic Resources Division prepared maps for the report, as well as contributing a program review. The Geoscientists-in-the-Parks program (GIP), now the Scientists in Parks program (SIP), provided support for the internships.

Geologists and paleontologists outside of the National Park Service also contributed to this project. Robert Blodgett (Blodgett & Associates LLC) contributed identifications on difficult invertebrate specimens. He also shared his knowledge of Permian limestone deposits and fossil preparation methods. We thank Nancy Stamm and Dave Soller from the U.S. Geological Survey for providing access to the USGS's Examine & Report archives, and their assistance with using these files. We also thank David Elliott (Museum of Northern Arizona emeritus), David Gillette (Museum of Northern Arizona emeritus), Spencer Lucas (New Mexico Museum of Natural History and Science), Lorenzo Marchetti (Museum für Naturkunde), Jim Mead (The Mammoth Site of Hot Springs), Andrew Milner (St. George Dinosaur Discovery Site), Stephen Rowland (University of Nevada, Las Vegas emeritus), and the Ichnology group on Facebook. Aubrey Bonde (University of Nevada, Las Vegas) and Fred Sundberg (Museum of Northern Arizona research associate) provided reviews. We would also like to thank Ed Robeck at the American Geosciences Institute for his assistance with Justin's position.

Dedication

We are pleased to dedicate the Grand Canyon-Parashant National Monument Paleontological Resource Inventory Report to our valued National Park Service colleague Jeff Bradybaugh. Jeff began his career with the NPS in 1982 at Theodore Roosevelt National Park (1982–1990). He has held assignments at Mammoth Cave National Park (1991–1996), Zion National Park (1997–2006), Grand Canyon-Parashant National Monument (2006–2010), Bryce Canyon National Park (2010–2014), and a return to Zion National Park as superintendent (2014–present). Jeff is widely recognized as a champion for NPS natural resources, including paleontological resources, throughout his career, and supported paleontology work at PARA during his time there. Many thanks to Jeff for his many contributions to the NPS throughout his career.



Jeff Bradybaugh

Introduction

Grand Canyon-Parashant National Monument (PARA), also called Parashant National Monument, protects a remote area of northwestern Arizona. The geology and paleontology of PARA are a significant part of the enabling legislation of the monument, and the Paleozoic fossils are specifically cited (see below under "Significance of Paleontological Resources at PARA"). PARA was established January 11, 2000, by Presidential Proclamation 7265 (2000), 65 FR 2825, and is managed jointly by the National Park Service (NPS) and Bureau of Land Management (BLM). It hosts abundant natural and cultural resources, from caves, to wildlife, to wide areas of sedimentary and igneous rock outcrops, to traces of more than 10,000 years of human history. There are two parcels of NPS land in PARA, both of which are also part of Lake Mead National Recreation Area (LAKE) (Figure 1). These are the Parashant Canyon parcel, which includes part of Parashant Canyon and the south end of the Shivwits Plateau, and a parcel west of the Grand Wash and east of the Arizona–Nevada state line. These two parcels constitute all of the land of LAKE in Arizona north of Lake Mead, and make up 84,357 ha (208,451 acres) of PARA's total 424,240 hectares (1,048,321 acres), approximately 20% (land figures after PARA's foundation document [NPS 2016]). The two parcels will be referred to herein as the Grand Wash and Parashant Canyon parcels of PARA-NPS. The emphasis of this report is on NPS fossils, but for completeness the BLM fossils will also be included; this report will use PARA-NPS and PARA-BLM to distinguish between the lands managed by the two agencies. The BLM administers 328,840 hectares (812,581 acres) of PARA, approximately 78%. There are also areas within PARA owned by the state of Arizona and private lands. Lands under Arizona State Trust administration constitute 9,391 hectares (23,206 acres), approximately 2% of the total, and private lands constitute 1,653 hectares (4,085 acres), less than 1% (NPS 2016). Areas under Arizona State Trust administration are designated PARA-STATE in this document. A reference map of park land management is included as Figure 2.

PARA is located in the Arizona Strip of Mohave County, Arizona. It is bordered on the west and northwest by the Virgin Mountains and on the south and southeast by the gorge of the Grand Canyon, part of Grand Canyon National Park (GRCA) (Figure 1). The Grand Wash Cliffs, the division between the Basin and Range province on the west and Colorado Plateau province on the east, are a prominent feature of western PARA. Most of central PARA is made up of the Shivwits Plateau, and most of eastern PARA is occupied by the Uinkaret Plateau. The Arizona Strip is sparsely populated, but there is one nearby large population center in the vicinity: St. George in southwestern Utah about 35 km (22 mi) to the northeast of PARA. Central Las Vegas is about 100 km (60 mi) west of the nearest part of PARA. The land now included in PARA-NPS was administered by LAKE until the 2000 establishment of PARA. When LAKE was created in 1936, its eastern boundary was much farther east than at present, in anticipation of the creation of a dam and reservoir at Bridge Canyon, Arizona. The proposed dam was never built, and in the 1970s a reorganization of NPS lands along the Colorado River put much of eastern LAKE in GRCA, except for the Grand Wash and detached Parashant Canyon units.

This report provides detailed information on the paleontological resources of PARA, including the history of study at the monument, source geologic units, taxonomic groups, localities, museum

collections, research, interpretation, and management and protection. Joint BLM/NPS management has the potential to complicate paleontological resource management. Although the BLM permits casual collecting on some other lands it manages, it does not permit casual collecting within PARA-BLM, as the NPS does not permit casual collecting within PARA-NPS.

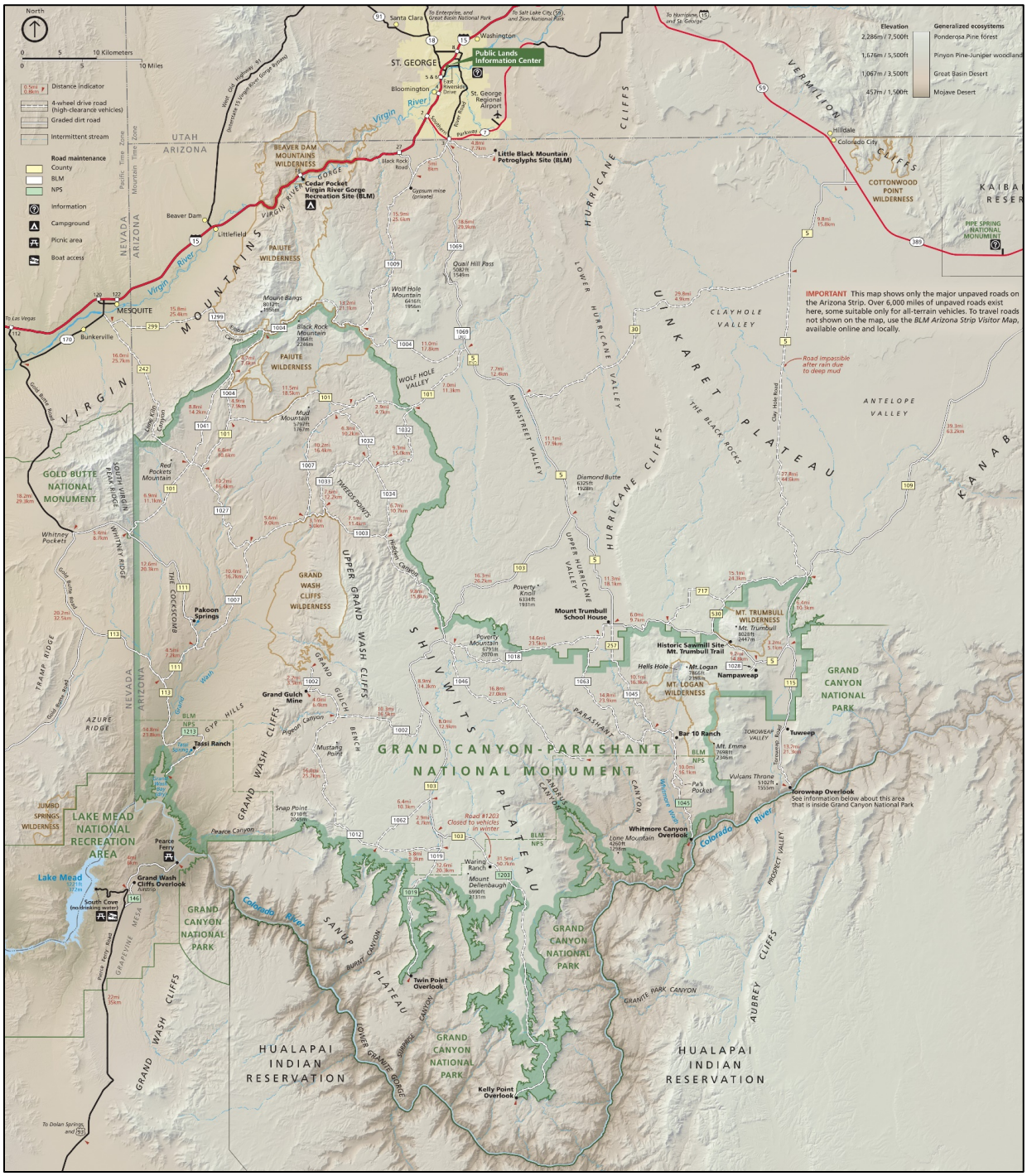


Figure 1. Geography of PARA and eastern LAKE (NPS map, cropped). The NPS areas of PARA are also part of LAKE.

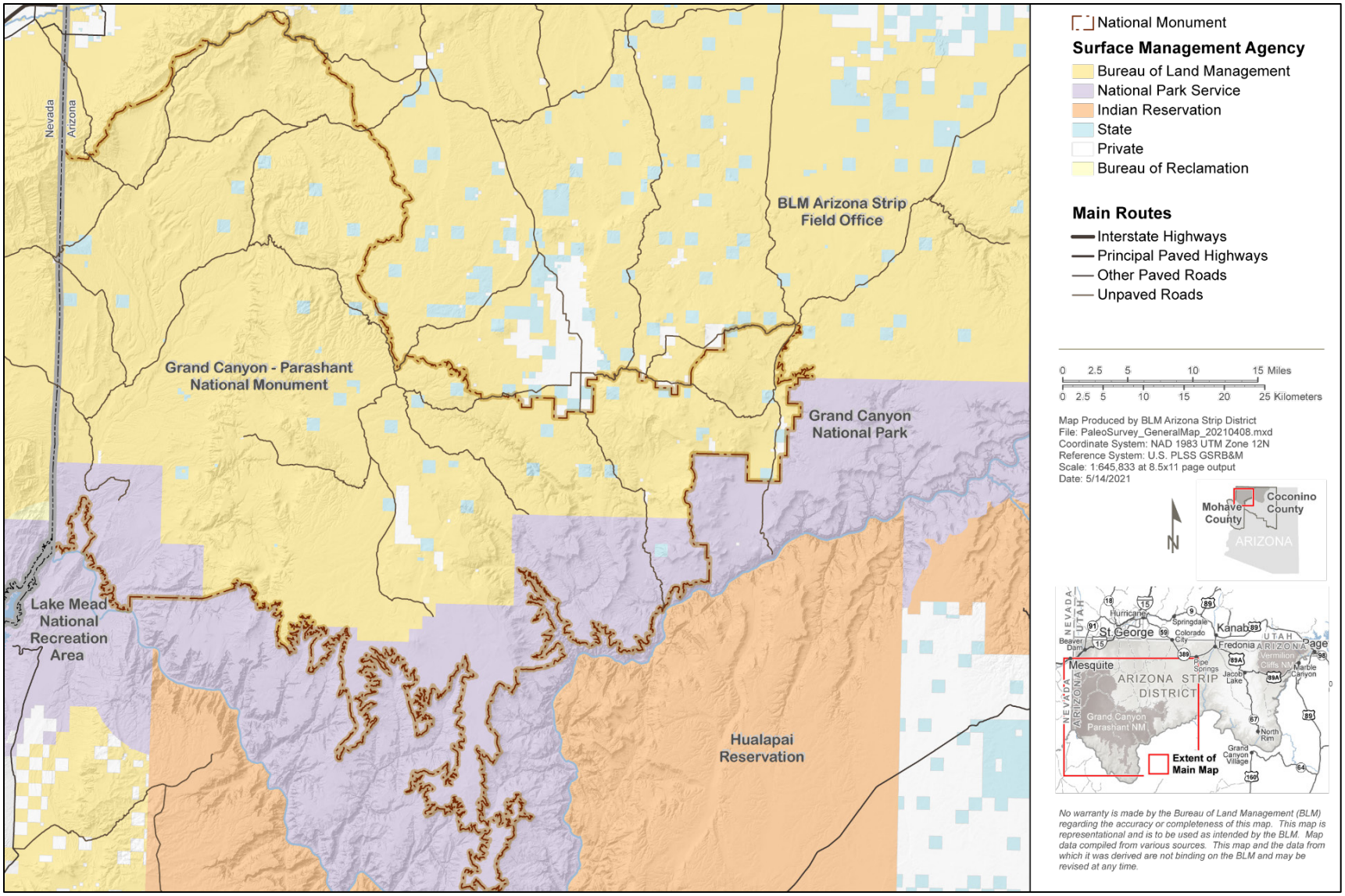


Figure 2. Land management jurisdictions in PARA. Map courtesy of Jennifer Fox (PARA).

In addition to the main body of text, there are seven appendices: Appendix A, tables of paleontological species arranged by stratigraphy; Appendix B, museum collections data; Appendix C, repository contact information; Appendix D, selected paleontological locality data; Appendix E, glossary; Appendix F, paleontological resource law and policy; and Appendix G, geologic time scale.

Significance of Paleontological Resources at PARA

Paleontological resources, or fossils, are any evidence of past life preserved in geologic context. PARA is one of 18 NPS units for which paleontological resources are specifically mentioned in the enabling legislation or establishing proclamation. The presidential proclamation establishing PARA (Presidential Proclamation 7265, 65 FR 2825, 2000; https://www.federalregister.gov/documents/2000/01/18/00-1296/establishment-of-the-grand-canyon-parashant-national-monument) describes the geology of the monument in some detail, including several sentences dealing with invertebrate paleontology excerpted below:

> "*Fossils are abundant in the monument. Among these are large numbers of invertebrate fossils, including bryozoans and brachiopods located in the Calville* [sic] *limestone of the Grand Wash Cliffs, and brachiopods, pelecypods, fenestrate bryozoa, and crinoid ossicles in the Toroweap and Kaibab formations of Whitmore Canyon. There are also sponges in nodules and pectenoid pelecypods throughout the Kaibab formation of Parashant Canyon.*"

PARA's bedrock and fossils are within a transition from areas with more of a terrestrial influence on the east to areas farther within deeper marine settings on the west. Bedrock outcrops of PARA are primarily of upper Paleozoic rocks (Mississippian through Permian). They represent a counterpart to the well-studied rocks of the Grand Canyon to the south and east. Most of the same formations are represented in both areas, although PARA's rocks were deposited in more marine facies than the rocks of the Grand Canyon. For example, the terrestrial Coconino Sandstone has a reduced presence in PARA compared to GRCA, and much more of the Supai Group interval is occupied by the marine Callville Formation and Pakoon Limestone rather than more terrestrial rocks. The stratigraphic section at PARA also includes a better representation of younger rocks than GRCA, where the section essentially stops in the Permian. PARA is therefore more illustrative of Mesozoic and Cenozoic events than the Grand Canyon. Finally, PARA has significant Quaternary cave paleontological resources that are of value not only at the local level, but within the regional framework of paleoecological and paleoclimatological knowledge.

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. The authorities and guidance directly applicable to paleontological resources are cited below in Appendix F. 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. Options for paleontological resource management are locality-specific, and may include no

action, surveys, site monitoring, cyclic prospecting, stabilization and reburial, shelter construction, excavation, closure, patrols, and alarm systems or electronic surveillance. See Appendix F for additional information on applicable laws and legislation.

PARA is an unusual case, due to a variety of challenges and complicating factors: the great abundance of fossils; the sheer size of the monument; its undeveloped and logistically challenging geography; the limited existing knowledge; and its joint management situation.

Project Objectives

This monument-focused paleontological resource inventory project was initiated to provide information to PARA 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, interpretation and education, and resource management practices associated with the paleontological resources at PARA. 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.
- Extensive photo-documenting of fossils and geologic features (including sedimentary structures useful for interpreting paleoenvironments, and pseudofossils); these photos can be used as visual records, reference materials for staff, imagery for education and interpretive products, and so on.
- Relocating and assessing historical localities.
- Assessing and addressing any needs associated with collections of PARA fossils maintained within monument collections and in outside repositories.
- Documenting current information on faunal assemblages and paleoecological reconstructions.
- Interviewing staff to gather information on the current status of paleontological resources, to aid in formulating plans for management, ideas for interpretation, and recommendations.
- Conducting a thorough literature search for relevant publications, unpublished geologic notes, and outside fossil collections from PARA.

History of Paleontological Work at PARA

The geology and paleontology of the lands now within PARA have not attracted as much attention from geoscientists as areas around it, so the history of exploration is comparatively short and there are relatively few publications, but geologic map coverage is extensive. Relevant publications include Hill (1914), Longwell (1928, 1936), Schenk (1936, 1938), McKee (1937a, 1979, 1982a), Schenk and Wheeler (1942), Koons (1945), McNair (1951), Easton and Gutschick (1953), Schleh (1960, 1966), Gordon (1961), Fisher (1962), Brill (1963), Seager (1966), Skipp et al. (1966), McKee and Gutschick (1969), Skipp (1969), Moore (1972), Pierce (1979), Lucchitta and Beard (1981a, 1981b), Johansen (1981), Gordon (1982), Lucchitta et al. (1983, 1986, 1995a, 1995b), Sando and Bamber (1985), Brathovde (1986), Billingsley (1990, 1991, 1993, 1997a, 1997b), Bohannon (1991, 1992), Bohannon and Lucchitta (1991), Sorauf and Billingsley (1991), Fillmore (1993), Beard (1996), Billingsley and Workman (2000), Billingsley et al. (2000, 2004, 2006), Brady et al. (2002), Billingsley and Wellmeyer (2003), Covington (2003), McCracken and Mead (2003), Mead (2003), Santucci et al. (2004), Voyles and Wynne (2006), Voyles (2008), Felger and Beard (2010), Hunt et al. (2012), Tweet et al. (2012, 2016), Truini (2013), Carter et al. (2014), Rowland and Olsen (2016), Bonde et al. (2018), Lamb et al. (2018), and Beard et al. (in press). The NPS Geologic Resources Division produced a Geologic Resource Evaluation scoping summary for PARA in 2003 (Covington 2003, which essentially duplicated the paleontological information in the presidential proclamation), and has completed digital geologic maps of GRCA and LAKE, which overlap the NPS parcels of PARA and include part of PARA-BLM as well. Santucci et al. (2004) prepared the original paleontologic resource inventory and summary for PARA as part of the Mojave Desert Inventory & Monitoring Network (MOJN) paleontological resources summary. A longer revised version was included in Tweet et al. (2016), the updated MOJN paleontological resources summary. Tweet et al. (2016) formed much of the basis for this report, with reference to the recent paleontological inventories for GRCA (Santucci and Tweet 2020) and LAKE (Bonde et al. 2018).

Paleontology has generally been a secondary focus in publications documenting PARA geology. The oldest report of fossils from PARA may be that of Hill (1914), who in passing reported horn corals, brachiopods, gastropods, and echinoids in upper Paleozoic rocks in what is now PARA-BLM. A more substantial geologic report can be found in Longwell (1928), which includes the first geologic map to document the Grand Wash parcel of PARA-NPS and surrounding areas of PARA-BLM. Again, fossils were not the primary focus, but Longwell reported several small collections of fossils from Paleozoic rocks in PARA-NPS and PARA-BLM. Longwell (1936) revisited some of the areas described in 1928, focusing on areas being submerged by Lake Mead.

The 1930s were also a time when NPS geologists were investigating the geology of parts of PARA. In the 1930s, the National Park Service employed Edward Schenk to describe the geology and paleontology of the area that would become LAKE. Schenk collected a number of fossils from in and around LAKE, eventually accumulating between 800 and 1,000 invertebrate fossils and 542 vertebrate fossils (Schenk no date). Some of these fossils were used for his work on the Cambrian of the western Grand Canyon (Schenk and Wheeler 1942), others pertain to Rampart Cave (now in GRCA) and Pleistocene sites at Glendale, and another group, consisting of upper Paleozoic fossils

from the Iceberg Canyon–Grand Wash area, has never been published outside of collections documentation in Bonde et al. (2018) (relevant collections included here in Appendix B). In fact, they were not fully studied until the 1960s, when they were sent to the U.S. Geological Survey for identification. Some of them are in the collections of LAKE, and others were retained in USGS collections in Washington, D.C., now transferred to the National Museum of Natural History (USNM). Six of the Grand Wash collections came from areas now within the Grand Wash parcel of PARA-NPS, and all of the specimens from these collections are now at LAKE. Schenk's work is little known today because he did not publish much of it. However, there are a number of unpublished progress reports and manuscripts by Schenk in LAKE archives, the most detailed being Schenk (1938). Copies of Schenk's reports are also maintained in the NPS Paleontology Archives and Library.

At the same time, GRCA park naturalist Edwin McKee, in the early stages of a geological career that would take him through most of the Paleozoic formations of the Grand Canyon region, was working at the opposite end of what would become PARA. During the winter of 1936–1937 he made collections in Parashant Canyon as part of a larger field study (McKee 1937a). He did not include much information on areas within PARA in his first few large reports. McKee (1933) on the Coconino Formation and McKee and Resser (1945) on the Tonto Group dealt with geologic units that are not widely exposed in PARA, and McKee (1938) on the Toroweap and Kaibab Formations relied on existing information for outcrops in PARA. However, his later works on the Redwall Limestone (McKee and Gutschick 1969) and Supai Group (McKee 1982a) included several fossiliferous localities in PARA-NPS and PARA-BLM.

Little information was added to the knowledge of PARA paleontology during the 1940s and 1950s. McNair (1951) included brief mentions of fossils, but is more significant for naming the Pakoon Limestone and Queantoweap Sandstone. Easton and Gutschick (1953) gave descriptions of Redwall Limestone corals, including from two localities that are now in PARA. The 1960s were more productive. Graduate work by several students documented the Paleozoic formations of several canyons in PARA, particularly the Toroweap and Kaibab Formations (Schleh 1960, 1966; Gordon 1961; Fisher 1962), and examined the Virgin Mountains at the north end of PARA (Seager 1966). Brill (1963) mentioned a few foraminifera taxa from sections in PARA-BLM. Skipp (Skipp et al. 1966; Skipp 1969) documented Redwall Formation foraminifera from the Grand Canyon area, including from PARA-NPS and PARA-BLM. The Virgin Mountains area was further documented in Moore (1972) and Pierce (1979).

The 1980s are notable for the first of a series of USGS geologic maps documenting PARA (Lucchitta and Beard 1981a, 1981b; Lucchitta et al. 1983, 1986, 1995a, 1995b; Billingsley 1990, 1991, 1993, 1997a, 1997b; Bohannon 1991, 1992; Bohannon and Lucchitta 1991; Billingsley and Workman 2000; Billingsley et al. 2000, 2004, 2006; Brady et al. 2002; Billingsley and Wellmeyer 2003; Felger and Beard 2010; Beard et al. in press). Graduate projects focused on the Queantoweap Sandstone (Johansen 1981) and the dolomites above the Muav Formation (Brathovde 1986), now known as the Frenchman Mountain Dolostone (Karlstrom et al. 2020). In the 1990s, Sorauf and Billingsley (1991) re-evaluated the Toroweap and Kaibab Formations, and Beard (1996) re-evaluated the Cenozoic

rocks at Tassi Spring (followed by Lamb et al. 2018). In 2014, a publication of Redwall Limestone brachiopods, intended for the McKee and Gutschick (1969) monograph but not completed at the time, was issued (Carter et al. 2014). It includes brachiopods from two PARA sites.

With the establishment of PARA and the initiation of the Natural Resource Challenge, along with the Inventory & Monitoring program in the NPS in 2000, the NPS became more involved in documenting paleontological resources in PARA. PARA was not initially included in the Inventory & Monitoring program, so PARA staff reached out to have similar inventories produced in a parallel effort. McCracken and Mead (2003) and Mead (2003) provided the initial monument paleontological information, followed by the initial paleontological resource summary for PARA (Santucci et al. 2004). In the latter part of the decade, Jim Mead, then at Northern Arizona University (Flagstaff), began an assessment of PARA caves with monument staff, particularly Kyle Voyles. When Mead left the area to take a position at East Tennessee State University, the PARA project was taken up by David Gillette (Museum of Northern Arizona, Flagstaff) and Stephen Rowland (University of Nevada, Las Vegas) (J. Mead, The Mammoth Site of Hot Springs, Hot Springs, South Dakota, pers. comm., April 2021). Most of their findings and collections remain unpublished. Voyles (2008) gave an account of a newly discovered cave with paleontological resources. PARA was briefly touched on in inventories of NPS packrat middens (Tweet et al. 2012) and vertebrate coprolites (Hunt et al. 2012), and another midden was mentioned in Rowland and Olsen (2016). The most detailed accounts of PARA paleontology before this inventory can be found in the second MOJN paleontological resource summary (Tweet et al. 2016) and the LAKE paleontological resources inventory (Bonde et al. 2018).

Summary of 2020 Paleontological Survey

Due to the relatively small amount of information about PARA paleontology in the literature and the limited field work done by monument staff thus far in the monument's young history, eyes in the field were an important component of this inventory. Two Geoscientists-in-the-Parks interns, Holley Flora and Rose Weeks, spent three months systematically surveying the hills, canyons, and plateaus of PARA searching for and documenting fossils. The paleontology interns were assisted on many occasions by PARA volunteers Ken and Stephanie Wallace and PARA Physical Scientist Eathan McIntyre. Most localities were identified by Eathan McIntyre based on personal observation or reports from other monument staff, previous interns, and even firefighters. Collectively the field team documented 38 localities from PARA using GPS, photographs, locality forms, and field notes, and conducted interviews with eight staff members. Field activities were conducted under permit PARA-2020-SCI-0002. A small number of fossils were collected and are now in LAKE collections. Consult Appendix B for details on collections and Appendix D for details on localities.

The remoteness of the monument presented logistical challenges for the paleontological resource inventory team. Monument lodging was provided for the field team, but some fossil localities required overnight excursions in the backcountry. Navigating around PARA necessitates long hours of slow driving on rough terrain, so the interns were certified to drive UTVs (utility terrain vehicles). The COVID-19 pandemic introduced further challenges. Nevertheless, the field team did not experience any significant delays or other issues that required changes to the schedule or the list of areas to visit.



Field team members, left to right: Rose Weeks, Stephanie Wallace, and Holley Flora (NPS/2020 FIELD INVENTORY).

Geology

Geologic History

The bedrock geology of PARA is best represented by Pennsylvanian and Permian sedimentary rocks and Neogene–Quaternary volcanic rocks, but encompasses strata from the Cambrian to the present (see Appendix G for a geologic time scale). During the Paleozoic and Mesozoic, the area was a coastal region that alternated between being situated below and above sea level (Mathis and Bowman 2007). The monument has minor outcrops of Cambrian rocks, perhaps as old as 510 Ma (million years ago). These rocks were deposited in shallow marine settings (Middleton and Elliott 2003). Cambrian deposition is followed by a regional hiatus that eliminates the Ordovician, the Silurian, and most of the Devonian, about 100 million years of geologic history (approximately 485 to 385 Ma). Until near the end of the Paleozoic, most of the deposition was below sea level. Terrestrial deposition is not well-represented at PARA until Pennsylvanian time. Pennsylvanian deposition featured a westward-thickening wedge of sedimentary rocks, transitioning from marine carbonates in the west to coastal and terrestrial clastics in the east (Blakey and Knepp 1989; North America was rotated clockwise compared to the present, but modern directions are used for convenience). This situation persisted into the early Permian. Permian deposition at PARA began as an eastern dune field meeting a western shallow sea (Blakey and Knepp 1989), followed by marine retreat and the formation of a dry floodplain (Blakey 2003), then the return of dunes, and finally a shallow sea transgressing and regressing multiple times (Blakey and Knepp 1989). After this, some 20 million years of geologic time is not represented in northwestern Arizona, until a return to nearshore and coastal plain conditions in the Early Triassic (Heckert et al. 2005a), beginning approximately 252 Ma.

Triassic rocks at PARA are primarily represented by the Moenkopi Formation (Lower–Middle Triassic) and the Chinle Formation (Upper Triassic). Northwestern Arizona during the Early and Middle Triassic was a broad coastal plain that was occasionally inundated by a sea advancing from the west (Stewart et al. 1972a; Blakey et al. 1993). The top of the Moenkopi Formation is separated from the Chinle Formation by millions of years, with intervening erosion (Pipiringos and O'Sullivan 1978). The Late Triassic climate in this area is thought to have been seasonal, with wet and dry periods (Lucas 1993). Fluvial and lacustrine deposition alternated over time (Blakey and Gubitosa 1983). Distant volcanic eruptions occurred to the west and south during deposition; these eruptions contributed substantial amounts of volcanic sediment to the Chinle Formation (Riggs et al. 2003).

As the deposition of the Chinle Formation ended, aridity increased (Tanner 2003). The end of the Triassic and beginning of the Jurassic, approximately 201 Ma, featured the shallow lacustrine system of the Moenave Formation in northwestern Arizona, with an erg to the east (Tanner and Lucas 2007, 2009a). A brief episode of increased humidity resulted in the deposition of the Kayenta Formation, on a broad, gentle floodplain separated from the sea to the west (Blakey 1994; Peterson 1994). This setting was gradually replaced by the vast erg that became the Navajo Sandstone (Harshbarger et al. 1957; Dickinson and Gehrels 2003, 2009; Rahl et al. 2003; Lucas et al. 2005), the largest erg known from North America (Blakey 2008; Blakey and Ranney 2008). This Sahara-like desert existed from Nevada through the Colorado Plateau region and into Wyoming (Hintze and Kowallis 2009). At this time during the Early Jurassic, the latitude of the area was only about 10° N, near the western edge of

the supercontinent Pangaea (Loope et al. 2004a). Strong cross-equatorial winds blew from the northwest during the winter, driving dune movement, and monsoonal rains occurred during the summer (Loope et al. 2004a, 2004b).

Following the Navajo Sandstone, most of the rest of the Mesozoic into the middle Cenozoic are not represented. Rocks of these ages were either eliminated by erosion or were never deposited, with the exception of small areas of Cretaceous rocks in PARA-BLM deposited approximately 100 Ma. Geologic evidence supports that the Colorado Plateau was first uplifted near the end of the Cretaceous (Hintze and Kowallis 2009). The rock record of PARA resumes in the late Oligocene, about 25 Ma. Basin and Range extension began approximately 17 Ma (Hintze and Kowallis 2009). Igneous activity was frequent in the area between approximately 9.2 and 4.7 Ma, continuing with lesser frequency to the present, with numerous eruptive centers across and near PARA (Billingsley and Workman 2000; Billingsley et al. 2000, 2004; Billingsley and Wellmeyer 2003). Some of the flows escaped the volcanic fields of PARA and entered the Grand Canyon, damming the Colorado River and creating lakes on multiple occasions (Hamblin 1989, 1994; Crow et al. 2008). During the ice ages of the Pleistocene (about 2.58 Ma to 11,000 years ago), only the highest elevations in the Colorado Plateau were covered by ice, and the climate was cooler with wetter winters (Anderson et al. 2000). During the transition from the Pleistocene into the Holocene, the climate of the Great Basin became warmer and more arid, and was comparable to present climatic conditions by around 7,500 years ago (Mehringer 1977). Archeological evidence indicates that humans have been present in the region since at least 13,000 years before present (Shutler 1967).

Geologic Formations

Geologic Maps and Stratigraphic Units Present Within PARA

In the absence of a formal compiled NPS geologic map for PARA, four maps have been used as the primary sources for the geology of the monument: Billingsley and Workman (2000), which documents the Littlefield 30’ x 60’ topographic quadrangle, including the northern part of PARA (PARA-BLM); Billingsley and Wellmeyer (2003), which documents the Mount Trumbull 30’ x 60’ quadrangle, including the Parashant Canyon parcel of PARA-NPS, part of the Grand Wash parcel of PARA-NPS, and the southern part of PARA-BLM; Billingsley et al. (2006), which documents the Peach Springs 30’ x 60’ quadrangle, including the southernmost fingers of the Parashant Canyon parcel of PARA-NPS; and Beard et al. (in press), the geologic map of LAKE, including the Grand Wash parcel of PARA-NPS (see also Felger and Beard 2010). These maps provide coverage of the entire monument except for a small strip of western PARA-BLM along the Arizona–Nevada state line. The great majority of the sedimentary formations exposed at PARA are fossiliferous, with a variety of marine and terrestrial fossils spanning more than 500 million years of history (Table 1).

Table 1. Summary of PARA stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2016). PARA-NPS is also part of LAKE.

Formation	Age	Fossils Within PARA-NPS	Fossils Within PARA-BLM	Depositional Environment
Pliocene and Quaternary sediments	Pliocene–Holocene	Quaternary: packrat middens	Quaternary: unspecified trace fossils and petrified wood in travertine; cave/rock shelter pine cone?, gastropods, tortoises, snakes, birds, rodents, chiropterans, canids, felids, equids, bovids, undetermined mammals, bat guano, and packrat middens; also pre-Quaternary reworked petrified wood pieces, rugose corals, bryozoans, brachiopods, and crinoids in surficial deposits	Fluvial, alluvial, lacustrine, cave, landslide, and eolian
Various igneous rocks	late Miocene–Holocene	None to date; fossils are unlikely but not impossible in extrusive igneous rocks and volcaniclastic sediments	None to date directly, although fossils are present in a maar fill (undetermined mollusks, oncoids or inorganically coated grains, stromatolites?, microbial laminations?, and invertebrate burrows); fossils are unlikely but not impossible in extrusive igneous rocks and volcaniclastic sediments	Igneous rocks extruded at the surface or solidified at depth
Rocks of the Grand Wash Trough	middle–late Miocene	None to date	Fossil “algae”? and root casts?	Alluvial, fluvial, and lacustrine
Rainbow Gardens Formation	late Oligocene–early Miocene	Plant molds?, bioturbation, root traces, invertebrate burrows, and tubular features	Root traces and invertebrate burrows	Fluvial to lacustrine
Willow Tank Formation	Late Cretaceous	Formation not present in PARA-NPS	None to date	Fluvial
Navajo Sandstone	Early Jurassic	Formation not present in PARA-NPS	None to date	Desert with large eolian sand dunes
Moenave and Kayenta Formations undivided	Late Triassic–Early Jurassic	Formation not present in PARA-NPS	Petrified wood and invertebrate burrows	Fluvial, floodplain, lacustrine, and eolian
Chinle Formation	Late Triassic	Formation not present in PARA-NPS	Petrified wood and invertebrate burrows	Fluvial, floodplain, lacustrine, and eolian

Table 1 (continued). Summary of PARA stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2016). PARA-NPS is also part of LAKE.

Formation	Age	Fossils Within PARA-NPS	Fossils Within PARA-BLM	Depositional Environment
Moenkopi Formation	Early–Middle Triassic	None to date	Brachiopods, bivalves, crinoids, echinoids, undetermined invertebrate fossils, microbially induced sedimentary structures?, invertebrate burrows and trails, and undetermined fossils	Coastal plain with marine incursions
Kaibab Formation	early Permian	Sponges, rugose corals, bryozoans, brachiopods, scaphopods?, crinoids, echinoids, undetermined invertebrate fossils, stromatolites?, and undetermined fossils	Sponges, rugose and undetermined corals, bryozoans, brachiopods, bivalves, gastropods, scaphopods, undetermined mollusks, trilobites, crinoids, echinoids, undetermined invertebrate fossils, invertebrate burrows, and undetermined fossils	Shallow marine
Toroweap Formation	early Permian	Bryozoans, brachiopods, and echinoids (undivided Toroweap and Kaibab)	Petrified wood?, bryozoans, brachiopods, bivalves, nautiloids, gastropods, crinoids, echinoids, echinoderm debris, undetermined invertebrate fossils, and invertebrate burrows	Shallow marine
Coconino Sandstone	early Permian	Undetermined shells? (possibly Toroweap Formation instead)	None to date	Desert with large eolian sand dunes
Hermit Formation	early Permian	Seed ferns, undetermined plants, potential microbially induced sedimentary structure *Rivularites*, and invertebrate burrows	Invertebrate burrows	Low energy fluvial
Queantoweap Sandstone	early Permian	Formation not present in PARA-NPS	Invertebrate burrows	Eolian
Esplanade Sandstone	early Permian	Stromatolites, bioturbation, “algal” limestone?, invertebrate burrows, foraminifera, and marine fossil fragments	The conifer *Walchia*, plant stems, *Rivularites*, invertebrate burrows, and marine fossil fragments	Primarily coastal eolian

Table 1 (continued). Summary of PARA stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2016). PARA-NPS is also part of LAKE.

Formation	Age	Fossils Within PARA-NPS	Fossils Within PARA-BLM	Depositional Environment
Pakoon Limestone	early Permian	Probable sponges, corals, bryozoans, brachiopods, gastropods?, crinoids, echinoids, and undetermined invertebrate fossils	Tabulate and rugose corals, bryozoans, brachiopods, gastropods, scaphopods?, crinoids, echinoids, undetermined invertebrate fossils, stromatolites? "algal" laminations?, invertebrate burrows, foraminifera, and undetermined fossils	Shallow marine
Wescogame Formation	Late Pennsylvanian	Bioturbation, "algal" structures?, reworked foraminifera (Manakacha Formation?), and fragments of marine fossils such as pelmatozoans, brachiopods or bivalves, and foraminifera	Tabulate and rugose corals, gastropods, crinoids, cartilaginous fish *Deltodus*, invertebrate trails, foraminifera, and fragments of marine fossils such as bryozoans, pelmatozoans, and brachiopods or bivalves	Primarily coastal eolian
Manakacha Formation	Middle Pennsylvanian	The conifer *Walchia*, bioturbation, foraminifera, and fragments of bryozoans, pelmatozoans, and brachiopods or bivalves	Tabulate and rugose corals, bryozoans, brachiopods, bivalves, nautiloids, gastropods, trilobites, crinoids, echinoids, stromatolites, and foraminifera	Primarily coastal eolian
Watahomigi Formation	Late Mississippian–Middle Pennsylvanian	Tabulate and undetermined corals, bryozoans, bivalves, brachiopods, gastropods, trilobites, pelmatozoan bioclasts, cartilaginous fish *Deltodus*, "fucoidal structures", foraminifera bioclasts, and fossil molds	Corals, bryozoans, brachiopods, bivalves, gastropods, trilobites, crinoids, echinoids, undetermined echinoderms, conodonts, stromatolites, foraminifera bioclasts, "algae", and unspecified fossils	Coastal plain with marine incursions

Table 1 (continued). Summary of PARA stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2016). PARA-NPS is also part of LAKE.

Formation	Age	Fossils Within PARA-NPS	Fossils Within PARA-BLM	Depositional Environment
Callville/Supai interval	Late Mississippian–early Permian	Callville or Pakoon: rugose and undetermined corals, brachiopods, bivalves, nautiloids, undetermined cephalopods, gastropods, scaphopods, trilobites, crinoids, echinoids, undetermined echinoderms Undivided Pakoon/Esplanade: fragments of bryozoans, pelmatozoans, brachiopods or bivalves, and foraminifera	Callville: sponges, rugose corals, brachiopods, conodonts, and foraminifera Supai undetermined: rugose and undetermined corals, bryozoans, brachiopods, gastropods, crinoids, echinoids, microbially induced sedimentary structures?, invertebrate burrows, and undetermined fossils Wescogame or Pakoon: bryozoans, brachiopods, crinoids, echinoids, undetermined invertebrate fossils, and stromatolites? Undivided Pakoon/Esplanade: fragments of corals, bryozoans, pelmatozoans, brachiopods or bivalves, and foraminifera Undetermined: bryozoans and brachiopods	Complex interfingering of shallow marine and coastal terrestrial
Surprise Canyon Formation	Late Mississippian	None to date	None to date	Fluvial to estuarine to marine over time
Redwall Limestone	Early–Middle Mississippian	Tabulate and rugose corals, bryozoans, brachiopods, bivalves, gastropods, scaphopods?, trilobites, crinoids, stromatolites, foraminifera, calcispheres, and undetermined fossils	Tabulate and rugose corals, bryozoans?, brachiopods, crinoids, undetermined invertebrates, foraminifera	Shallow marine
Temple Butte Formation	Middle–Late Devonian	Possibly rugose corals and brachiopods (locality uncertain)	None to date	Shallow marine
Nopah Formation	late Cambrian	Formation not present in PARA-NPS	Possibly invertebrate burrows and fossil fragments (locality uncertain)	Marine, lagoonal, and microbial bank

Table 1 (continued). Summary of PARA stratigraphy, fossils, and depositional settings in descending order of age, from youngest to oldest. Details and references can be found in the text and in Tweet et al. (2016). PARA-NPS is also part of LAKE.

Formation	Age	Fossils Within PARA-NPS	Fossils Within PARA-BLM	Depositional Environment
Frenchman Mountain Dolostone	middle–late Cambrian	Stromatolites	None to date	Offshore marine
Muav Formation	middle Cambrian	“Algal” laminations, possibly trilobites and “coral-like structures” (locality uncertain); invertebrate trace fossils likely present	None to date	Offshore marine
Bright Angel Shale	middle Cambrian	Possibly trilobites (locality uncertain); invertebrate trace fossils likely present	Formation not present in PARA-BLM	Shelf marine

Rock units exposed in the Grand Wash parcel of PARA-NPS include, in ascending order (oldest to youngest): the Bright Angel Shale and Muav Formation (middle Cambrian); Frenchman Mountain Dolostone (middle–upper Cambrian); Temple Butte Formation (Middle–Upper Devonian); Redwall Limestone (Lower–Middle Mississippian); Callville Limestone (Upper Mississippian–Upper Pennsylvanian); Watahomigi Formation (Upper Mississippian–Lower Pennsylvanian); Manakacha Formation (Middle Pennsylvanian); Wescogame Formation (Upper Pennsylvanian); Pakoon Limestone, Esplanade Sandstone, Hermit Formation, Coconino Sandstone, Toroweap Formation, and Kaibab Formation (lower Permian); Moenkopi Formation (Lower–Middle Triassic); Rainbow Gardens Formation (upper Oligocene–lower Miocene); the informal "rocks of the Grand Wash trough" (middle–upper Miocene); Pliocene basalt flows and unnamed sedimentary deposits (Pliocene); and Quaternary sedimentary deposits (Pleistocene–Holocene) (Billingsley and Wellmeyer 2003; Beard et al. in press; Rainbow Gardens Formation after Lamb et al. 2015) (Figures 3 and 4). "Lower" (stratigraphic position)/"early" (age), "middle", and "upper"/"late" are capitalized if such a subdivision has been formally designated. If a subdivision has not been formalized, for example in the Cambrian, it is not capitalized.

The Parashant Canyon parcel of PARA-NPS, overlooking GRCA, has typical upper Grand Canyon stratigraphy (Figure 5; see Figure 4 for legend). In ascending order, the formations mapped here include: the Temple Butte Formation (Middle–Upper Devonian); Redwall Limestone (Lower–Middle Mississippian); Watahomigi Formation (Upper Mississippian–Lower Pennsylvanian); Manakacha Formation (Middle Pennsylvanian); Wescogame Formation (Upper Pennsylvanian); Pakoon Limestone, Esplanade Sandstone, Hermit Formation, Coconino Sandstone, Toroweap Formation, and Kaibab Formation (lower Permian); Moenkopi Formation (Lower–Middle Triassic); igneous rocks of the Shivwits Plateau (upper Miocene); other Miocene dikes (Miocene); igneous rocks of the Uinkaret Plateau (Pleistocene); and Quaternary surficial sediments (Pleistocene–Holocene) (Billingsley and Wellmeyer 2003; Billingsley et al. 2006). Of these, the most widely exposed rocks are the lower Permian and Miocene rocks.

PARA-BLM includes most of the same units as the two NPS parcels (Figures 6 and 7). The Bright Angel Shale (middle Cambrian) is absent, but several other Paleozoic and Mesozoic formations are exposed, including the Nopah Formation (upper Cambrian), Chinle Formation (Upper Triassic), undivided Moenave and Kayenta Formation (Upper Triassic–Lower Jurassic), Navajo Sandstone (Lower Jurassic), and the Willow Tank Formation (Upper Cretaceous) (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003). Generally speaking, most rocks exposed in PARA-BLM pertain to the Toroweap Formation, Kaibab Formation, and Neogene–Quaternary volcanics. Pre-Pennsylvanian rocks are largely limited to canyons and the lower part of the Grand Wash Cliffs. Mesozoic formations are mostly found in extreme northern PARA, not included on Figure 6.

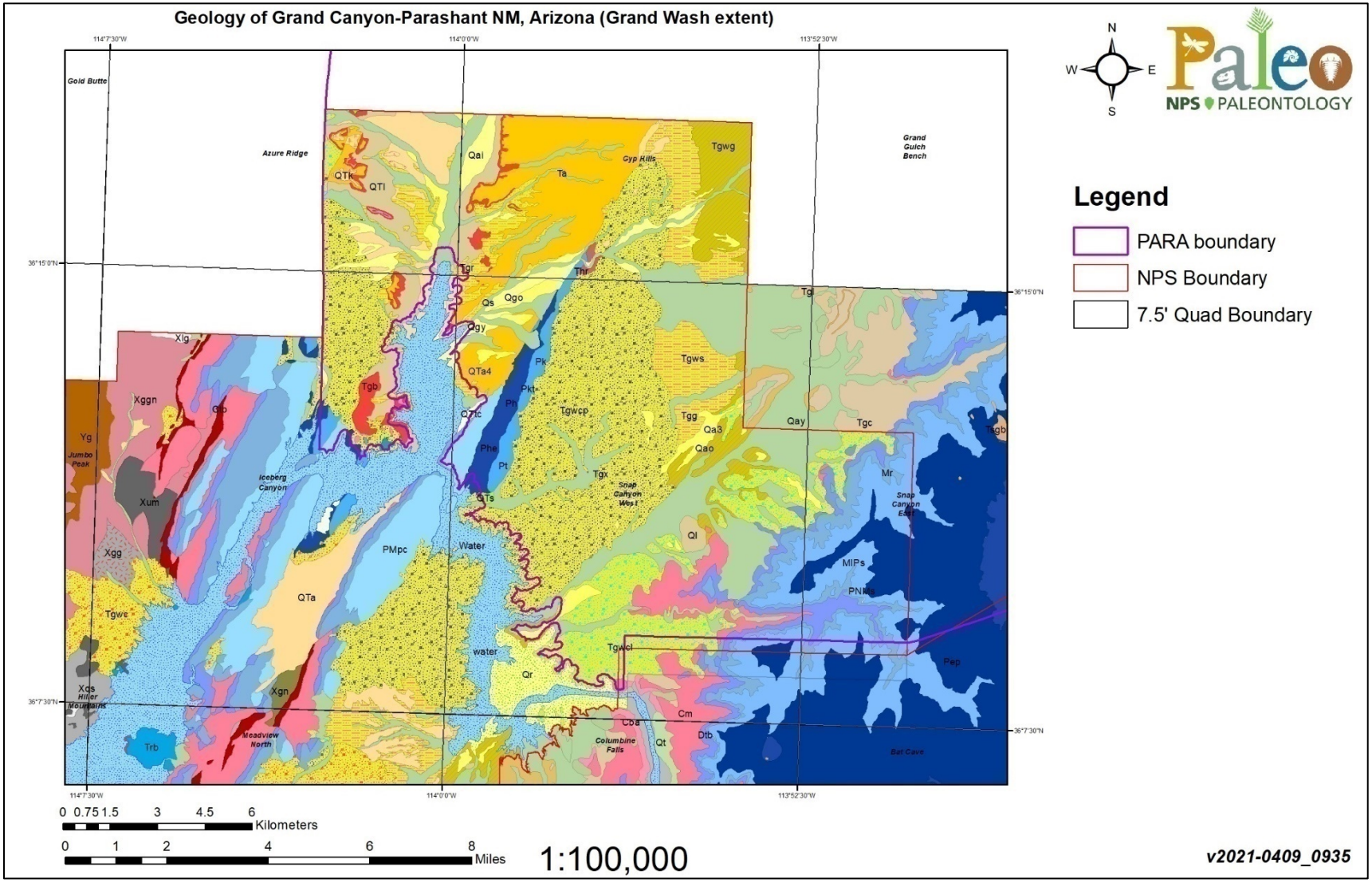


Figure 3. Geologic map of the Grand Wash parcel of PARA-NPS (see Figure 4 for full legend), derived from Beard et al. (in press) and Billingsley and Wellmeyer (2003), digitized by the NPS Geologic Resources Inventory (GRI). Digital map data is available at https://irma.nps.gov/DataStore/Reference/Profile/2203644 and https://irma.nps.gov/DataStore/Reference/Profile/2202839.

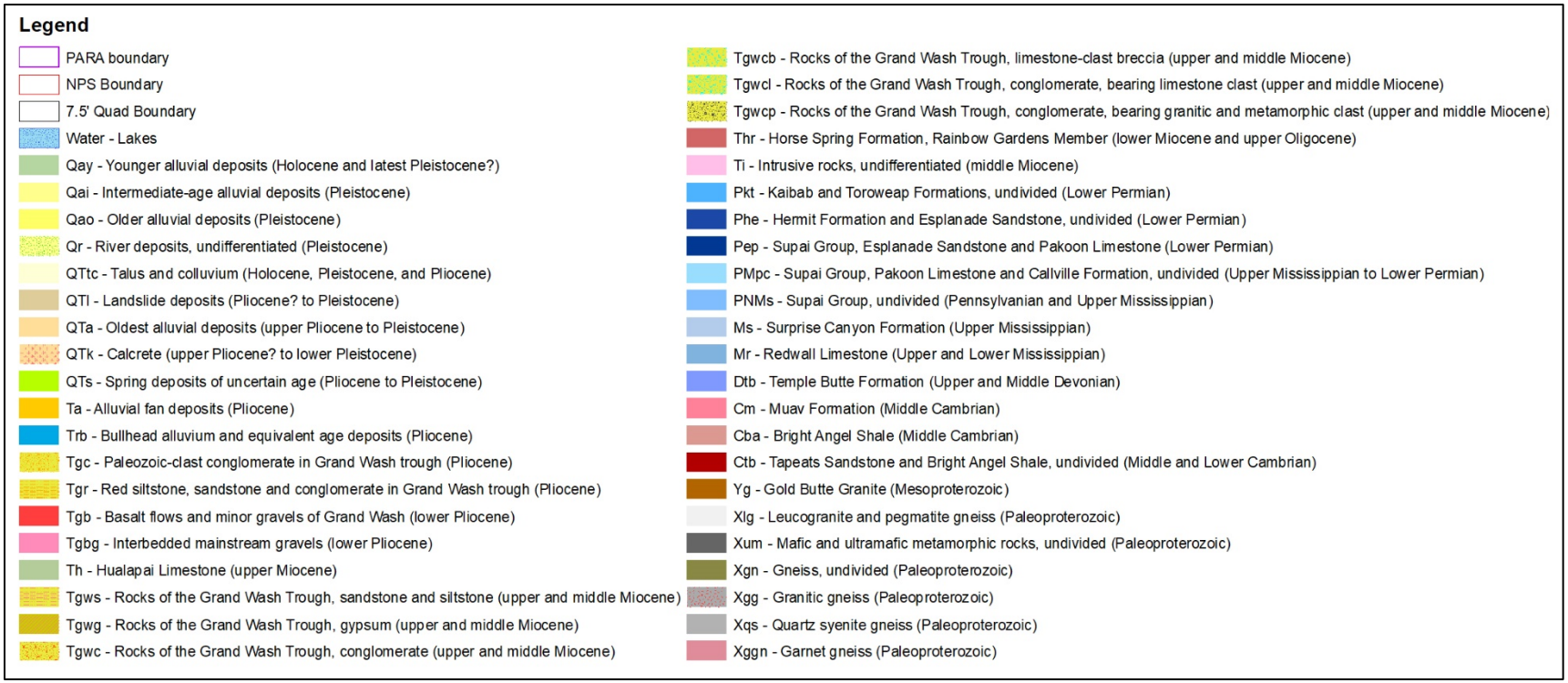


Figure 4. Full legend for Figures 3 and 5. The undivided Supai Group (PNMs) includes in ascending order the Watahomigi, Manakacha, and Wescogame Formation. The Rainbow Gardens Member of the Horse Spring Formation (Thr) was elevated to a formation after the creation of the base map; “Ths” as used by Billingsley and Wellmeyer (2003) is preferred elsewhere in this report. The recognition of the Frenchman Mountain Dolostone also postdates the base map, which includes its rocks in the Muav Formation (Cm).

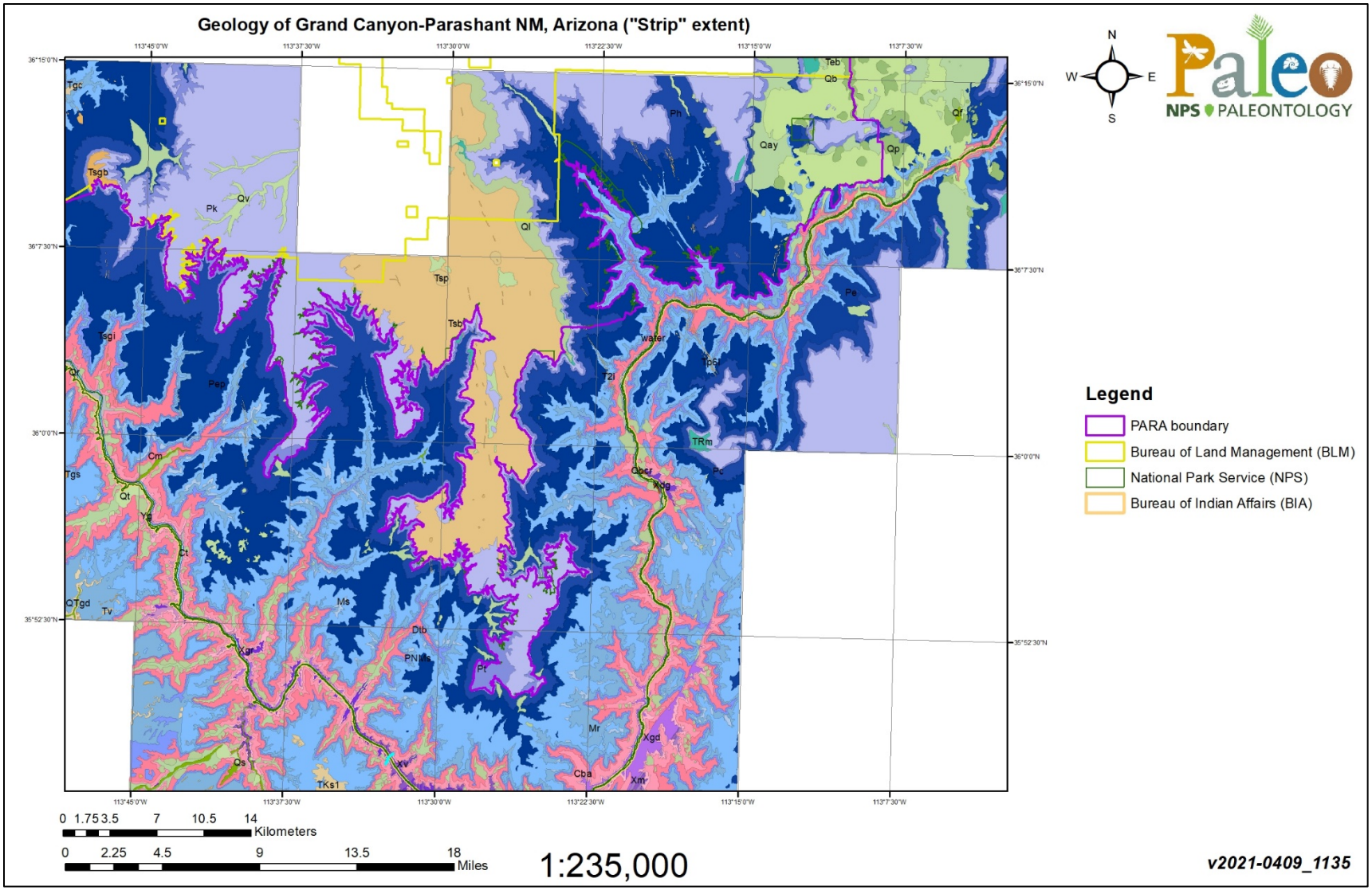


Figure 5. Geologic map of the Parashant Canyon parcel of PARA-NPS (see Figure 4 for full legend), derived from Billingsley and Wellmeyer (2003) and Billingsley et al. (2006), digitized by the NPS GRI. Digital map data is available at https://irma.nps.gov/DataStore/Reference/Profile/2203644.

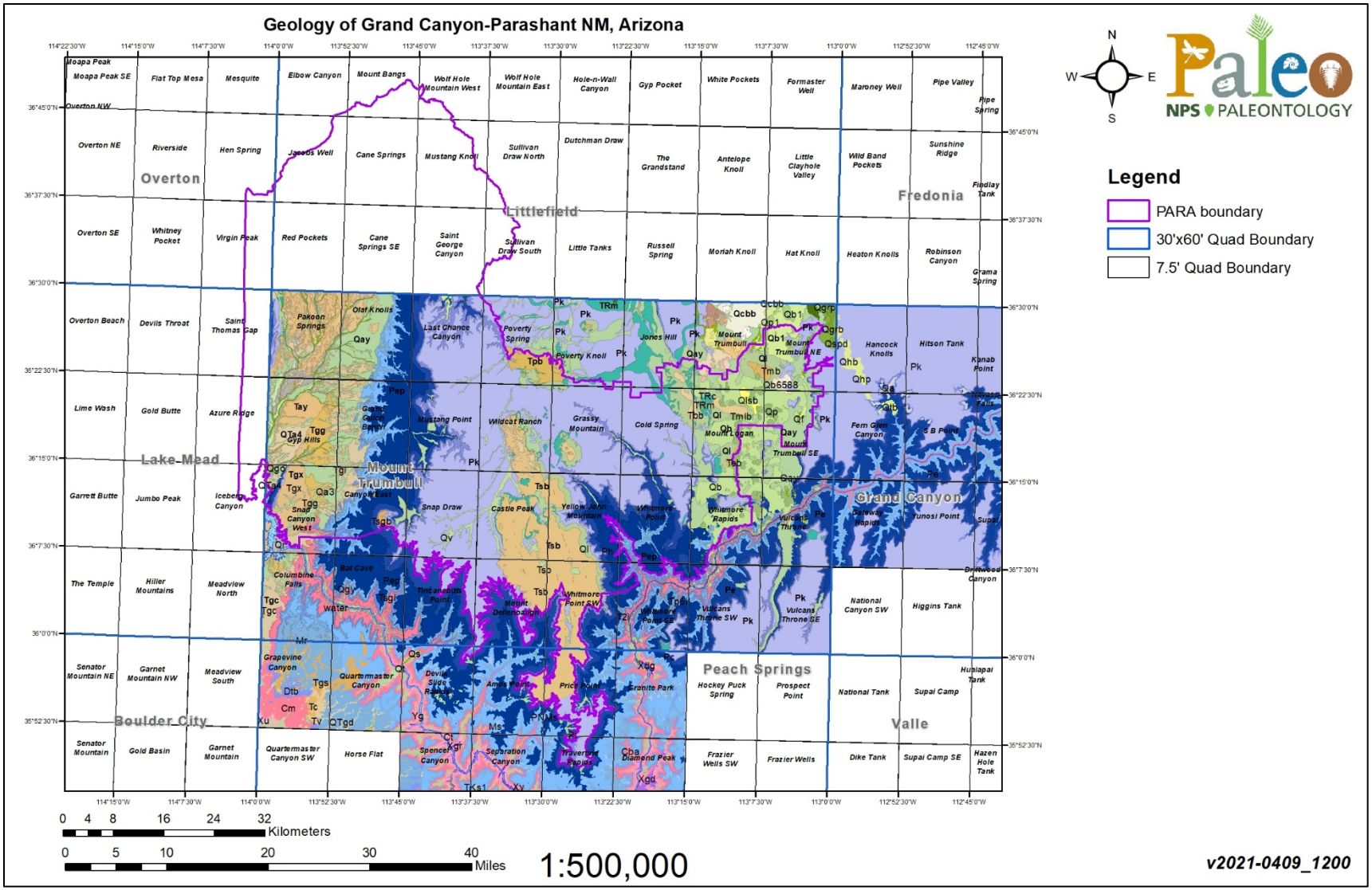


Figure 6. Geologic overview map of PARA (see Figure 7 for full legend), derived from Billingsley and Wellmeyer (2003) and Billingsley et al. (2006), digitized by the NPS GRI. Digital map data is available at https://irma.nps.gov/DataStore/Reference/Profile/2203644.

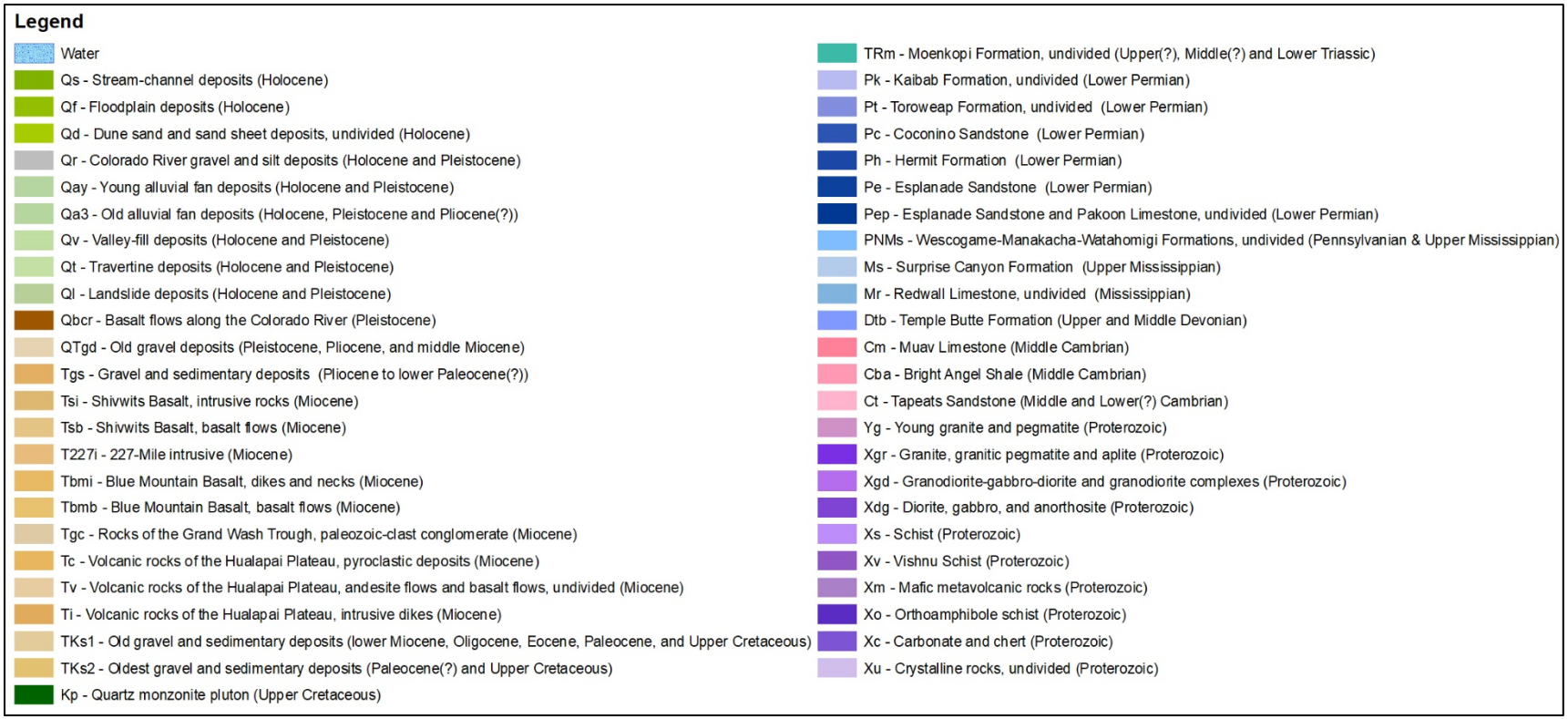


Figure 7. Full legend for Figure 6. The Mesozoic Chinle Formation, undivided Moenave and Kayenta Formations, Navajo Sandstone, and Willow Tank Formation referenced in the text are mostly exposed in far northern PARA, outside of the map's extent. However, some exposures in PARA-BLM have yielded fossil resources and are included in this report.

Tonto Group: Bright Angel Shale (middle Cambrian) (PARA-NPS Only)

Description: The Bright Angel Shale (or Formation) is found in the Grand Wash PARA-NPS parcel, where it is a lithologically variable unit composed primarily of slope-forming green or purple-red siltstone and shale and red-brown to brown sandstone, up to approximately 150 m (500 ft) thick (Billingsley and Wellmeyer 2003). Beds of the upper Bright Angel Shale intertongue with limestone and dolomite beds of the kind found in the overlying Muav Formation (Billingsley and Wellmeyer 2003), so the placement of the contact for mapping is arbitrary.

Historically, the Tonto Group was considered to span much of the Cambrian, and was interpreted as a classic example of a gradual marine transgression in which the nearshore sands of the Tapeats Sandstone (not exposed in PARA) were replaced by successively deeper marine deposits of the Bright Angel Shale and Muav Formation (McKee 1945). More recent study indicates that the marine transgression responsible for the Tonto Group took place over a much shorter time frame (Karlstrom et al. 2018, 2020), between about 510 and 505 Ma from west to east across northern Arizona (Karlstrom et al. 2020). The Bright Angel Shale is generally interpreted as a shallow marine shelf unit (Middleton and Elliott 2003). When interpreted as more continental, the rocks are instead seen as representing estuarine and tidal flat settings (Baldwin et al. 2004).

Fossils found within PARA-NPS: It is unclear if the Bright Angel Shale of PARA is fossiliferous, but invertebrate trace fossils are often reported as common in descriptions of the rocks in the Grand Wash Cliffs area (Schenk 1938), to the point of being included in the generalized description of the formation in Beard et al. (in press), so their presence in the Grand Wash parcel of PARA-NPS is quite likely. In addition, a few early reports have vague locality information that does not allow a distinction to be made between GRCA, LAKE, PARA-NPS, PARA-BLM, or reservation land. Longwell (1936) reported that trilobites were present in Cambrian rocks at the mouth of the Grand Canyon. Schenk (1938) reported trilobites in the middle to upper Bright Angel Shale at the Grand Wash Cliffs.

Fossils found elsewhere: Types of fossils found elsewhere in the Bright Angel Shale include: palynomorphs such as spores, cuticle fragments, and possible egg cases (Baldwin et al. 2004); invertebrates such as brachiopods, hyoliths, trilobites, bradoriids, and eocrinoid echinoderms (Resser 1945; Foster 2011); invertebrate trace fossils (Miller et al. 2020); and a variety of more enigmatic fossils, including specimens of sac-like *Chancelloria* (Elliott and Martin 1987), *Margaretia* (Schenk and Wheeler 1942), *Tontoia* (Walcott 1912), and, in GRCA collections, possible sponges, undetermined gastropods, an “echinoid imprint?”, and a “pelecypod” (Lassiter et al. 2020). See the glossary (Appendix E) for definitions of terms.

Tonto Group: Muav Formation (middle Cambrian)

Description: The Muav Formation (or Limestone) has been mapped in the Grand Wash Parcel of PARA-NPS (Beard et al. in press) and isolated areas of PARA-BLM (Billingsley et al. 2004; Billingsley and Workman 2000). It is composed of a lower interval of cliff-forming medium- to dark-gray bedded dolomite interbedded with lighter-colored sandy dolomite and limestone, and an upper interval of light gray unbedded (massive) dolomite over a recessive white and gray banded zone (Beard et al. in press; this includes rocks now designated the Frenchman Mountain Dolostone). The

Muav Formation thickens from east to west (Karlstrom et al. 2020); Beard et al. (in press) reported the thickness as ranging from approximately 520 to 630 m (1,700 to 2,100 ft), but this includes the interval now assigned to the Frenchman Mountain Dolostone. The Muav Formation is interpreted as representing subtidal to supratidal offshore marine deposits (Middleton and Elliott 2003).

Fossils found within PARA-NPS: "Algal" laminations were observed in a stratigraphic section within PARA-NPS (Brathovde 1986). ("Algal" structures were often formed by microbial organisms that are no longer considered true algae.) Invertebrate trace fossils are often reported as common in descriptions of the rocks in the Grand Wash Cliffs area (Schenk 1938; Beard et al. in press), so are likely present in PARA-NPS. In addition, Schenk (1938) reported "branching coral-like structures" in the middle Muav Formation and a trilobite in the upper part of the formation at the Grand Wash Cliffs, potentially within PARA.

Fossils found elsewhere: Other types of fossils found in the Muav Formation include: sponges (Resser 1945); brachiopods (Noble 1922; Resser 1945); snail-like helcionelloid mollusks (A. R. Palmer, USGS, written communication to M. B. Ingham, 1963/10/17); trilobites (Schenk and Wheeler 1942; Resser 1945); several more enigmatic forms, among them "cystoids" in GRCA collections (more likely eocrinoids if actually echinoderms), *Chancelloria* (Schenk and Wheeler 1942), and snail-like *Scenella* (Resser 1945); stromatolites (Middleton 1989); "algal" balls (Middleton 1989); and pellets (Middleton 1989).

Tonto Group: Frenchman Mountain Dolostone (middle–upper Cambrian)

Description: Above the Muav Formation in the western Grand Canyon is a unit historically known as the "undifferentiated dolomites", assigned to the Frenchman Mountain Dolostone by Karlstrom et al. (2020). It consists primarily of white to gray dolomite with thin layers of shale (mudstone) between beds, especially in the lower part of the unit (Beus and Billingsley 1989). Its exact age is uncertain, due to the paucity of fossils. The thickness varies from 60 to 140 m (200 to 450 ft) (Beus and Billingsley 1989). It is also sometimes called the "Supra-Muav" or "Grand Wash Dolomite" in the literature (Brathovde 1986; Middleton 1989), although the latter name is precluded from formal usage because "Grand Wash" is already in use for a different unit in the area (Elston 1989). This unit is interpreted as shallow subtidal to possibly intertidal in depositional setting (Middleton and Elliott 2003), deposited in a regressing sea (Spamer 1984). The upper contact with the Temple Butte Formation is disconformable (Beard et al. in press). The contact may be difficult to find, though, because the Cambrian and Devonian rocks can be difficult to distinguish (Schenk 1936).

Fossils found within PARA-NPS: Stromatolites have been found in a stratigraphic section described by Brathovde (1986) within PARA-NPS.

Fossils found elsewhere: Rare trilobite fragments, eocrinoid plates, stromatolites, and invertebrate burrows have been observed in the area of Lake Mead (Rowland et al. in prep.). Undefined trace fossils are reported in McKee (1945), Middleton (1989), and Middleton and Elliott (2003).

Nopah Formation (upper Cambrian) (PARA-BLM Only)

Description: There is an area on the northwestern boundary of PARA-BLM that was mapped as the Ordovician Pogonip Group by Seager (1966) and more recently as the older Nopah Formation by Bohannon (1991) and Billingsley and Workman (2000); the Nopah terminology is accepted here. Seager (1966) described the rocks as 168 m (551 ft) thick and almost exclusively composed of dolomite, primarily medium gray and thick-bedded, but with some light gray, brown, yellowish, reddish, or green beds, sometimes thin-bedded, sometimes with shale or sandstone beds. Bohannon (1991) reported it as much thinner, about 60 m (200 ft) of light gray dolomite and sandy dolomite with a discontinuous yellowish sandy basal unit. Billingsley and Workman (2000) had a similar description but a thickness intermediate between the two previous authorities, 115 m (378 ft). It is possible that the greater reported thickness of Seager's section is due to unrecognized faulting, given the complex structural geology of the area. Another possibility for the variations in thickness is different placements of contacts. Bohannon (1991) mapped an unnamed dolomite (=Frenchman Mountain Dolostone?) and the Muav Limestone (=Formation) under the Nopah Formation, and Billingsley and Workman (2000) included the unnamed dolomite in their Muav Limestone. The Nopah Formation is a shallow marine unit (Cooper et al. 1981), deposited during the late Cambrian (Keller et al. 2012).

Fossils found within PARA-BLM: The Pogonip Group section detailed in Seager (1966) is located in area partially within PARA-BLM. Seager (1966) reported that biosparite, carbonate rock with a framework of fossil fragments, was present in the middle part of the Pogonip Group at this locality, and invertebrate burrows were present in the upper part. At the moment, it is not possible to determine whether Seager's locality was within or just outside of PARA-BLM. Although as mentioned it is possible that some of Seager's Pogonip Group is actually the Frenchman Mountain Dolostone or Muav Formation, the placement of the fossils in the upper and middle parts of the section indicates that these should be in the Nopah Formation.

Fossils found elsewhere: Body fossils include specimens of *Chancelloria*, the sponge *Hintzespongia* (Miller et al. 1981), other sponges (Hazzard and Mason 1936; the Cornfield Springs Formation is a synonym of the Nopah Formation), brachiopods (Miller et al. 1981), the early chiton relative *Matthevia* (Yochelson et al. 1965), gastropods (Miller and Sundberg 1984), trilobites, eocrinoids (Miller et al. 1981), and conodonts (Miller and Paden 1976). A reference to cystoids in Hazzard and Mason (1936) may pertain to eocrinoids instead. Trace fossils include various microbial structures (Cooper et al. 1981) and invertebrate trace fossils and bioturbation (Droser and Bottjer 1985), the latter including predatory borings on shells (Miller and Sundberg 1984).

Temple Butte Formation (Middle–Upper Devonian)

Description: The Temple Butte Formation is exposed in the Grand Wash parcel of PARA-NPS (Beard et al. in press), small areas of the Parashant Canyon parcel of PARA-NPS and southwestern PARA-BLM (Billingsley and Wellmeyer 2003), and possibly to a limited extent near the PARA-BLM boundary with the Virgin Mountains (Billingsley and Workman 2000). In the eastern part of PARA, it is composed of purple and gray ledge-forming dolomite, sandy dolomite, sandstone, mudstone, and limestone (Billingsley and Wellmeyer 2003). In western PARA, it is a brown to black

or gray fetid-smelling dolomite (the odor comes from its organic content), "with interbedded red-brown sandstone and sandy shale" in the basal 10 m (33 ft) and occasionally basal channels (Beard et al. in press). It thickens from east to west, from as little as 84 m (275 ft) in eastern PARA (Billingsley and Wellmeyer 2003) to 180 m (460 to 590 ft) in the Grand Wash parcel of PARA-NPS (Beard et al. in press). The thickness also varies between publications due to different interpretations of the position of the basal contact (Ritter 1991). The upper contact with the Redwall Limestone is unconformable (Beus 1989).

Most of the Temple Butte Formation is interpreted as having been deposited in a shallow, subtidal, open marine setting, although some of the dolomite may be supratidal and the channel fill could correspond to tidal channels. Deposition was under progressively shallower conditions west to east in the Grand Canyon area (Beus 2003a). A transgression occurred during deposition, moving west to east (Beus 1989). Fish fossils from South Virgin Peak Ridge just west of PARA are of Middle Devonian age (Elliott and Johnson 1997), and microfossils from just outside of PARA establish that the youngest Devonian rocks here are from the late Late Devonian (Famennian stage, about 372 to 359 Ma) (Ritter 1991).

Fossils found within PARA-NPS: Schenk (1938) reported a few Devonian brachiopods from the Grand Wash area, but did not spend much time on these rocks because of the difficulty of access and the need to concentrate on areas that would be inundated after completion of Hoover Dam. His fossil locality may be in GRCA or PARA-NPS. Schenk and Wheeler (1942) reported the horn coral *Streptelasma* from a short distance north of the western end of Grand Canyon. This is most likely within the Grand Wash parcel of PARA-NPS, although the location is vague enough that it could also be within GRCA.

Fossils found elsewhere: Overall, fossils are uncommon in the Temple Butte Formation (McKee 1969; Beus 1989), and are often represented by molds and casts (McKee 1969). Nearby in LAKE, fossils include stromatolites (Beus 1969) and/or stromatoporoid sponges (Beus 1980; Ritter 1991; Ritter's Crystal Pass Member of the Sultan Limestone is here considered part of the Temple Butte Formation), horn corals (Beus 1980), brachiopods (Ritter 1991), gastropods, crinoids (Beus 1980), conodonts, and fish bones up to 10 cm (4 in) long (Ritter 1991). Stromatolites and stromatoporoids are superficially similar layered fossils and can easily be confused when observed in passing. The only other types of fossils that have been reported from this formation are the sponge *Chaetetes* (Spamer 1992), armored placoderm fish (Beus 1989; Elliott and Blakey 2005), lobe-finned fish (Elliott and Blakey 2005), and trace fossils (Beus 2003a).

Redwall Limestone (Lower–Middle Mississippian)

Description: The Redwall Limestone of PARA is a massive gray limestone, with chert lenses in some members. Much of it is cliff-forming; however, the upper units form stair-stepping slopes (Billingsley and Wellmeyer 2003). Where fossils have been destroyed by dolomitization, fossils can be seen with good detail in the chert lenses (H. Flora and R. Weeks, pers. obs.). Overall, it is about 200 m (660 ft) thick (Beard et al. in press). It is divisible into four members, in ascending order the Whitmore Wash, Thunder Springs, Mooney Falls, and Horseshoe Mesa Members (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003; Beard et al. in press). The Thunder Springs

Member makes a distinctive dark band (Beard et al. in press). The formation's upper contact with Pennsylvanian rocks is unconformable (Billingsley and Wellmeyer 2003), and there is an internal unconformity between the Thunder Springs and Mooney Falls Members (Beus 1989). In PARA, rocks of the Redwall Limestone are mostly exposed on the lower Grand Wash Cliffs (Billingsley and Wellmeyer 2003; Beard et al. in press), but there are also exposures in the Parashant Canyon parcel of PARA-NPS (Billingsley and Wellmeyer 2003). Despite the name, the Redwall Limestone is not actually red; it is stained red by iron-bearing minerals washed down from the overlying Supai Group (McKee and Gutschick 1969). In PARA, it often appears gray because of the absence of the Supai Group and Hermit Formation above many outcrops (H. Flora and R. Weeks, pers. obs.) (Figure 8).



Figure 8. An outcrop of gray Redwall Limestone, with a large chert lens near the center of the image indicating this is the Thunder Springs Member; PARA-NPS (NPS/2020 FIELD INVENTORY).

The Redwall Limestone records two marine transgression-regression cycles. The older and larger cycle is represented by the transgressional Whitmore Wash Member and the regressional Thunder Springs Member, and the second cycle is represented by the transgressional Mooney Falls Member and the regressional Horseshoe Mesa Member (Beus 1989). The marine body transgressed from the west to the east, forming a shallow sea (Beus 2003b). Several types of limestone and other rocks are found throughout the members, and correspond to different environments on the shelf (McKee and Gutschick 1969). Distinct fossil assemblages are found from these different settings. For example, featureless (aphanitic) limestone appears to represent lime mud deposits that were not conducive to life, with rare fossils. Oolitic limestone (limestone composed of small spherical particles) is probably

from warm shallow water with moderate energy, and has a faunal assemblage of foraminifera, corals, ostracodes, and holothurians, with microbial structures (i.e., stromatolites) (McKee and Gutschick 1969). Deposition in the Iceberg Ridge area near PARA occurred during the Early and Middle Mississippian (Ritter 1991).

Fossils found within PARA-NPS: The Redwall Limestone is fossiliferous in PARA, in both NPS- and BLM-administered lands. It is, however, less fossiliferous than many of the other limestones in PARA (H. Flora and R. Weeks, pers. obs.). The key publication on the paleontology of Redwall Limestone sites in PARA-NPS is McKee and Gutschick (1969). Two sections in PARA-NPS were reported to have fossils of tabulate and rugose corals, bryozoans, brachiopods, bivalves, trilobites, crinoids, foraminifera, and calcispheres (possible algae). The 2020 field inventory found most of the same types of fossils, and added gastropods, possible scaphopods, and stromatolites. Corals reported by McKee and Gutschick (1969) are also documented in Easton and Gutschick (1953) and Sando and Bamber (1985). Brachiopods from PARA-NPS are also reported in Carter et al. (2014).

Fossils found within PARA-BLM: McKee and Gutschick (1969) also included sections from PARA-BLM, with fossils of tabulate and rugose corals and foraminifera. Other fossils reported from the Redwall Limestone of PARA-BLM include possible bryozoans (2020 field inventory), brachiopods (Carter et al. 2014), crinoids, undetermined invertebrates (2020 field inventory), and foraminifera (Skipp 1969). Skipp (1969) named two species of foraminifera from the Redwall Limestone of PARA-BLM: *Endothyranopsis eocompressa* and *Globoendothyra redwallensis*.

Fossils found elsewhere: Significant fossil assemblages are known from the Redwall Limestone throughout northern Arizona. According to McKee and Gutschick (1969), all four members yielded corals, brachiopods, bivalves, gastropods, ostracodes, and foraminifera. All but the Horseshoe Mesa Member yielded bryozoans, blastoids, crinoids (McKee and Gutschick 1969), and conodonts (Ritter 1991); all but the Thunder Springs Member yielded calcispheres (McKee and Gutschick 1969); and all but the Whitmore Wash Member yielded trilobites and echinoids (McKee and Gutschick 1969). Less widely distributed fossils groups include “algae” (HM Member), sponges (TS, MF), conulariids (TS), cephalopods (MF), worm tubes (TS), holothurians (WW), fish teeth (MF, HM), and microbial structures (WW, MF) (McKee and Gutschick 1969). The fossil groups most frequently encountered in the Redwall Limestone are corals, bryozoans, brachiopods, and foraminifera. Gastropods are diverse but locally distributed. Bivalves, cephalopods, blastoids, crinoids, and some microbial structures are also locally distributed. “Algae”, trilobites, ostracodes, holothurians, and fish fossils are rare (McKee and Gutschick 1969).

Fossil preservation in the Redwall Limestone is variable, depending on the matrix, fossil type, and environment. Fossils found in chert are often the best, though usually preserved as molds (McKee and Gutschick 1969). Fossils in the Whitmore Wash Member were often destroyed when its limestone was altered to dolomite (Beus 2003b). Fossils are most common in the Thunder Springs and Mooney Falls Members (Beus and Billingsley 1989). The limestone beds of the Thunder Springs Member are crinoid-rich, while the chert beds preserve bryozoan beds (Beus and Billingsley 1989). A mixed bryozoan-brachiopod-gastropod-crinoid fauna is common in this member in the western Grand Canyon (McKee and Gutschick 1969). Fossils of the Mooney Falls Member are only well-

preserved in a few scattered zones. Otherwise, specimens are fragmentary (McKee and Gutschick 1969). Fossils are rare again in the Horseshoe Mesa Member (Beus and Billingsley 1989); however, when present Horseshoe Mesa Member fossils are well-preserved (Beus 2003b).

Surprise Canyon Formation (Upper Mississippian)

Description: The Surprise Canyon Formation is a discontinuous three-part unit found filling paleovalleys and other features eroded in the upper Redwall Formation. It is found only in the Grand Canyon and the vicinity. Before it was formally named, its outcrops were thought to be part of the underlying Redwall Limestone or the overlying Watahomigi Formation (Billingsley and Beus 1985). The Surprise Canyon Formation has been mapped in PARA-NPS in two isolated areas in the Grand Wash parcel of PARA-NPS, where it is as much as 100 m (330 ft) thick and composed of dark reddish-brown sandstone, siltstone, limestone, and conglomerate (Beard et al. in press). Outcrops are also present in nearby areas of PARA-BLM (Billingsley and Wellmeyer 2003). The lower division is composed of conglomerate and sandstone with some mudstone and siltstone. The middle division is a cliff-forming limestone. Finally, the upper division includes siltstone, sandstone, and silty to sandy limestone (Beus 2003b). The formation was deposited a few million years after the Redwall Limestone, and dates to the end of the Mississippian (Beus 2003b). The upper contact with the Watahomigi Formation is disconformable (Beus 1989).

The Surprise Canyon Formation forms a dendritic drainage system that can be traced through the Grand Canyon. Flow moved from east to west. The three divisions of the formation formed under different conditions. In general, the lower sandstone/conglomerate division is interpreted as fluvial, the middle limestone division is interpreted as estuarine, and the upper silty division is interpreted as including restricted marine and tidal flat settings. It is possible that the eastern region was fluvial during its entire deposition. An alternate paleoenvironmental interpretation for the entire formation is as a more widespread shallow sea. This would be more consistent with the distribution of some of the marine fossils, but is not favored (Beus 2003b).

Fossils found within PARA: The Surprise Canyon Formation is not known to be fossiliferous in PARA, but it is fossiliferous elsewhere. If the few outcrops within PARA were visited, they would likely prove to have numerous fossils.

Fossils found elsewhere: Fossils of the Surprise Canyon Formation are found in all three of the above divisions (Beus 2003b), as well as in the ancient cave-fill (Billingsley et al. 1999; Santucci et al. 2001). Fossils in the lower division include palynomorphs, burrows, *Lepidodendron* logs in the sandstone, and other plants in the shale (such as ferns and the sphenopsid *Calamites*) (Beus 2003b). The most detailed description of the Surprise Canyon Formation plants is in Tidwell et al. (1992). The middle division has abundant fossils, including rugose and tabulate corals, bryozoans, brachiopods, bivalves, gastropods, scaphopods, ostracodes, trilobites, asteroids, blastoids, crinoids, conodonts, bone fragments, shark teeth, trace fossils, “algae”, and foraminifera (Billingsley and McKee 1982; Beus 1999, 2003b). The upper division has a smaller aquatic assemblage, including brachiopods, bivalves (Billingsley and McKee 1982), ostracodes, conodonts, stromatolites (Beus 2003b), “algae”, and foraminifera (Billingsley and McKee 1982). Fishes from the formation are described in Hodnett and Elliott (2018, 2020). Marine fossils are also known from the Surprise

Canyon Formation cave-fill deposits (Billingsley and Beus 1985). Reworked fossiliferous chert and limestone cobbles from the Redwall Limestone may also be found in the Surprise Canyon Formation (Billingsley and Beus 1985).

Callville/Supai interval (Upper Mississippian–Pennsylvanian)

Description: The interval of rocks between the Redwall Limestone and Toroweap Formation in western PARA is complex and has been described under different names. The difficulty with these rocks arises because the Grand Wash part of PARA is within a transition zone between dominantly coastal and eolian terrestrial rocks on the east (the Grand Canyon), represented by beds of sandstone and siltstone, and dominantly marine rocks on the west (Nevada), represented by limestone and dolomite. The eastern rocks are described as the Supai Group, including in ascending order the Watahomigi Formation, Manakacha Formation, Wescogame Formation, and Esplanade Sandstone. The western rocks are described as the Callville Formation and the overlying Pakoon Limestone. Assigning names and placing contacts are matters of personal judgement, and geologic maps frequently employ one or more lumped units. For example, Beard et al. (in press) map the rocks in question as an undivided "Supai Group, Callville Formation, and Pakoon Limestone" unit. This section of the report includes records from the Callville Formation and undifferentiated lower Supai Group rocks, representing an uppermost Mississippian to Pennsylvanian interval. For records attributed to one of the Watahomigi, Manakacha, and Wescogame Formations of the Supai Group, each unit has a separate section below. The Pakoon Limestone and Esplanade Sandstone are also treated separately.

The undivided Callville/Supai interval is about 200 m (660 ft) thick in the western PARA area, and is composed of dark- to medium-gray cherty limestone, sandstone, and sandy dolomite, intertonguing with reddish and brownish sandstone and siltstone (Figure 9). The dark carbonates represent the Callville Formation and the red beds represent the Supai Group. The upper contact with the Pakoon Limestone is gradational (Beard et al. in press). These rocks range in age from the Late Mississippian to the end of the Pennsylvanian (Beard et al. in press), about 330 to 300 Ma. Foraminifera spanning the entire Pennsylvanian have been found in LAKE (Beus 1979).

An additional unit, the Bird Spring Formation named from the Goodsprings region of Nevada, is sometimes used in the PARA area (e.g., Bohannon 1992, Lucchitta et al. 1995a), especially where there is little of the Supai Group to allow the Callville Formation and Pakoon Limestone to be distinguished. The Bird Spring Formation is regarded as correlative to the Callville Formation and Pakoon Limestone, at least in part (Fisher and Sorauf 1962; Bissell 1969).



Figure 9. An example of limestone (light-colored, lower in section) meeting cross-bedded sandstone (orange-brown, higher in section) in the undivided Supai Group, PARA-BLM (NPS/2020 FIELD INVENTORY).

Fossils found within PARA-NPS: Schenk (1938) reported the presence of corals, brachiopods, and crinoids from Pennsylvanian rocks in the Grand Wash Canyon north of the Colorado River (here attributed to the Grand Wash parcel of PARA-NPS). These are presumably part of the Callville/Pakoon fossils in LAKE collections, documented in Bonde et al. (2018). Schenk's upper Paleozoic collections were not studied again until the 1960s, when they were sent to the USGS for identification, as documented in a series of internal USGS memos. Of the Pennsylvanian fossils recovered from the Grand Wash parcel, identifications were provided for several taxa of corals (W. Sando, USGS, pers. comm. to LAKE, October 1963), brachiopods (R. Grant, USGS, pers. comm. to

LAKE, October 1963), bivalves, gastropods, scaphopods (E. Yochelson, USGS, pers. comm. to LAKE, October 1963), trilobites, crinoids, and echinoids (R. Grant, USGS, pers. comm. to LAKE, October 1963); the collection also includes nautiloids and undetermined cephalopods and echinoderms.

Fossils found within PARA-BLM: Sponges (Brill 1963; Pierce 1979), rugose corals (McNair 1951), brachiopods (McNair 1951; Pierce 1979), conodonts (Pierce 1979), and foraminifera (McNair 1951; Brill 1963; Pierce 1979) have been reported in the Callville Formation in PARA-BLM. Longwell (1928) reported bryozoans and brachiopods from the lower Grand Wash apparently in PARA-BLM. The 2020 field inventory reported rugose and unidentified corals, bryozoans, brachiopods, gastropods, crinoids, echinoids, possible microbially induced sedimentary structures, invertebrate burrows, and undetermined fossils from undivided Supai Group locations in PARA-BLM.

Fossils found elsewhere: The units of the Supai Group are fossiliferous at PARA and adjacent areas (see below sections), and the Callville Formation contains abundant fossils just outside of PARA. Fossils from the Callville/Supai interval at LAKE include plants (*Walchia* sp.), corals, bryozoans, brachiopods, bivalves, ammonoids, gastropods, scaphopods, crinoids, echinoids, trilobites, conodonts, cochliodont shark teeth (*Cladodus* sp., *Deltodus* sp.), invertebrate burrows, and foraminifera (McKee and Gutschick 1969; Beus 1979; McKee 1982b, 1982c; Ritter 1991).

Supai Group: Watahomigi Formation (Upper Mississippian–Middle Pennsylvanian)

Description: The Supai Group was recognized for many years as a formation-level unit in the Grand Canyon region. It was divided into four formations in 1975. In ascending order, these are the Watahomigi Formation, Manakacha Formation, Wescogame Formation, and Esplanade Sandstone (McKee 1975). The lower three units are not differentiated on the maps used for this project; the undivided lower Supai Group is widely exposed on Grand Wash Cliff and within Parashant Canyon in PARA. The Watahomigi Formation in the PARA area is composed of gray and purplish-red limestone, siltstone, mudstone, and conglomerate. The lower part consists of limestone over a mudstone/siltstone interval, and the upper part is composed of alternating limestone ledges and mudstone/siltstone slopes (Billingsley and Wellmeyer 2003). The formation is 30 to 60 m (100 to 200 ft) thick in this area, thickening to the west. Most of it is Pennsylvanian, but Upper Mississippian beds are present at the base (Billingsley and Wellmeyer 2003). The Watahomigi Formation was deposited after a short hiatus following the Surprise Canyon Formation (Beus 1989). The upper contact with the Manakacha Formation is unconformable (Billingsley and Wellmeyer 2003).

The Supai Group as a whole is thought of as representing deposition on a broad coastal plain, over which the sea advanced from the west and retreated several times. The four formations represent different stages of several transgressive-regressive cycles, with depositional settings shifting between continental and shallow marine (Blakey 2003). The Watahomigi Formation is interpreted as a shoreline unit, deposited in shallow marine to coastal plain settings (Blakey and Knepp 1989) during a marine transgression (McKee 1982d). During the Early Pennsylvanian, a sea was present west of the modern Little Colorado River, which expanded to the east during the early Middle Pennsylvanian (McKee 1982a). Fossils in the Watahomigi Formation suggest low energy conditions (McKee

1982c), but possibly too energetic or with too great an influx of sand and silt for extensive coral growth (Gordon 1982).

Fossils found within PARA-NPS: McKee's sections within PARA-NPS included fossils of tabulate corals, bryozoans, brachiopods, bivalves, gastropods, trilobites, echinoderm fragments, the cartilaginous fish *Deltodus*, and foraminifera (Gordon 1982; McKee 1982b, 1982c). The GRCA museum collection also contains "fucoidal structures" (probably invertebrate trace fossils) and fossil molds probably derived from the Watahomigi Formation of PARA-NPS.

Fossils found within PARA-BLM: McKee's sections within PARA-BLM included fossils of corals, bryozoans, brachiopods, bivalves, gastropods, trilobites, crinoids, echinoids, undetermined echinoderms, conodonts, stromatolites, "algae" and possible "algae", foraminifera, and unspecified fossils (Gordon 1982; McKee 1982b, 1982c).

Fossils found elsewhere: The Watahomigi Formation is the most fossiliferous of the four formations of the Supai Group, with abundant marine fossils in limestone beds (Beus and Billingsley 1989). Fossils known from the Watahomigi Formation in the Grand Canyon area that have not yet been reported from PARA include the early plants *Calamites*, *Cordaites*, *Neuropteris*, and *Taeniopteris*, the conifer *Walchia*, invertebrates such as conulariids, nautiloids, and rostroconchs, and trace fossils such as worm borings and possible microbially induced sedimentary structures identified as *Rivularites* (Gordon 1982; McKee 1982c). Additionally, corals from the Redwall Limestone are sometimes found reworked into the Supai Group (Sando 1969).

Supai Group: Manakacha Formation (Middle Pennsylvanian)

Description: The Manakacha Formation in the region of the PARA-NPS Parashant Canyon parcel is a red, white, and gray unit composed of an upper slope of shaley siltstone and mudstone and a lower cliff of cross-bedded sandstone, dolomite, and sandy limestone. It averages about 55 m (180 ft) thick (Billingsley and Wellmeyer 2003). Carbonates are prominent in the western Grand Canyon, grading to mudstone and sandstone going east. The top of the unit, the contact with the Wescogame Formation, is unconformable and distinguished by a widely recognized channeled surface (McKee 1982e). The Manakacha Formation dates to the early Middle Pennsylvanian (Blakey 2003).

The Manakacha Formation was initially interpreted as a dominantly marine formation (McKee 1982d), representing marine shelf to open marine environments (Blakey and Knepp 1989). More recently, it has been interpreted as dominantly terrestrial with significant eolian influence (Blakey 2003; Rowland et al. 2020). Eolian deposition began encroaching from the north into the area that had been submerged by the marine transgression of the Watahomigi Formation (Blakey 2003).

Fossils found within PARA-NPS: The Manakacha Formation is sparsely fossiliferous, but it is fossiliferous within PARA, mostly within PARA-BLM. Fossils from PARA-NPS include specimens of the conifer *Walchia* (McKee 1982b, 1982c), bioturbation (Johansen 1981), whole foraminifera, and sand-sized fragments of bryozoans, brachiopod or bivalves, pelmatozoans, and foraminifera (McKee 1982c).

Fossils found within PARA-BLM: These include tabulate and rugose corals, bryozoans, brachiopods, bivalves, nautiloids, gastropods, trilobites, crinoids, echinoids, stromatolites, and foraminifera (McKee 1982b, 1982c).

Fossils found elsewhere: The overall fossil record of the Manakacha Formation is very similar to that of PARA. In the Grand Canyon area, the red mudstone has yielded additional land plant fossils including stems and ferns (McKee 1982c), and tetrapod tracks have been described from GRCA (Rowland et al. 2020). Invertebrate trace fossils (Blakey 2003) and fragments of *Girvanella*-like microbial structures (McKee 1982c) have also been reported.

Supai Group: Wescogame Formation (Upper Pennsylvanian)

Description: The Wescogame Formation of the PARA region is composed of an upper slope of dark red siltstone and mudstone and light red sandstone, and a lower cliff of light red to gray cross-bedded sandstone, with local limestones in channels eroded into the Manakacha Formation. It is 40 to 64 m (130 to 210 ft) thick. The upper contact with the Esplanade Sandstone is also a channeled unconformity (Billingsley and Wellmeyer 2003). It is the most complex of the Supai Group formations, with large changes in rock types over short distances (Blakey and Knepp 1989). This formation dates to the end of the Late Pennsylvanian (Blakey 2003). The Wescogame Formation is interpreted as mostly eolian, representing one or more large dune fields (Blakey 2003). Fluvial, coastal plain, shoreline, shelf, and open marine settings are also probably represented in its various rock types (Blakey and Knepp 1989).

Fossils found within PARA-NPS: Fossils again are sparse in this formation, and most of those in PARA have been reported from PARA-BLM localities. Fossils reported from PARA-NPS include bioturbation, possible "algal" structures (Johansen 1981), foraminifera probably reworked from the Manakacha Formation, and fragments of marine fossils such as brachiopods or bivalves, pelmatozoans, and foraminifera (McKee 1982c).

Fossils found within PARA-BLM: These include tabulate and rugose corals, gastropods, crinoids, the cartilaginous fish *Deltodus*, foraminifera, and fragments of marine fossils such as bryozoans, brachiopods or bivalves, and pelmatozoans (McKee 1982c).

There is a locality in the Supai Group of PARA-BLM where a block heavily marked by ichnofossils (*Psammichnites* isp.) has been observed (see cover photo and "Ichnofossils" below). The stratigraphy of this locality is unsettled. As reported in Tweet et al. (2016), although the traces resemble some found in the middle sandstone of the Surprise Canyon Formation, the host lithology and the limited distribution of the Surprise Canyon Formation indicate that the traces are most likely in the lower Watahomigi Formation (G. Billingsley, U.S. Geological Survey emeritus, pers. comm. to V. Santucci, March 2013). The 2020 field team revisited the site and suggested that it is actually in the upper lower Supai Group (tentatively Wescogame Formation). They also observed stratigraphically higher fossiliferous limestone with bryozoans, brachiopods, crinoids, echinoids, undetermined invertebrate fossils, and possible stromatolites. Based on the lithology and position, these higher fossils may pertain to the Pakoon Limestone. A higher position in the Supai/carbonate sequence would be more consistent with the geologic map of the area (Billingsley and Wellmeyer 2003).

Fossils found elsewhere: Other types of fossils reported from the Wescogame Formation include land plants (possibly ferns or cycads), bivalves, and trace fossils of invertebrates and tetrapods (McKee 1982c). Marine fossils are mostly known from the western carbonate rocks (McKee 1982d).

Pakoon Limestone (lower Permian)

Description: The Pakoon Limestone of PARA is a medium- or light-gray dolomitic unit with white to light gray gypsum beds (Figure 10). It is about 70 m (230 ft) thick at Wheeler Ridge in eastern LAKE (Beard et al. in press) and thins to the east, with a thin wedge present as far east as Whitmore Wash (Billingsley 1997c). The Pakoon Limestone intertongues laterally with the lower Esplanade Sandstone on the east, and also intertongues with the overlying upper Esplanade (Beard et al. in press). The Pakoon Limestone was designated from what had been the upper Callville Formation (McNair 1951), and it is not always recognized as distinct. For example, Longwell et al. (1965) regarded it as the upper part of the Callville Formation. It was named after Pakoon Ridge/Cockscomb in western PARA-BLM. (Confusingly, there is another Cockscomb in PARA, located in the Grand Wash parcel of PARA-NPS.) The formation is not mapped on the central part of the ridge itself (Billingsley and Wellmeyer 2003), but is exposed in a large area just west of the spine of Pakoon Cockscomb (Beard et al. 2007).

The Pakoon Limestone is a marine formation (Blakey and Knepp 1989). Deposition occurred during the earliest part of the Permian (Beus 1979; Pierce 1979).



Figure 10. Boulders of eroded Pakoon Limestone with Stephanie Wallace for scale, PARA-NPS (NPS/2020 FIELD INVENTORY).

Fossils found within PARA-NPS: Although the Pakoon Limestone is noted as a fossil-producing unit, and there are several localities documented in PARA-BLM (see below), until the 2020 field inventory there had been no documentation of Pakoon Limestone fossils in PARA-NPS. Fossils observed in 2020 include probable sponges, corals, bryozoans, brachiopods, possible gastropods, crinoids, echinoids, and undetermined invertebrate fossils. These and the abundant fossils observed in PARA-BLM show the paleontological potential in PARA for this formation, which has been relatively overlooked compared to units above, below, and equivalent to it on the east.

McKee (1982c) reported sand-sized fragments of bryozoans, brachiopods or bivalves, pelmatozoans, and foraminifera from undivided Pakoon–Esplanade rocks at PARA-NPS localities.

Fossils found within PARA-BLM: Similar fossils are known from localities in PARA-BLM. Fossils reported in the literature include tabulate corals (McKee 1979, 1982b, 1982c), rugose corals (Hill 1914; McKee 1982b, 1982c), bryozoans (McKee 1982b, 1982c), brachiopods (Hill 1914; McKee 1982b), gastropods (Hill 1914), crinoids (McKee 1982b), echinoids (Hill 1914; McKee 1982b), possible "algal" laminations (Johansen 1981), foraminifera (Brill 1963; Pierce 1979; McKee 1979, 1982b), and undetermined fossils (McKee 1982b). The 2020 field inventory recorded examples of almost all of these types of fossils, as well as possible scaphopods, undetermined invertebrate fossils, possible stromatolites, and invertebrate burrows.

McKee (1982c) reported sand-sized fragments of corals, bryozoans, brachiopods or bivalves, pelmatozoans, and foraminifera from undivided Pakoon–Esplanade rocks in PARA-BLM localities.

Fossils found elsewhere: The only type of Pakoon Limestone fossil found in the literature but not yet reported from PARA is fish teeth (McKee 1982b, 1982c). Corals and foraminifera are the most abundant forms in the formation (McKee 1982c). Of note, mollusks do not appear to have been a major part of the Pakoon Limestone assemblage, compared to several of the other Paleozoic marine limestones known from PARA (e.g., the Watahomigi Formation limestones, Toroweap Formation, and Kaibab Formation).

Supai Group: Esplanade Sandstone (lower Permian)

Description: The Esplanade Sandstone of western PARA is composed of white to pinkish or reddish fine- to medium-grained cross-bedded sandstone. It grades vertically into the overlying Hermit Formation and is about 60 to 80 m (200 to 260 ft) thick (Beard et al. in press). At the Tassi Cockscomb in PARA-NPS, the Hermit and Esplanade interfinger to a great extent. It is hard to distinguish the two formations (Figure 11) (Weeks, pers. obs.). In the Parashant Canyon parcel of PARA-NPS, it includes a distinct upper cliff and slope, middle cliff, and lower slope, it is closer to 167 m (550 ft) thick, and the upper contact with the Hermit Formation is unconformable (Billingsley and Wellmeyer 2003). The color of the formation can be bright orange here (Flora and Weeks, pers. obs.) (Figure 12).



Figure 11. Esplanade Sandstone on the left transitions into the dark red recessive beds of the Hermit Formation (center) below a more resistant ridge of Permian carbonates on the right, PARA-NPS (NPS/2020 FIELD INVENTORY).



Figure 12. An outcrop of the Esplanade Sandstone, PARA-NPS (NPS/2020 FIELD INVENTORY).

The Esplanade Sandstone was initially interpreted as mostly high-energy marine sandstone with more terrestrial beds at the top and bottom (McKee 1979, 1982d; Blakey and Knepp 1989). More

recently it has been described as an eolian unit (Beus and Billingsley 1989; Blakey 2003), part of a large coastal plain (Blakey 2003). Sediment came from the north or northwest (McNair 1951) and marine influence increased going west, as evidenced by the change into the Pakoon Limestone (McKee 1982d). The base was probably less eolian than the rest of the unit (Blakey 2003). Some evaporite deposition is also present (Blakey 2003). The age of the sandstone is not clear, because of sparse fossils, but it is equivalent in part to the intertonguing Pakoon Limestone (McKee 1982a).

Fossils found within PARA-NPS: The Esplanade Sandstone is sparsely fossiliferous, but there are a few reports of fossils from PARA-NPS, including stromatolites (McKee 1982c), bioturbation (Johansen 1981), possible "algal" limestone (McKee 1982b), invertebrate burrows (2020 field inventory), foraminifera (McKee 1979, 1982c), and fragments of unidentified marine fossils (McKee 1982c).

Fossils found within PARA-BLM: PARA-BLM has examples of the conifer *Walchia*, plant stems, possible microbially induced sedimentary structures identified as *Rivularites*, invertebrate burrows, and fragments of unidentified marine fossils (McKee 1982c). A locality in northern PARA-BLM, attributed to the problematic Queantoweap Sandstone, includes burrows (Johansen 1981). The Queantoweap Sandstone name is used in northwestern Arizona and nearby areas for sandstone that overlies the Pakoon Limestone but does not intertongue with it, meaning it is partially equivalent to the Esplanade Sandstone (Johansen 1981; Billingsley 1997c). The Queantoweap Sandstone as it is used is not the same as it was defined in McNair (1951): the name has become disassociated from its type section (Billingsley 1997c; Billingsley and Workman 2000), and the type section, at Paws Pocket in the PARA-NPS/PARA-STATE part of Whitmore Wash, is in part the Esplanade Sandstone (Johansen 1981).

Fossils found within PARA-STATE: Invertebrate burrows were observed on state land in PARA during the 2020 field inventory.

Fossils found elsewhere: Types of fossils found in the Esplanade Sandstone but not yet known from PARA include horseshoe-shaped tracks (McKee 1982c) and tetrapod trackways (S. Rowland, University of Nevada–Las Vegas, pers. comm., March 2016).

Hermit Formation (lower Permian)

Description: The Hermit Formation, also known as the Hermit Shale, is a red bed unit best known from the Grand Canyon. In the PARA area, it is a slope-forming unit of thinly interbedded siltstone and sandstone, from 213 m (700 ft) thick in the east to as much as 260 m (860 ft) thick along the Grand Wash Cliffs (Billingsley and Wellmeyer 2003). Flora and Weeks (pers. obs.) found it to consist of bright red sandy shale, with some friable silty shale in the upper part of the formation, as well as fine-grained sandy beds (Figure 11). At the Tassi Cockscomb, the Hermit Formation consisted almost entirely of red and white-tan sandstones and sandy siltstones (Weeks, pers. obs.). The upper contact with the Coconino Sandstone is disconformable (Billingsley and Wellmeyer 2003). The Hermit Formation is interpreted as primarily a low-energy fluvial unit, deposited across a broad coastal plain (Blakey 2003). The climate was probably semi-arid, with long hot dry seasons (White 1929). Deposition occurred during the late early Permian (Blakey 1990).

Fossils found within PARA-NPS: The Hermit Formation is fossiliferous within PARA, although there is some question about localities. McKee collected Hermit Formation plant fossils from an area that includes both PARA-NPS and PARA-BLM (McKee 1937a; Schenk 1938). Based on the overall stratigraphic profile of specimens from his collection, which includes multiple formations, and McKee's description of his field season (McKee 1937a), it is most likely that the Hermit Formation specimens originated from PARA-NPS. The Hermit Formation specimens are in GRCA collections and include the seed ferns *Callipteris* (now *Autunia*) *conferta*, *Gigantopteris americana*, *Supaia thinnfeldioides*, *Supaia* sp., and undetermined plants, plus *Rivularites* (originally described as algal, now classified as a microbially induced sedimentary structure). Possible plant fossils and invertebrate burrows were observed in PARA-NPS during the 2020 field inventory.

Poorly preserved plant fossils are present in siltstone beds in the lower Hermit Formation along the Grand Wash Cliffs (Billingsley and Wellmeyer 2003), potentially in either PARA-NPS or PARA-BLM.

Fossils found within PARA-BLM: Invertebrate burrows were observed during the 2020 field inventory.

Fossils found elsewhere: The Hermit Formation is best known for plant fossils (see White 1929, Spamer 1992, and Knight 2020 for summaries) and vertebrate tracks (see Gilmore 1927, Gilmore 1928, and Marchetti et al. 2020 for summaries), although invertebrate traces are also common (Miller et al. 2020). The Hermit Formation tetrapod track record is extensive. Most of the tetrapod tracks were described by Gilmore (1927, 1928). They attracted little scientific attention for many years, during which time it became clear that many of the genera and species were probably synonyms (Spamer 1984). Invertebrate fossils recovered from the Hermit Formation include an impression perhaps of a crustacean or eurypterid (White 1929), meganeurid wings, a now-lost partial fossil of a true dragonfly, and a possible blattoid wing (Spamer 1984). Seed ferns and conifers were the main elements of the flora, with the seed fern *Supaia* the dominant genus (White 1929). Plant fossils are most common near the base of the unit (Beus and Billingsley 1989).

Coconino Sandstone (lower Permian)

Description: The Coconino Sandstone is found in eastern PARA, where it consists of tan to white cross-bedded, cliff-forming, fine-grained quartz sandstone (Figure 13). It is up to 47 m (155 ft) thick in the eastern PARA area but pinches out going west across the monument. The upper beds intertongue with the overlying Toroweap Formation (Billingsley and Wellmeyer 2003). Beard et al. (in press) reported lenses of white to buff medium- to coarse-grained quartz sandstone probably equivalent to the Coconino Sandstone at the base of the Toroweap Formation, up to 15 m (50 ft) thick, forming a ledge. The Coconino Sandstone is interpreted as an eolian unit formed as a dune field (Hunt et al. 2005). Sand was deposited by wind action (Blakey and Knepp 1989), and dune sands advanced from the north (Schuchert 1918; McNair 1951). The setting has been described as like the modern Sahara Desert (Morales 1995). The age of the formation is not known directly, but it is bracketed by early Permian units (Blakey and Knepp 1989).



Figure 13. A ledge of Coconino Sandstone, PARA-BLM (NPS/2020 FIELD INVENTORY).

Fossils found within PARA: There is currently one record of potential Coconino Sandstone fossils in PARA. GRCA museum collection records list two specimens, GRCA 5899 and 6541, collected by McKee apparently during the same season as the Hermit Formation fossils discussed above. The specimens are described as gray quartz-rich limestone with molds of mollusk shells and attributed to Bed 4 of the Coconino Sandstone. Photos of the specimens indicate that GRCA 5899 is more accurately described as a reddish sandstone, but both specimens do include mm-scale "eyelashes" representing small shells in cross-section (especially GRCA 6541; Figure 14). If the stratigraphy is accurate, they would be the first record of body fossils in the Coconino Sandstone. Potentially they could represent fossils from an oasis lacustrine setting. Alternatively, Schleh (1966) found the contact of the Coconino Sandstone and Toroweap Formation to be arbitrary in the area McKee was working, and Billingsley et al. (2000) described the Coconino Sandstone there as rather thin (only up to 6 m or 20 ft thick) and intertongued with the lower Seligman Member of the Toroweap Formation. The Seligman Member is not known for its fossils, but McKee (1938) reported "a few poorly preserved mollusks" from a limestone bed in this member 0.3 m (1 ft) above the Coconino Sandstone at Fossil Mountain. With these considerations in mind, it is possible that the two specimens are actually from a tongue of the lower Toroweap Formation. As with the Hermit Formation specimens discussed above, these two specimens may have come from PARA-NPS or PARA-BLM, but they are tentatively accepted as PARA-NPS.

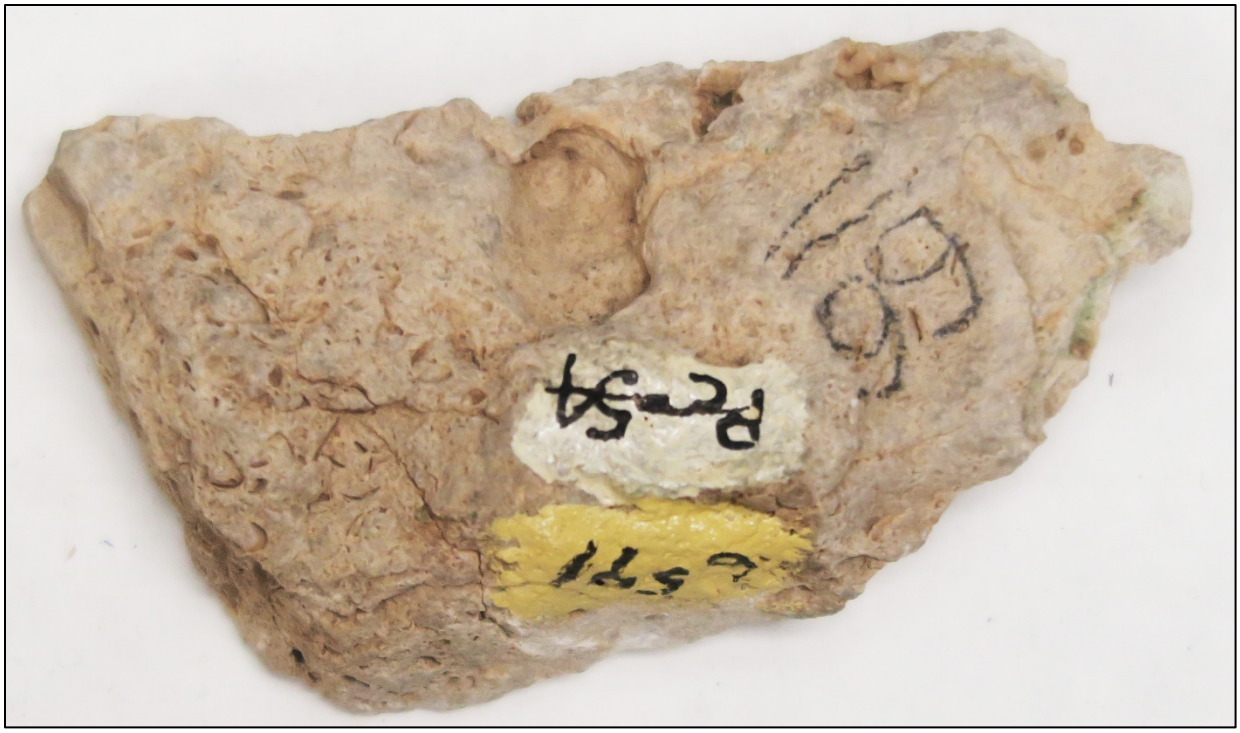


Figure 14. GRCA 6541, described as a piece of limestone from the Coconino Sandstone (NPS/KIM BESOM). Linear to gently curved voids on the left side are indicative of molds of small shells.

Fossils found elsewhere: The only fossils definitely known from the Coconino Sandstone are trace fossils (Spamer 1984). Vertebrate tracks produced by several varieties of anamniotes, synapsids, and reptiles have been found; the taxonomy has been volatile, with the most recent summary in Marchetti et al. (2020). Invertebrate traces are also known at GRCA, including traces possibly made by worms, millipedes, isopods, spiders, scorpions, and insects (Miller et al. 2020). The most abundant invertebrate ichnofossil is *Paleohelcura*, a possible scorpion track (Brady 1939). The animal tracks in the Coconino Sandstone were probably made on dry sediments that were then moistened and covered by windblown dry sand before the sediments and tracks again dried out, or on dunes dampened by moisture (Brady 1939; McKee 1944).

Toroweap Formation (lower Permian)

Description: The Toroweap Formation is one of the more widespread and well-exposed formations of PARA. The Toroweap Formation is sometimes mapped undivided with the overlying Kaibab Formation in the PARA-NPS area, and before the Toroweap Formation was described, its rocks were included in the Kaibab Formation (e.g., Longwell 1921, 1928; Schenk 1938). It is divisible into three members, in ascending order the Seligman, Brady Canyon, and Woods Ranch Members; these correlate to the old informal gamma, beta, and alpha members, respectively (Sorauf and Billingsley 1991). In the PARA area, the Toroweap Formation is a heterogeneous unit of dolomite, limestone, sandstone, siltstone, and gypsum. The Seligman Member is a recessive, variegated unit of dolomite, sandstone, siltstone, and gypsum, with some tongues of the Coconino Sandstone in the lower part. It thickens going north, and is 8 to 50 m (30 to 160 ft) thick. The contact with the overlying Brady

Canyon Member is gradational. The Brady Canyon Member forms a gray cliff of fossiliferous limestone, with some dolomite in the upper and lower portions (Figure 15). It thickens from east to west, from about 40 m (130 ft) to about 137 m (450 ft), and grades into the overlying Woods Ranch Member. The Woods Ranch Member is another recessive unit, forming a slope of gray to red gypsum-rich siltstone, silty sandstone, siltstone, gypsum, and limestone. The upper contact with the Kaibab Formation is disconformable, so the thickness of the member varies because of Permian erosion. It can be up to 110 m (360 ft) thick in the area of PARA (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003). The upper unconformity includes paleo-channel erosion 45 m (145 ft) deep and 2 km (1.2 mi) across (Billingsley and Wellmeyer 2003).



Figure 15. A cliff-forming outcrop of the Brady Canyon Member of the Toroweap Formation with Holley Flora for scale, PARA-BLM (NPS/2020 FIELD INVENTORY).

The Toroweap Formation formed during a transgression-regression cycle, with the Seligman Member as the early part of the transgression, the Brady Canyon Member as the maximum transgression, and the Woods Ranch Member as the regressive phase (Rawson and Turner 1974). In the Grand Canyon area, the Seligman Member is interpreted as a combination of tidal flat, subaqueous evaporite, and eolian settings, varying with sea level. The Brady Canyon Member is interpreted as a low-energy open marine to shallower water carbonate. The Woods Ranch Member is interpreted as a shallow evaporitic marine shelf. The climate during deposition of the Toroweap Formation is thought to have been semi-arid to arid (Turner 1990). Deposition occurred during the latter part of the early Permian (Blakey 1990).

Fossils found within PARA-NPS: There are no detailed records of fossils from the Toroweap Formation of PARA-NPS. Longwell (1928) reported a small assemblage of bryozoans, brachiopods, and echinoids from the Kaibab Formation at a location that can be placed in PARA-NPS. Because the Toroweap Formation had not yet been distinguished from the Kaibab Formation at the time of the report, it is not possible to rule out that some of these fossils came from what would now be called the Toroweap Formation.

Fossils found within PARA-BLM: The Brady Canyon Member within PARA-BLM has yielded bryozoans, brachiopods, bivalves (Schleh 1966; Sorauf and Billingsley 1991), nautiloids, gastropods (Schleh 1966), crinoids (McNair 1951; Schleh 1966; Sorauf and Billingsley 1991), echinoids (Schleh 1966; Sorauf and Billingsley 1991), echinoderm debris (Sorauf and Billingsley 1991), undetermined invertebrate fossils, and invertebrate burrows (2020 field inventory). Petrified wood was also observed during the field inventory, but the best specimen was not found in situ and could have derived from another formation. (It should be noted that it is certainly not impossible for petrified wood to have ended up in the Toroweap Formation, originating as wood that washed into the marine environment.) Near the top of the Woods Ranch Member there is a persistent shell bed of the bivalve *Schizodus* about 0.45 m (1.5 ft) thick (Schleh 1966).

Fossils found elsewhere: Almost all fossils in the Toroweap Formation are from the Brady Canyon Member. The only fossils reported from the Woods Ranch Member are brachiopods (Spamer 1992), the *Schizodus* bed, and stromatolites (Rawson and Turner 1974), and the only fossils reported from the Seligman Member are poorly preserved mollusks (McKee 1938). Fossil groups known from the Brady Canyon Member but not yet reported from PARA include sponges (Rigby 1988), corals, scaphopods (Rawson and Turner 1974), ostracodes (McKee 1938), foraminifera (Rawson and Turner 1974), and unspecified "algae" (Spamer 1992). Possible fish teeth and scales have been recovered from an unspecified member (Mullens 1967). Brady Canyon Member fossils are divided among two main assemblages. The open marine western assemblage has corals, bryozoans, brachiopods, and crinoids, while the eastern restricted marine "molluscan" assemblage has bivalves and gastropods, with a few cephalopods and scaphopods (Rawson and Turner 1974).

Kaibab Formation (lower Permian)

Description: The Kaibab Formation (or Limestone) is widely exposed in PARA, where it forms the rim and upper surface of the highest plateau north of the Grand Canyon (Figure 16). It is divisible into the Fossil Mountain and overlying Harrisburg members (Beard et al. in press). Early workers in the Kaibab Formation divided it into the gamma, beta, and alpha members (McKee 1938), which have since been subsumed into the modern members. The Fossil Mountain Member is the equivalent of the gamma and beta members, and the Harrisburg Member is the equivalent of the alpha member (Blakey and Knepp 1989). In the PARA area, the Fossil Mountain Member is a light gray cliff-forming unit of sandy fossiliferous cherty limestone, notable for forming the cliff rim of the Grand Canyon. It is 70 to 120 m (240 to 385 ft) thick, and the upper contact with the Harrisburg Member is gradational. The Harrisburg Member is a heterogeneous unit of white or gray to reddish limestone, gypsum, sandstone, and siltstone. It includes an upper and lower slope sandwiching a cliff. The upper contact with the Moenkopi Formation is disconformable, and locally the Harrisburg Member has

been entirely lost to pre-Moenkopi erosion. It can be as much as 107 m (350 ft) thick in the region (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003).



Figure 16. A Kaibab Formation cliff (Fossil Mountain Member), PARA-NPS (NPS/2020 FIELD INVENTORY).

The Kaibab Formation formed in a variety of marine settings (McKee 1938). The Fossil Mountain Member is interpreted as primarily representing a shallow marine setting, and the Harrisburg Member is interpreted as a shallow marine to evaporitic depositional setting (Jenson 1986). The sea transgressed from west to east, transgressing and regressing several times during deposition of the Fossil Mountain Member, and then regressing during deposition of the Harrisburg Member (Blakey and Knepp 1989). Historically there has been uncertainty about whether the formation dates to the late early Permian or the early middle Permian; late early Permian is preferred here for consistency with the geologic maps.

Distinguishing between Kaibab Formation members in the field was based on the presence or absence of gypsum, how cliff-forming the outcrop was, the distribution of fossils, and the abundance of siliceous clastic material. The Fossil Mountain Member is cliff-forming and most of its beds contain some fossils. The Harrisburg Member forms slopes, contains large gypsum beds, and has a higher concentration of silt and sand. The fossils of the Harrisburg Member also seem to be more localized to specific beds, with some unfossiliferous beds. Also, although both members have chert, it seems that the Fossil Mountain Member contains more of it.

Fossils found within PARA-NPS: Prior to the 2020 field inventory, information about Kaibab Formation fossils within PARA-NPS was very limited. The 2020 field inventory documented a diverse assemblage of sponges, rugose corals, bryozoans, brachiopods, possible scaphopods, crinoids, echinoids, undetermined invertebrate fossils, possible stromatolites, and fossils of undetermined origin.

Fossils found within PARA-BLM: Several Kaibab Formation localities in PARA-BLM have been documented in the literature (Longwell 1928; McNair 1951; Schleh 1966; Sorauf and Billingsley 1991). Fossils reported from the Fossil Mountain Member of PARA-BLM include sponges in chert, rugose corals, bryozoans, brachiopods, bivalves, crinoids, echinoids, and rare gastropods and trilobites (Schleh 1966; Sorauf and Billingsley 1991). Fossils reported from the Harrisburg Member include bryozoans, brachiopods, bivalves, gastropods, scaphopods, crinoids, echinoids, and invertebrate burrows (Schleh 1966). The 2020 field inventory almost completely corroborated these lists, with only trilobites and invertebrate burrows not observed. The field inventory also documented visually striking examples of mineral replacement, producing bright red and green fossils (Figures 17–19). The surficial texture of the replaced fossils may bear no resemblance to the original fossil (Figure 19). The red color resembles red agate varieties, and likely reflects a similar origin of silicification combined with iron-bearing fluids. The green mineral is thought to be malachite, known from the Kaibab Formation (McKee 1938).



Figure 17. Invertebrate fossils in this block have been replaced by red mineralization. Kaibab Formation, Harrisburg Member, PARA-BLM (NPS/2020 FIELD INVENTORY). For this and other images with this scale bar, the white and black squares are 1 cm (0.4 in) across, the minor tick marks are 1 mm (0.04 in), and the major tick marks, identified by numbers, are 10 mm (=1 cm; 0.4 in).



Figure 18. Examples of fossil replacement in the Kaibab Formation, PARA-BLM. In the lower left the void space of a shell has been filled with crystals and the outside is a thin red remineralized rind. The fossil in the left-center, which resembles a cidaroid echinoid body but lacks the typical plated structure, has had both red and green mineralization (NPS/2020 FIELD INVENTORY).

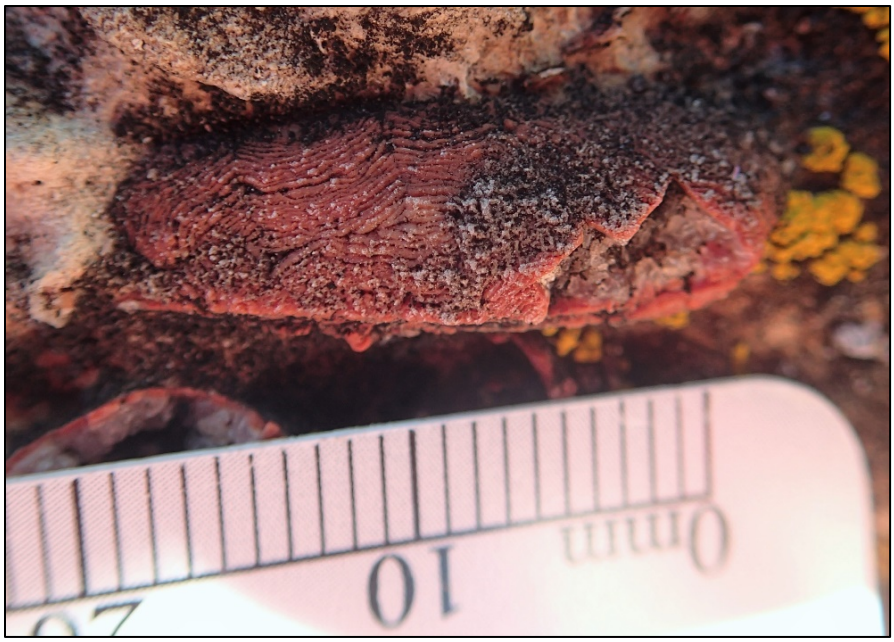


Figure 19. Replacement mineralization does not necessarily replicate original surface texture, as shown by the “woven” appearance of this bivalve. Kaibab Formation, PARA-BLM (NPS/2020 FIELD INVENTORY).

Fossils found elsewhere: Considering the Kaibab Formation over its entire area of deposition, the taxonomic list is extensive. Fossils found elsewhere in the Fossil Mountain Member but not yet in PARA include conulariids, cephalopods, scaphopods (Sorauf and Billingsley 1991; Spamer 1992), ostracodes, conodonts (Thompson 1995), teeth and other remains of cartilaginous and ray-finned fish (Thompson 1995; Hodnett and Elliott 2020), and invertebrate trace fossils (Spamer 1992). Fossils found elsewhere in the Harrisburg Member include cephalopods (Spamer 1992), worm tubes (Nicol 1944), conodonts (Clark 1979), shark teeth (Ossian 1976), "algae" (Billingsley and Workman 2000), and foraminifera (Spamer 1992). The most diverse assemblages of this member occur lower in section (Nicol 1944). The formation has distinct mollusk and open marine faunas (McKee 1938; Hopkins 1990). Kaibab Formation fossils may also be found in rock fragments incorporated into younger formations (McKee 1937b).

Moenkopi Formation (Lower–Middle Triassic)

Description: The Moenkopi Formation is a heterogeneous coastal plain and shallow marine unit present in several western states. It is preserved in a few locations in the PARA area where it is capped by Cenozoic volcanic rocks (Billingsley and Wellmeyer 2003), and is also exposed south of the Virgin Mountains in the northernmost part of PARA (Billingsley and Workman 2000). Almost all of the PARA outcrops are in PARA-BLM, but the formation is present in isolated areas of the Parashant Canyon parcel of PARA-NPS (Billingsley and Wellmeyer 2003).

In northwestern Arizona, the Moenkopi Formation is divided into six members. In ascending order (oldest to youngest) these are the Timpoweap, lower red, Virgin Limestone, middle red, Shnabkaib, and upper red members. The Timpoweap Member is a conglomeratic unit, becoming finer-grained going up, found in paleovalleys cut into the Kaibab Formation. The lower red member is a slope-forming unit composed of red mudstone with thin gypsum and sandstone beds (Figure 20). Above it, the Virgin Limestone Member is composed of light gray limestone with interbedded siltstone and gypsum (Figure 21). It is more resistant to erosion than the underlying and overlying units, and is locally fossiliferous. The middle red member is another dominantly red siltstone and mudstone unit. The Shnabkaib Member above it is quite variable, being composed mostly of light-colored dolomite and gypsum and red siltstone, with sandstone and mudstone beds (Figure 22). Finally, the upper red member is another red siltstone and sandstone unit (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003). The overall thickness of the Moenkopi Formation in PARA is as much as approximately 365 m (1,200 ft) (Billingsley and Wellmeyer 2003). The upper contact with the Chinle Formation is an unconformity known as the Tr-3 unconformity (Pipiringos and O'Sullivan 1978).



Figure 20. The contact of the lower red member and overlying Virgin Limestone Member, PARA-BLM (NPS/2020 FIELD INVENTORY).



Figure 21. The Virgin Limestone Member, exposed as both a flaggy “floor” and a low bluff, PARA-BLM (NPS/2020 FIELD INVENTORY).



Figure 22. The heterogenous Shnabkaib Member, PARA-BLM (NPS/2020 FIELD INVENTORY).

The alternating limestone/evaporite and red bed members of the Moenkopi Formation in the PARA area represent parts of three transgression-regression cycles. The Timpoweap Member was deposited during a marine highstand (Stewart et al. 1972a; Blakey et al. 1993), with an open sea west of the present-day Hurricane Cliffs and an alluvial plain to the east (Blakey 1979). The overlying lower red member is a coastal plain and tidal flat unit (Stewart et al. 1972a). It represents the regressive part of the transgression-regression cycle began in the Timpoweap Member (Stewart et al. 1972a; Blakey et al. 1993). The upper contact with the Virgin Limestone Member may be disconformable (McKee 1954; Stewart et al. 1972a). The Virgin Limestone Member represents the next marine transgression (Stewart et al. 1972a). Large stromatolites and other microbial structures formed in the absence of marine animals to feed on them (Pruss and Bottjer 2004a, 2004b). The upper contact with the middle red member is gradational (McKee 1954). The middle red member is a tidal flat and coastal plain unit deposited during a regression (Stewart et al. 1972a). The upper contact with the Shnabkaib Member is intertonguing and can be difficult to establish (Stewart et al. 1972a). The Shnabkaib Member includes tidal flat, sabkha, and restricted marine depositional settings, and has been compared to the southern coast of the Persian Gulf and lagoons in Ojo de Liebre, Baja California (Lambert 1984). This member represents another transgression, although not as extensive as previous events. The upper contact with the upper red member is gradational and arbitrary (Stewart et al. 1972a). The upper red member, like the other red members, is a tidal flat and coastal plain unit (Biek 2007; Biek et al. 2010). The Moenkopi Formation dates to the Early and early Middle Triassic (Heckert et al. 2005a); the members at PARA are thought to date to the Early Triassic (Blakey et al. 1993), between about 250 and 245 Ma. However, an apparent unconformity within the upper red member may represent the Early–Middle Triassic boundary (Billingsley and Workman 2000), and

the upper Moenkopi Formation at Petrified Forest National Park is dated to 241.31 ± 0.44 Ma, well within the Middle Triassic (Rasmussen et al. 2021).

Fossils found within PARA-NPS: None have been reported to date from the few outcrops.

Fossils found within PARA-BLM: Various fossils were observed during the 2020 field inventory, including possible brachiopods, bivalves, star-shaped crinoid columnals typical of *Holocrinus*, echinoids, undetermined invertebrate fossils, possible microbially induced sedimentary structures, invertebrate burrows and trails, and unidentified fossils. The majority of these fossils came from the Virgin Limestone Member, with some marine fossils in the Shnabkaib? Member and invertebrate burrows in red members, and marine fossils in float associated with the lower red member.

Fossils found elsewhere: Most fossils in the Moenkopi Formation of the northwestern Arizona–southeastern Nevada–southwestern Utah area come from the Timpoweap and Virgin Limestone Members. The fossil assemblage of the Timpoweap Member includes brachiopods, bivalves, ammonoids (particularly *Meekoceras*) (Stewart et al. 1972a), gastropods, ostracodes, echinoderms, conodonts, fish fragments (ichthyoliths), stromatolites (Lucas et al. 2007a), and reptile tracks (Zeilstra and Lohrengel 2001). The Virgin Limestone Member has the most diverse fossils. Its assemblage includes sponges (Bonde et al. 2018), bryozoans, brachiopods, bivalves, ammonoid and nautiloid cephalopods, gastropods, ostracodes, the crustacean *Halicyne*, crinoids (Poborski 1954; Hintze 1986; Jenson 1986; Stewart et al. 1972a), asteroids (Santucci and Kirkland 2010), echinoids (Moffat and Bottjer 1999), stromatolites, oncoids (Sanderson 1967; Pruss and Bottjer 2004a, 2004b), microbial wrinkle structures (Pruss et al. 2004), several types of invertebrate trace fossils (Pruss and Bottjer 2004a), probable microbial spheroids (Pruss and Payne 2009), and "algal" filaments (Sanderson 1967).

The other members have much smaller fossil assemblages. The lower red member has produced plant fragments (Billingsley and Workman 2000), bivalves (Mickelson et al. 2006), possible gastropods (Stewart et al. 1972a), invertebrate traces (Gregory and Williams 1947; Jenson 1986; Mickelson et al. 2006), and tetrapod tracks (Mickelson et al. 2006). The middle red member has produced unspecified fossils (Lundberg and Lohrengel 2005). The Shnabkaib Member has produced brachiopods, bivalves, ammonoids, gastropods, crinoids, stromatolites, invertebrate trace fossils and "algal" filaments, (Lambert 1984). Microbial structures are common, but fossils are otherwise rare (Lambert 1984). Bivalves, gastropods, and crinoids may be found in carbonate beds (Hintze 1986; Jenson 1986). The upper red member has produced plant impressions and microfossils, amphibian bones (Benz 1980), tetrapod tracks (Milner and Spears 2007; Klein and Lucas 2010) such as those of *Rotodactylus* (Stewart et al. 1972a), and coprolites (Benz 1980). In general, red members may yield stromatolites, microbial-coated grains, burrows and bioturbation (Reif and Slatt 1979), and bits of wood and bone (Gregory and Williams 1947). Limestone beds interbedded with the red beds may contain skeletal fragments of brachiopods, bivalves, gastropods, and ostracodes (Reif and Slatt 1979).

Chinle Formation (Upper Triassic) (PARA-BLM Only)

Description: The Late Triassic-age Chinle Formation is an important fossiliferous unit of the Colorado Plateau. It is a heterogeneous terrestrial unit largely deposited in fluvial and lacustrine

settings, and is divisible into several members depending on location (Stewart et al. 1972b). In PARA, the Chinle Formation is only found in PARA-BLM, where it is most commonly found near the northern end of PARA (Billingsley and Workman 2000), but it is also present in eastern PARA-BLM (Billingsley and Wellmeyer 2003). Two members are recognized in the area of PARA, the Shinarump Member (commonly Shinarump Conglomerate) at the base of the formation and the Petrified Forest Member above (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003). The Shinarump Member is composed of orange, brown, tan, and black cliff-forming conglomerate and conglomeratic sandstone, with common petrified wood. It fills erosional channels in the Moenkopi Formation in some places and is absent in others, so it varies in thickness; it can be as much as 55 m (180 ft) thick (Billingsley and Workman 2000). Older publications for the area sometimes treated this member as a distinct formation (Longwell 1928; Schenk 1938). The field team did not observe any instances of typical Shinarump Member strata at PARA localities. The overlying Petrified Forest Member is a variegated unit of interbedded sandstone, siltstone, and mudstone (Figure 23). It is between 60 and 122 m (200 and 400 ft) thick (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003). The upper contact with the undivided Moenave–Kayenta Formation is gradational (Billingsley and Workman 2000).



Figure 23. A Chinle Formation (Petrified Forest Member) site showing more resistant and less resistant intervals, PARA-BLM (NPS/2020 FIELD INVENTORY).

The Shinarump Member is one of the most widely exposed units of the Chinle Formation, and is present in Utah, Nevada, Arizona, and New Mexico (Colbert 1972; Ash 1974). It is interpreted as the

product of north- to northwest-flowing braided streams (Stewart et al. 1972b). The braided streams were part of a drainage system flowing north into the center of the depositional basin (Parrish 1989). The climate is interpreted as monsoonal (Demko et al. 2005). The overlying Petrified Forest Member was deposited by streams as a sandstone/mudstone fluvial unit with volcanic input (Blakey and Gubitosa 1983, 1984). The Chinle Formation spans much of the Late Triassic. Its base dates to at least 227 Ma (Rasmussen et al. 2021), and its top predates the Triassic–Jurassic boundary (201.4 Ma), which is found in the overlying Moenave Formation (Lucas et al. 2011).

Fossils found within PARA-NPS: This formation is not exposed in PARA-NPS.

Fossils found within PARA-BLM: During the 2020 field inventory, petrified wood was found at two sites, and invertebrate burrows were found in the Petrified Forest Member. Chinle Formation petrified wood is traditionally assigned to the conifer *Araucarioxylon* (Gregory 1950), but recent research has shown that multiple forms are present in the material referred to this name (Savidge 2007; Philippe 2011).

Fossils found elsewhere: Over its entire depositional area, the most common fossils of the Shinarump Member are plants (Colbert and Gregory 1957). Types of plants found in the Shinarump Member include horsetails, ferns and fern-like plants, bennettitales, cycads, and conifers and other gymnosperms (Ash 2005a). Some specimens show traces of arthropod attacks (Ash 1996). Bone fragments are commonly preserved as cobbles, usually too eroded to identify, but some can be identified as belonging to metoposaur amphibians, bony fish, or phytosaurs (Colbert and Gregory 1957; Breed 1972; Parrish 1989). Tetrapod footprints, swim traces (Lockley and Milner 2006), and coprolites are also known (Heckert et al. 2002). For invertebrates, freshwater mussels, gastropods, microconchids (previously misidentified as shells of the worm *Spirorbis*), insect eggs, and possible beetle feeding traces have been found (Ash 2005a). Reworked marine fossils from older formations have also been found, such as foraminifera and crinoids (McKee 1937b; Miller and Breed 1962).

The Petrified Forest Member has similar types of fossils, but differs in the genera and species present and which taxa are most commonly found. Plants are represented by charophyte green algae (Lucas and Keitzke 1993), diverse palynomorphs (Gottesfeld 1972; Fisher and Dunay 1984; Parker 2004), and leaves, wood, and other remains of lycopods, horsetails, ferns and fern-like plants, cycads, bennettitales, ginkgoes, conifers, and taxa of uncertain classifications (Ash 1972, 1989, 2003, 2005b; Stewart et al. 1972b). Amber has also been found (Litwin and Ash 1991). Fungal remains are also present (Ash 1972; Stewart et al. 1972b). Invertebrates are represented by bivalves, gastropods, ostracodes, conchostracans (Breed 1972; Stewart et al. 1972b), crabs (Rinehart et al. 2003), crayfish (Miller and Ash 1988), insects (Breed 1972; Stewart et al. 1972b), and various trace fossils (Caster 1944; Breed 1972; Gillette et al. 2003; Demko et al. 2005), including borings in wood (Walker 1938; Tapanila and Roberts 2012) and a variety of feeding traces on plants (Ash 1996).

The Chinle Formation's vertebrate assemblage has been summarized in a number of documents, including Stewart et al. (1972b), Colbert (1972), Parrish (1989), Long and Murry (1995), Heckert et al. (2005a, 2005b), Irmis (2005a), Parker (2005, 2009), Lucas et al. (2007b), Loughney et al. (2011), and Parker and Martz (2011). Vertebrates include (see the glossary, Appendix E, for brief

definitions): freshwater sharks; ray-finned fish; lungfish; coelacanths; several types of enigmatic tetrapods known from isolated bones and teeth; metoposaur amphibians; procolophonids; sphenodontians; trilophosaurids; tanystropheids; the unusual aquatic reptile *Vancleavea*; drepanosaurids; phytosaurs; aetosaurs; the small unusual armored *Revueltosaurus*; diverse early crocodile relatives; lagerpetids; silesaurids; several early dinosaur taxa; and dicynodonts. Lungfish, metoposaurs, aetosaurs, and phytosaurs are the most common forms. Vertebrate trace fossils include coprolites (Hunt et al. 1998), swim traces, and footprints possibly attributable to sphenodontians, tanystropheids, phytosaurs, aetosaurs, carnivorous and herbivorous dinosaurs, and mammal relatives (Hunt and Lucas 2007). Bones accumulated in floodplains, bogs, small ponds, and in or near channels (Parrish 1989).

Glen Canyon Group: Moenave Formation and Kayenta Formation, undivided (Upper Triassic–Lower Jurassic) (PARA-BLM Only)

Description: The undivided Moenave–Kayenta Formation is found near the northern end of PARA-BLM. The lower part, assigned to the Moenave Formation, is a brick red to dark red, fine-grained, slope-forming sandstone and siltstone unit (Billingsley and Workman 2000) (Figure 24). It grades into the overlying upper part, assigned to the Kayenta Formation, which is composed of red, fine-grained, slope- and ledge-forming sandstone and siltstone (Billingsley and Workman 2000). Intertonguing sandstone beds with large-scale cross-stratification are found near the top, representing basal tongues of the overlying Navajo Sandstone. The overall thickness is about 170 m (560 ft) (Billingsley and Workman 2000). The Moenave Formation, Kayenta Formation, and overlying Navajo Sandstone (see next section) make up the Glen Canyon Group in PARA.

The Moenave Formation is a mosaic of fluvial, lacustrine, and eolian environments deposited under a semi-arid to arid climate. An area of ephemeral and perennial lake systems, centered in southwestern Utah, received drainage from a fluvial system flowing to the north and northwest from northern Arizona (Tanner and Lucas 2007, 2009a). During deposition, this area of North America was in a monsoonal belt, moving into arid climates (Riggs and Blakey 1993). The Kayenta Formation was deposited by shifting freshwater braided and meandering streams (Colbert 1974); floodplain deposits are also known (Lucas et al. 2005). The Moenave Formation is known to straddle the Triassic–Jurassic boundary (Kirkland and Milner 2006; Lucas et al. 2011), suggesting a Late Triassic–Early Jurassic age at PARA.

Fossils found within PARA-NPS: This formation is not exposed in PARA-NPS.

Fossils found within PARA-BLM: Petrified wood and invertebrate burrows were observed in the undivided Moenave–Kayenta Formation during the 2020 field inventory.



Figure 24. An area of Moenave–Kayenta exposures with Holley Flora for scale, PARA-BLM (NPS/2020 FIELD INVENTORY).

Fossils found elsewhere: The most likely correlative for the monument's Moenave Formation is the fluvial Dinosaur Canyon Member, known from northern Arizona. Outside of PARA, it has yielded palynomorphs (Cornet and Waanders 2006), plant fragments, root traces (Kirkland and Milner 2006), mollusks, invertebrate trace fossils (DeBlieux et al. 2006), the fish *Semionotus*, an undescribed lepidosaur, the early crocodile relative *Protosuchus*, two pelvises of a small theropod, tracks of crocodile relatives (Lucas et al. 2005), tracks of theropod and ornithischian dinosaurs (Tanner and Lucas 2009a), and possible burrows of mammal-like tritylodonts (Tanner and Lucas 2009b). The relevant ichnofossil taxonomy can be complicated. A recent summary for the Chinle Formation and Glen Canyon Group can be found in Lucas et al. (2006a).

The Kayenta Formation is known for vertebrate body fossils and tracks. Most vertebrate body fossils were discovered in the Gold Spring Wash area of northeastern Arizona, more than 230 km (140 mi) east of the mouth of the Grand Canyon in the vicinity of Cameron and Tuba City (Lucas et al. 2005). Per Lucas et al. (2005), taxa represented in the Kayenta Formation by body fossils include sharks, bony fish, frogs, caecilians, turtles, sphenodontians, numerous crocodile relatives, pterosaurs, several species of dinosaurs (including *Dilophosaurus*, other carnivores, sauropodomorphs, small beaked

herbivores, and armored dinosaurs), several tritylodontid species, possible early mammal *Dinnetherium*, and a haramyid mammal (there are discrepancies between the table and text in Lucas et al. 2005; the text seems more accurate). Also reported are lungfish (Jenkins and Shubin 1998), salamanders (Curtis and Padian 1999), lizards, and morganucodontid mammals (Jenkins et al. 1983). Kayenta Formation vertebrate trace fossils include coprolites (Luttrell and Morales 1993), therapsid tracks, lizard-like tracks (Hamblin and Foster 2000), and dinosaur tracks (Lucas and Tanner 2007). Kayenta Formation fossils that are not vertebrates or vertebrate traces include petrified wood (Jenkins and Shubin 1998), plant impressions (Rigby et al. 1971), freshwater bivalves and gastropods (Harshbarger et al. 1957), ostracodes (Lucas and Tanner 2007), invertebrate trails and burrows (Luttrell and Morales 1993), and microbial limestone (Luttrell and Morales 1993).

Glen Canyon Group: Navajo Sandstone (Lower Jurassic) (PARA-BLM Only)

Description: The Navajo Sandstone is exposed at the north end of PARA-BLM. It is composed of red to white, cliff-forming, fine-grained quartz sandstone (Figure 25), and is 850 to 1,100 m (2,800 to 3,600 ft) thick (Billingsley and Workman 2000). It is lithologically identical to the Aztec Sandstone (Billingsley and Workman 2000), which is exposed in southeastern Nevada (e.g., Valley of Fire State Park), and some authors have used the Aztec Sandstone name for outcrops in PARA (Longwell 1928; Seager 1966).



Figure 25. Weathered knobs of Navajo Sandstone, PARA-STATE (NPS/2020 FIELD INVENTORY).

The Navajo Sandstone represents the largest erg known from North America (Blakey 2008), and Kocurek (2003) identified it as the largest known on Earth. Recent research on geochronology of detrital zircon grains in the Navajo Sandstone suggests that most of the sand was eroded from the ancestral Appalachian Mountains, transported westward by a continental-scale river system to the western shore of Jurassic North America, and was then blown southward and incorporated into the Navajo–Nugget–Aztec dune field (Dickinson and Gehrels 2003, 2009; Rahl et al. 2003). The Navajo Sandstone formed in a tropical arid setting with eolian, playa, and sabkha deposits (Mahaney et al. 2004). Wetter restricted interdunes are also known, and are characterized by mudstone with planar bedding, dolomitic limestone, and sandstone (Irmis 2005b). Fossils are mostly associated with interdunal environments (Loope et al. 2004b). As time went on during the deposition of the Navajo Sandstone, the climate became drier (Irmis 2005b), although there were several wetter periods with durations on the order of tens of thousands of years (Milan et al. 2008). While dating of Glen Canyon Group units has proven difficult, the Navajo Sandstone has generally been dated to the middle and late Early Jurassic (Lucas et al. 2005), sometime between approximately 190 and 175 Ma, but recent dating indicates that the lower Navajo Sandstone is as old as 200.5 ± 1.5 Ma (Parrish et al. 2019).

Fossils found within PARA-NPS: This formation is not exposed in PARA-NPS.

Fossils found within PARA-BLM: The Navajo Sandstone is not known to be fossiliferous within PARA-BLM, but there is the potential to find fossils, particularly tetrapod trace fossils.

Fossils found elsewhere: To date, fossil organisms and traces represented in the Navajo Sandstone over its entire depositional area include pollen, spores, horsetails, ferns (Loope et al. 2004b), cycadeoids, conifers (Wilkens 2008), petrified wood (Irmis 2005b), unionid bivalves (Wilkens 2008), ostracodes, conchostracans (Harshbarger et al. 1957), a crocodylomorph, the small theropod dinosaur *Segisaurus* (Irmis 2005b), at least two species of prosauropod dinosaurs (Sertich and Loewen 2010), a tritylodontid synapsid, stromatolites, root traces (Irmis 2005b), worm burrows (Stokes 1978), insect burrows, scorpion tracks (Loope et al. 2004b), vertebrate trace fossils (Irmis 2005b), and possible fungal filaments (Mahaney et al. 2004), The assemblage may be a persistent remnant of the Kayenta Formation assemblage (Winkler et al. 1991). Sandstone dune deposits have mostly yielded vertebrates, while limestone interdune beds have mostly yielded plants and invertebrates (Stokes 1991), although arthropod tracks (*Octopodichnus*) are known from the dunes (Hunt and Lucas 2006). Interdune fossils include horsetails, ostracodes, stromatolites, root casts, and insect traces, with locally common petrified wood (Irmis 2005b).

Vertebrate trace fossils are much more common than body fossils in the Navajo Sandstone, and have been extensively described from localities primarily in Utah. More than 60 dinosaur track sites are known in the Navajo Sandstone across its depositional area (Loope 2006; Milan et al. 2008). The various vertebrate trace fossils have gone under different names and interpretations, depending on the author. Recent works (Irmis 2005b; Hunt and Lucas 2006; Loope 2006) have settled on several primary ichnogenera: *Brasilichnium* (synapsid, but see Milan et al. 2008 for an interpretation as a sauropodomorph dinosaur), *Batrachopus* (crocodile relative), *Grallator* (small theropod dinosaur), *Anchisauripus* (medium theropod), *Eubrontes* (large theropod), *Navahopus* (small ?sauropodomorph), *Otozoum* (larger sauropodomorph), and *Anomoepus* (ornithischian dinosaur)

(Irmis 2005b). A few oddities are also known, including lizard-like tracks (*Lacertipus*), a track once thought to be pterosaurian in origin ("*Pteraichnus*"), bird-like *Trisauropodiscus* tracks (Irmis 2005b), and large vertebrate burrows thought to have been made by mammals and/or mammal relatives (Lucas et al. 2006b; Riese et al. 2011). So far, large traces (*Anchisauripus*, *Eubrontes*, and *Otozoum*) are only known from interdunes, with smaller traces (*Batrachopus*, *Brasilichnium*, and *Grallator*) the only tracks found in dune sands (Loope 2006), although this may be due to preservational bias (Irmis 2005b). In general, the vertebrate trace fossils are consistent with the known body fossils.

Willow Tank Formation (Upper Cretaceous) (PARA-BLM Only)

Description: The Willow Tank Formation is exposed in small, isolated areas of the Grand Wash in northern PARA-BLM. It is a red, gray, brown, or tan unit, composed of a discontinuous basal conglomerate and overlying unit of claystone, siltstone, and sandstone. It is up to 60 m (200 ft) thick (Billingsley and Workman 2000). In some references, this unit is known as the Jacobs Ranch Formation, named after a landmark in northern PARA-BLM (Moore 1972; Fillmore 1993), but this unit has been subsumed under the Willow Tank Formation (Bohannon 1991; Billingsley and Workman 2000). Bohannon (1992) mapped an additional Cretaceous unit, the Baseline Sandstone, in the Red Pockets 7.5-minute topographic quadrangle of PARA; the same area was later mapped as part of the Rainbow Gardens Formation (Billingsley and Workman 2000).

The Willow Tank Formation is a terrestrial formation. The basal conglomerate was deposited in a braidplain, and the upper finer-grained portion was deposited in anastomosing rivers and their floodplains. The environment is interpreted as arid to semi-arid (Bonde et al. 2008). Flow was dominantly south-southwest (Fillmore 1993). The formation dates to near the Early–Late Cretaceous boundary of 100.5 Ma; dates on part of the formation include ages of 101.6 ± 1 Ma and 99.9 ± 2 Ma (Bonde et al. 2008), while recent studies of detrital zircons put the base of the formation as at most about 98.68 Ma, and the top as at most about 98.56 Ma (Pape et al. 2011). Detrital zircon dating is an indirect dating method similar to estimating the age of a coin hoard by the most recent coin; the youngest zircons constrain the maximum depositional age of the formation.

Fossils found within PARA-NPS: This formation is not exposed in PARA-NPS.

Fossils found within PARA-BLM: The Willow Tank Formation is not known to be fossiliferous in PARA-BLM, but it may prove fossiliferous.

Fossils found elsewhere: A small fossil assemblage has been recently described from the upper finer-grained unit in the Valley of Fire. Here, fossils include remains of the tree fern *Tempskya*, other ferns, freshwater snails, and bones and other remains of several types of fish (holosteans, gars, and the lungfish *Ceratodus*), turtles, crocodile relatives, carnivorous dinosaurs, sauropod dinosaurs, armored dinosaurs, and ornithopod dinosaurs, and trace fossils including root traces, the invertebrate trace *Scoyenia*, coprolites, and eggshells. Most of the vertebrate elements are teeth or other small elements (Bonde et al. 2008). Other fossils reported from the formation included charophyte algae, freshwater bivalves, and freshwater ostracodes (Ash and Read 1976). Paleozoic clasts are known from the lower conglomerate (Bonde et al. 2008), so it would not be surprising to find fossil-bearing Paleozoic clasts in this part of the formation in PARA.

Rainbow Gardens Formation (upper Oligocene–lower Miocene)

Description: The Rainbow Gardens Formation is mapped in PARA-NPS and in isolated areas of the Grand Wash of PARA-BLM (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003; Beard et al. in press). It is a heterogeneous formation (Figure 26), consisting of a basal conglomerate, a middle tuff-rich unit, and an upper limestone unit. The basal conglomerate forms a brown to red-brown cliff, up to 50 m (160 ft) thick. The upper contact with the middle unit is disconformable. The middle unit is composed of ledge- and cliff-forming, tuffaceous, green to white limestone interbedded with ledge-forming, tuffaceous sandstone and white, slope-forming claystone. It is 50 to 100 m (160 to 320 ft) thick. The upper contact with the overlying limestone unit is gradational. The limestone unit is composed of pale brown, white, or gray limestone, 75 to 100 m (240 to 320 ft) thick (Billingsley and Workman 2000). The limestone unit is not exposed in the Tassi Spring area of PARA (Billingsley and Wellmeyer 2003).

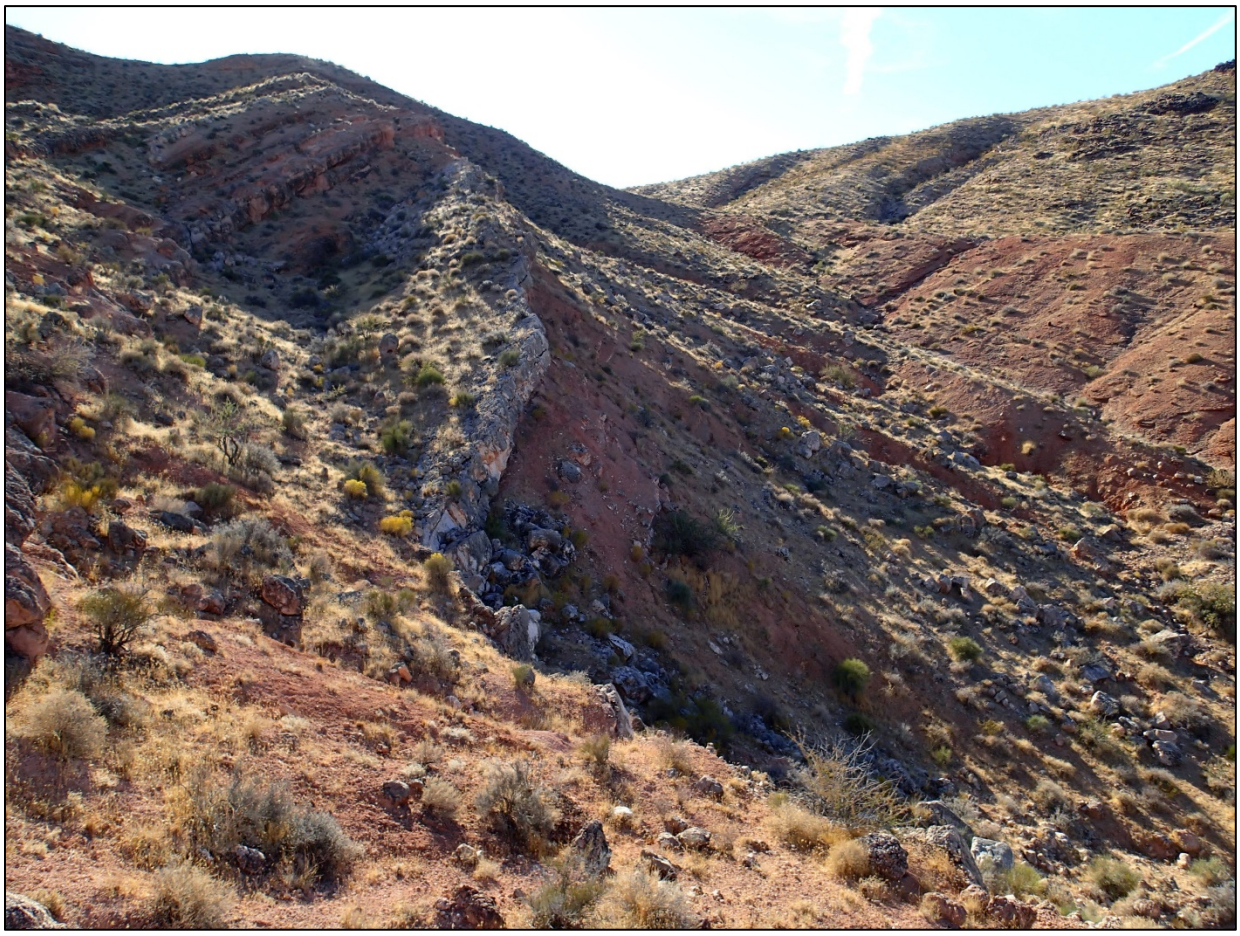


Figure 26. Outcrops of the heterogeneous Rainbow Gardens Formation, PARA-NPS (NPS/2020 FIELD INVENTORY).

The Rainbow Gardens Formation was formerly mapped in PARA under a variety of names, including the “Tassai [sic] Wash Group” (Longwell 1936, after mistaking it for the Moenkopi Formation in Longwell 1928), the Cottonwood Wash Formation of Moore (1972), and more recently

the Rainbow Gardens Member of the Horse Spring Formation (Billingsley and Wellmeyer 2003). The Rainbow Gardens Formation was long considered the basal member of the Horse Spring Formation, but was elevated to its own formation in Lamb et al. (2015). It differs from the overlying Horse Spring Formation in that it was deposited before Basin and Range extension, while the Horse Spring Formation was deposited during the extension (Lamb et al. 2015). "Ths" as a map acronym is an artifact of the former inclusion of the Rainbow Gardens Formation in the Horse Spring Formation, as on the Billingsley and Wellmeyer (2003) map of the area.

The Rainbow Gardens Formation was deposited in a mosaic of settings. The lower conglomerate unit is interpreted as having been deposited by braided streams, the middle mixed unit is interpreted as going from fluvial to lacustrine, with volcanic input from activity to the north, and the upper limestone is interpreted as marginal lacustrine or palustrine (Beard 1993, 1996; Lamb et al. 2015). Deposition occurred during the late Oligocene and early Miocene, from approximately 25 to 17 Ma (Lamb et al. 2015); at Tassi Wash, maximum dates range from 22.9 to 22.4 Ma (Lamb et al. 2018).

Fossils found within PARA-NPS: Possible plant stems (Longwell 1936), general bioturbation (Lamb et al. 2018), root traces (Beard 1996; Lamb et al. 2018), invertebrate burrows (Beard 1996), and other tubular features (Lamb et al. 2018) have been reported from PARA-NPS.

Fossils found within PARA-BLM: Root traces and invertebrate burrows have been observed in PARA-BLM (Beard 1996).

Fossils found elsewhere: The Rainbow Gardens Formation is limited in its geographic extent. However, to the southwest of PARA in the area around Lake Mead, fossils include stromatolites, root casts, bivalves, gastropods, possible ostracodes, burrows, and general bioturbation have been seen in the middle part of the Rainbow Gardens Formation, and root casts and burrows are present in the upper limestone of this formation (Beard 1996). In addition, the basal conglomerate is made up of reworked Paleozoic clasts (Moore 1972), so reworked Paleozoic fossils may be found.

Rocks of the Grand Wash Trough (middle–upper Miocene)

Description: The rocks of the Grand Wash Trough in PARA were previously included in the Muddy Creek Formation (Bohannon 1984). They include sandstone, siltstone, conglomerate, gypsum (Figure 27), and limestone (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003; Beard et al. in press). Exposures are present in western PARA between the Grand Wash Cliffs and highlands near the northern and western boundaries (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003). The rocks were deposited in a closed basin during Basin and Range tectonic activity (Bohannon 1984), with the coarser rocks representing alluvial fans; paleochannels have been observed as well (Beard et al. in press). Most dates are between about 13.9 and 10.8 Ma, although the base may be older than 15.3 Ma (Beard et al. in press).



Figure 27. The gypsum-rich facies of the rocks of the Grand Wash Trough, PARA-BLM (NPS/2020 FIELD INVENTORY).

The limestone/siltstone facies and gypsum/gypsiferous siltstone facies are likely equivalent to the Hualapai Limestone (Billingsley and Wellmeyer 2003; Billingsley et al. 2004), a formation better known from the Lake Mead area to the southwest. Some recent papers have identified areas mapped as these facies in PARA as the Hualapai Limestone (e.g., Faulds et al. 2016; Crow et al. 2019), although without elaborating on the decision; the usage is only apparent when comparing maps.

Fossils found within PARA-NPS: None have been reported to date.

Fossils found within PARA-BLM: Billingsley and Wellmeyer (2003) and Billingsley et al. (2004) included fossil "algae" and plant root casts in the generalized description of the limestone/siltstone facies, but did not specify any localities. The implication of their inclusion in the description is that they are likely found anywhere the facies is present. It is also quite likely that the Paleozoic-clast conglomerate facies of the Grand Wash Trough rocks includes reworked fossils.

Fossils found elsewhere: Aside from the generalized "algae" and root casts of Billingsley and Wellmeyer (2003) and Billingsley et al. (2004), fossils have not been reported from this formation.

Upper Cenozoic igneous rocks (upper Miocene–Holocene)

Description: Volcanic activity began in PARA during the Miocene. There are igneous rocks as old as 17.4 ± 0.3 Ma in nearby areas of GRCA (the plug of the Grand Pipe), but the oldest dated igneous

rocks in PARA date to around 9 Ma (Billingsley and Wellmeyer 2003). Volcanic activity has persisted in this area until practically the present day, with the youngest dated eruption that of the Little Spring Basalt in PARA-BLM about 1,000 years ago (Billingsley and Wellmeyer 2003). Igneous units in PARA can be divided into three groups: basalt flows, composed of light gray to dark gray alkali-olivine basalt; intrusive dikes and volcanic necks of the same types of basalt; and pyroclastic deposits of scoria, cinders, ash, and fragments of basalt and glass (Figure 28) (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003). Igneous rocks may be very localized, or they may cover much larger areas, such as the Shivwits Plateau basalt.



Figure 28. Pyroclastic deposits in PARA (NPS/2020 FIELD INVENTORY).

Igneous rocks are represented in the Grand Wash parcel of PARA-NPS by basalt flows and intrusive dikes and necks of the basalt of the Grand Wash Trough. At least two flows are represented, dating to between 4.70 ± 0.07 Ma and 3.99 ± 0.06 Ma, and 3.24 ± 0.05 Ma (Billingsley and Wellmeyer 2003). The Parashant Canyon parcel of PARA-NPS has a longer record of igneous activity, including the basalt of Shivwits Plateau capping most of the Shivwits "finger" of the parcel (8.2 ± 0.1 Ma to 6.2 ± 0.30 Ma dates) and rocks of the Uinkaret volcanic field (middle Pleistocene to Holocene) (see Koons 1945 for more on the Uinkaret rocks). PARA-BLM includes rocks from these eruptive events and others of comparable age, including an apparent maar that formed between 4.5 and 4.0 Ma (Billingsley and Wellmeyer 2003). This crater later filled with sandstone and limestone (Figure 29).

Fossils found within PARA-NPS: The igneous rocks of PARA-NPS are not known to be fossiliferous, but it is not impossible to find fossils in extrusive igneous rocks, such as molds of trees and other plants. Fossils may also be present in ash beds and other volcaniclastic deposits, as well as sedimentary rocks associated with volcanic rocks (i.e., deposited over one volcanic flow and then buried by another).



Figure 29. Limestone over sandstone within a maar, with Holley Flora for scale, PARA-BLM (NPS/2020 FIELD INVENTORY).

Fossils found within PARA-BLM: Although the igneous rocks of PARA-BLM are not known to be fossiliferous, the sediments filling the maar in PARA-BLM are fossiliferous. They are discussed here rather than under "Pliocene and Quaternary surficial sediments" because of their close relationship with volcanic activity, and the much different nature of the other fossils discussed in the latter section. A PARA educational website (https://www.nps.gov/para/learn/nature/parashant-s-volcanic-fields-and-lava-dams-in-the-grand-canyon.htm) relates that the maar contains "beach sands and mollusk fossils" (PARA 2021). The 2020 field inventory observed laminated features that may be inorganic or organic (Figure 30), as well as invertebrate burrows.

Fossils found elsewhere: Fossils have not yet been reported directly from these igneous rocks, only in associated sedimentary rocks.

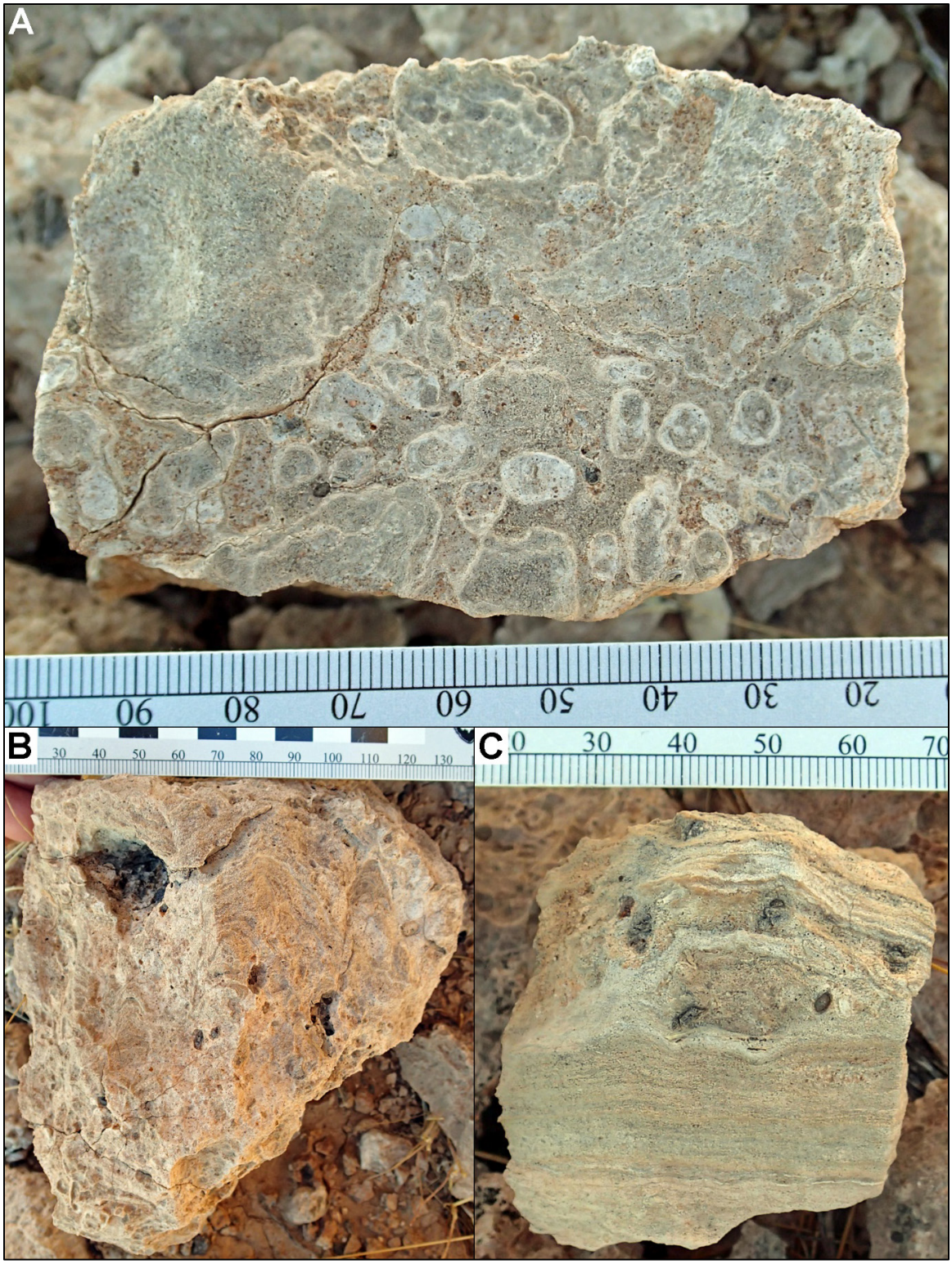


Figure 30. Organic or inorganic laminations, PARA-BLM (NPS/2020 FIELD INVENTORY). **A.** Rounded laminated objects in a cobble. **B.** Arched laminations. **C.** Horizontal laminations plus laminations around internal clasts.

Pliocene and Quaternary surficial sediments (Pliocene–Holocene)

Description: A variety of surficial deposits are found in PARA, deposited from the Pliocene to the present. These deposits range from cobble and boulder deposits, to mud, to limestone. They represent a variety of depositional processes and settings, such as alluvial fans, wind-deposited dunes, landslides, ponds, rivers, and springs (Billingsley and Workman 2000; Billingsley and Wellmeyer 2003; Beard et al. in press). PARA also has a number of caves, some of which are known to preserve fossils (Mead 2003; Voyles 2008). Ongoing cave inventories have documented 57 caves within PARA-BLM and three caves within PARA-NPS. As of May 2021, there are 78 additional cave leads for PARA-NPS in remote areas requiring extensive ropework for future efforts of inventory. Caves are preferentially developed in the Muav and Redwall limestones in the Grand Canyon region. However, many caves in PARA are gypsum solution caves, with faunal remains of recent natural trap kills (J. Mead, pers. comm., April 2021).

Fossils found within PARA-NPS: Mead (2003) reported observing undated packrat middens in several places in PARA, including sites in PARA-NPS. Packrat middens are collections of plant material and food waste constructed by packrats (*Neotoma* spp.) and cemented by their viscous urine. They can be well-preserved in dry caves and rock shelters, and illustrate the environment of the builder's foraging range. Middens are important tools for reconstructing the ecology and climate of the late Pleistocene and Holocene of the southwestern United States (Strickland et al. 2001). Fossils from NPS caves are described in Santucci et al. (2001), and additional information on NPS packrat middens can be found in Tweet et al. (2012).

Fossils found in PARA-BLM: Most of the Quaternary fossils found in PARA-BLM come from caves or rock shelters. Mead (2003) observed undated packrat in PARA-BLM. More recently, Voyles (2008) reported that undated bones and skeletons had been found in a cave in PARA-BLM. The remains represent at least one large bird and unidentified mammals, including a skeleton found in a dry pool, covered by calcite spar.

Cave inventory efforts in 2008–2009 revealed several cliff facing caves within the Redwall Formation which served as carnivore dens. These caves contained various Pleistocene bone remnants near the cave entrances and fully articulated skeletons in deeper reaches of the caves. During 2012–2014, specimens were collected along with cave sediment samples by Stephen Rowland (University of Nevada-Las Vegas) and further assessed by David Gillette (Museum of Northern Arizona) and Jim Mead (East Tennessee State University). Dr. Mead identified the smaller material, such as specimens of snake vertebrae and a Pleistocene hummingbird. Dr. Gillette identified the larger material, including a Pleistocene horse vertebra, a Harrington's mountain goat femur, and fully articulated skeletons of a large condor-like bird, a feline, and a canine. A tortoise skull and carapace were also found. As of May 2021, description of these specimens is not complete.

Also found in these caves are sizeable mounds of bat guano extending in piles 4 to 6 m (13 to 20 ft) wide. In 2014, Dr. Rowland sampled six guano piles for carbon-14 radiometric dating, with results ranging from 36,000 to 18,000 years before present. In 2015, Dr. Mathew Lachniet (University of Nevada-Las Vegas) dated two stalagmites using a uranium-series method while gathering data for a

regional climatology study. From his results, the uppermost ages for the stalagmites extend to 990,000 years before present, indicating these caves existed for a substantial part of the Pleistocene.

The field team visited several caves in PARA-BLM that included packrat middens and bones of various mammals. The remains have not yet been dated or rigorously identified, but include insectivores, rodents, bats, canids, felids, and artiodactyls. Also observed were a pine cone or nodule and gastropods.

Fossils have also been found in other Quaternary deposits in PARA-BLM. Deposits in northern PARA-BLM include organic trace fossils and petrified wood (E. McIntyre, pers. obs., January 2016). At another locality in PARA-BLM, the field team observed reworked fossils (interpreted as coming primarily from the Toroweap Formation) in Quaternary deposits, among them petrified wood, rugose corals, bryozoans, brachiopods, and crinoids. It is likely that such reworked fossils are fairly common, especially near outcrops of productive bedrock formations.

Fossils found in PARA-STATE: The field team collected packrat midden material from a rock shelter within PARA-STATE, along with apparently modern elements of rodents and rabbits from a carnivoran den at the same site.

Fossils found elsewhere: Additional remains should be expected. Aside from the caves and rock shelters, deposits from spring-fed wetlands have yielded abundant fossils elsewhere in the region, such as at Joshua Tree National Park (JOTR) and Tule Springs Fossil Beds National Monument (TUSK); these are typically isolated remains of large mammals such as mammoths, horses, and camels. It should also be noted that travertine precipitation can make "modern fossils" by encrusting roots and leaves (Billingsley and Workman 2000).

There are several well-documented Quaternary sites within about 100 km (60 mi) of PARA, including Glendale, Gypsum Cave, and Rampart Cave. The Glendale site is about 48 km (30 mi) west of PARA, on the other side of the Overton Arm of Lake Mead. The assemblage from this site is older than 38,500 radiocarbon years before present (Scott et al. 2004), and includes charcoal, horsetails, tule, impressions of plant leaves and stems, bivalves, gastropods, fish, amphibians, turtles, waterfowl, large and small rodents, rabbits, canids, mammoths, horses, camels, mountain sheep, deer, and pronghorns (Schenk 1938; Van Devender and Tessman 1975; Santucci et al. 2004; Scott et al. 2004; Jefferson et al. 2015). These plants and animals lived near a pluvial lake or marsh along a permanent river (Van Devender and Tessman 1975). (Note that radiocarbon dates are not the same as calendar dates, and must be calibrated to approximate calendar years. Dates can be calibrated using a calibration program such as Calib 8.2 [http://calib.org/calib/] if error ranges are provided. "Present" in "before present" is 1950.)

Gypsum Cave, about 76 km (48 mi) west of PARA, was one of the first places where sloth dung was found. It was initially reported by Harrington (1940), and the amphibians and reptiles were described by Brattstrom (1954). Fossil animals found here include snails (Schenk 1938), frogs, tortoises, lizards, snakes (Brattstrom 1954), condors, sloths, rabbits, felids, canids, mustelids, skunks, horses,

camels, llamas, deer, and bighorn sheep (Jefferson et al. 2015). The assemblage dates to the end of the Pleistocene (Long et al. 1974).

Rampart Cave, on the south side of the Colorado River at the mouth of the Grand Canyon, is the best-known of GRCA's many fossil caves. It is famous for its deposits of dung from *Nothrotheriops shastensis* (Shasta ground sloth). Sloths voided dung in the cave during at least two periods: from over 40,000 years ago to about 24,000 years ago, and between about 13,000 and 11,000 years ago; during the glacial maximum that separated the two periods, a layer formed including packrat middens, mountain goat dung and bones, and marmot bones. Packrat middens were constructed over the upper sloth dung layer as well, dating to the postglacial period. Bat guano is also found in multiple layers (Long et al. 1974). At least one piece of sloth dung was found to have roundworms and their eggs (Harington 1972), and other microscopic parasites were reported by Schmidt et al. (1992). The plants in the sloth dung show the animals to have been bulk feeders, with a preference for desert plants such as desert globemallow, Nevada Mormon-tea, saltbush, catclaw acacia, cacti, reeds, and yucca (Hansen 1978; Phillips 1984). Sloths appear to have gone extinct at a time when their forage was flourishing, lending support to the theory that they were overhunted by humans (Hansen 1978). Aside from plant material in the middens and dung, plants are also represented by pollen (Martin et al. 1961). Bones are known from the cave, with the middens holding bones of many small animals, such as tortoises, lizards, snakes, rodents, and bats. More than 200 sloth bones have been found in the cave (Hansen 1978). Other vertebrates from the cave include condors, vultures, hawks, falcons, herons, owls (Carpenter 2003), rabbits, felids, mustelids, ringtails (Spamer 1992), horses, bighorn sheep, mountain goats, and undetermined artiodactyls (Carpenter 2003). Soft tissues such as sloth hair, sinews, and tracheal remains (Schenk 1937), goat horn sheaths (Mead et al. 1986), and a goat forefoot with muscle, cartilage, and skin (Harington 1972) have also been reported. Archeological material is not known from Rampart Cave (Spamer 1984).

Taxonomy

See Appendix A for full lists of taxa.

Fossil Plants

Fossil plants are poorly known from PARA at this time, with only scattered reports from a handful of formations spread throughout the Paleozoic, Mesozoic, and Cenozoic. The conifer *Walchia* has been reported from the Manakacha Formation of PARA-NPS and the Esplanade Sandstone of PARA-BLM (McKee 1982b, 1982c). A few specimens of seed ferns and conifers were collected from the Hermit Formation of PARA-NPS by McKee and are now in GRCA museum collections; McKee (1937a) and Schenk (1938) briefly refer to these fossils. During the 2020 field inventory, petrified wood was observed at PARA-BLM localities in the Chinle Formation (Figure 31) and undifferentiated Upper Triassic–Lower Jurassic rocks, and apparent petrified wood was observed as float at a Toroweap Formation locality. Petrified wood can usually be recognized by its woody texture or "wood grain" structure on broken surfaces. Because of its durability, petrified wood is likely widespread throughout PARA as "float" transported by streams. Longwell (1936) reported possible plant molds from rocks now assigned to the Rainbow Gardens Formation in PARA-NPS. Finally, plant material of Quaternary age is present in packrat middens.



Figure 31. Several large pieces of petrified wood, Chinle Formation, Petrified Forest Member, PARA-BLM (NPS/2020 FIELD INVENTORY).

Fossil Invertebrates

Of all of the fossils in PARA that can be seen with the naked eye, invertebrate body fossils are the most abundant and diverse. They are primarily represented by marine forms that lived during the second half of the Paleozoic, between approximately 360 and 275 million years ago. The Redwall Limestone, Watahomigi Formation, Callville Limestone, Pakoon Limestone, Toroweap Formation, and Kaibab Formation are particularly productive.

Phylum Porifera (sponges)

Sponges are porous aquatic animals that do not have differentiated organs. Sponges have a relatively poor fossil record compared to their known abundance and diversity, which can be attributed to many sponges either lacking hard parts entirely or having only a spicular skeleton that disintegrates into microscopic structural elements upon death. The sponge record of PARA is mostly limited to the Kaibab Formation. The Kaibab Formation is noted for rounded concretions that, if broken, prove to have formed around specimens of the heavily silicified sponge *Actinocoelia maeandrina* (Griffin 1966). *Actinocoelia* fossils were observed in the Kaibab Formation of both PARA-NPS and PARA-BLM during the 2020 field inventory (Figure 32).

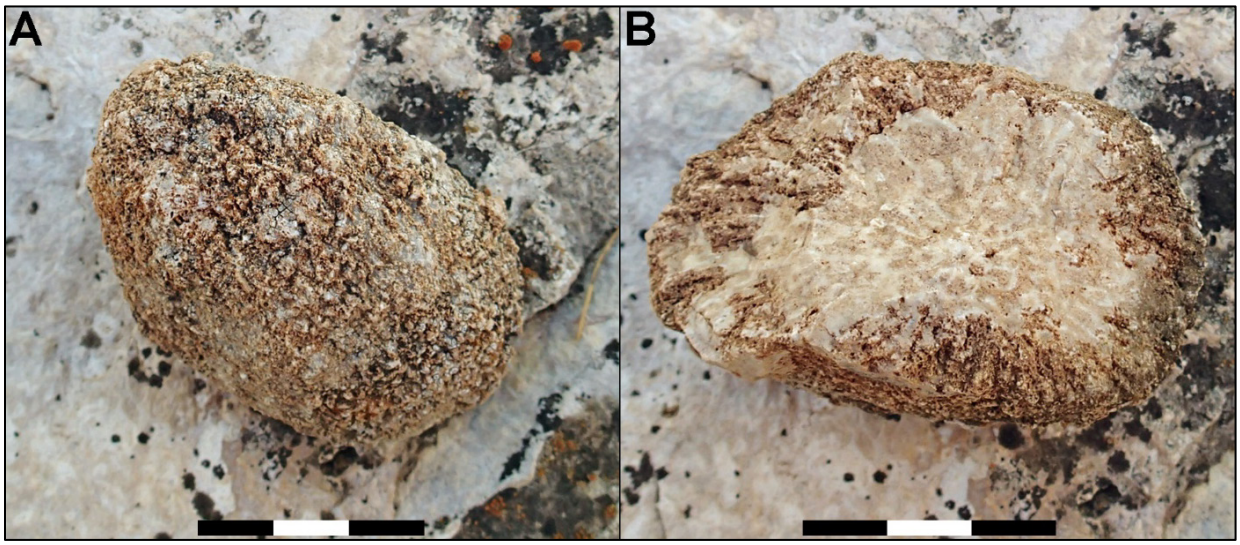


Figure 32. The sponge *Actinocoelia maeandrina*, Kaibab Formation, PARA-BLM. Scale bars are 3 cm. **A.** The outside of a concretion. **B.** A broken surface shows the sponge (NPS/2020 FIELD INVENTORY).

Outside of the Kaibab Formation, Pierce (1979) reported the tabulate-coral-like *Chaetetes* sp. from a Callville Formation locality in PARA-BLM (Pierce 1979). A probable sponge was photographed in the Pakoon Limestone of PARA-NPS during the 2020 field inventory (Figure 33). This layered fossil also resembles the microbial fossil *Girvanella*, which has been reported from the Pakoon Limestone at other locations. However, a close look reveals the presence of an internal framework inconsistent with *Girvanella* but compatible with various heavily calcified sponges such as chaetetids.

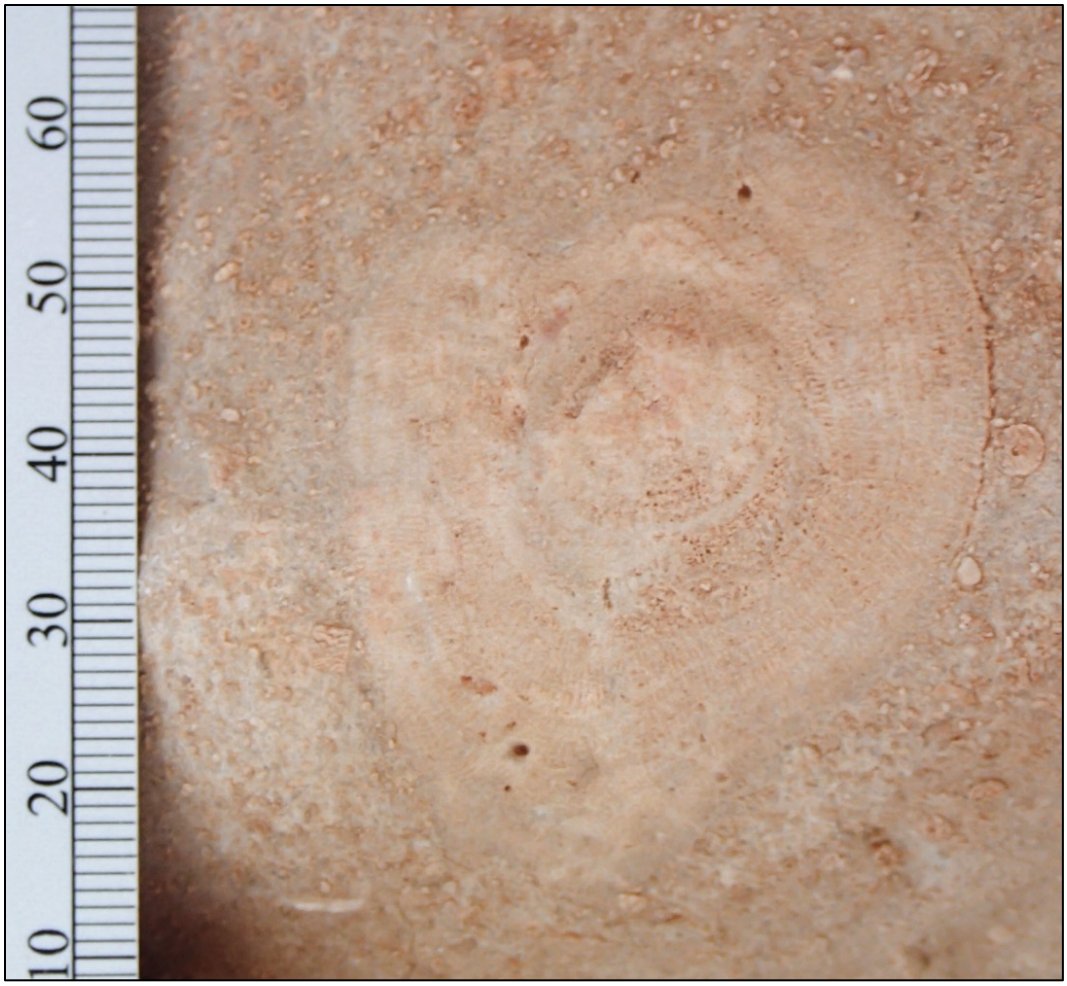


Figure 33. A probable chaetetid-type sponge in cross-section from the Pakoon Limestone, PARA-NPS (NPS/2020 FIELD INVENTORY).

Phylum Cnidaria (jellyfish and corals)

Most Paleozoic coral fossils belong to one of three extinct groups, all of which are represented at PARA: tabulate corals, and solitary and colonial rugose corals. Tabulate corals are colonial, but can usually be distinguished from colonial rugose corals by the sizes of the corallites or living chambers (less than a few millimeters in tabulates, substantially larger in rugose corals) and structures in the chambers (simple or no vertical structures in tabulates, generally more complex in rugose corals). Common varieties of tabulate corals include "chain corals" (*Favosites*) and "honeycomb corals" (*Syringopora*) (Figure 34). Tabulate corals are known from the Redwall Limestone of PARA-NPS and PARA-BLM (McKee and Gutschick 1969; 2020 field inventory), Watahomigi Formation (PARA-NPS), Manakacha Formation (PARA-BLM), Wescogame Formation (PARA-BLM), and Pakoon Limestone (PARA-BLM) (Gordon 1982; McKee 1979, 1982b, 1982c).

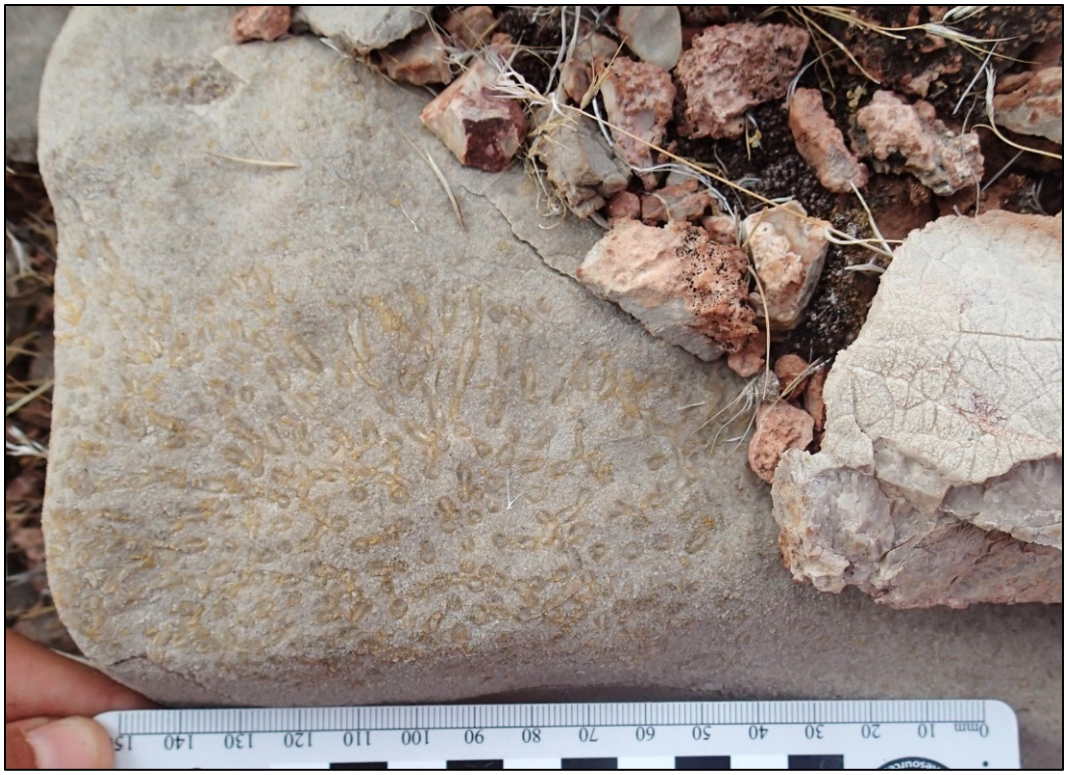


Figure 34. A weathered example of the tabulate *Syringopora*, Redwall Limestone, PARA-NPS (NPS/2020 FIELD INVENTORY).

Solitary rugose corals are better known as horn corals for their shape, often resembling a cow's horn. Colonial rugose corals may look similar to modern stony corals. Rugose corals appear to be more abundant and diverse than tabulates at PARA. They are present in most of the formations from the Redwall Limestone stratigraphically through to the Kaibab Formation, but are most prominent in the Redwall Limestone (both PARA-NPS and PARA-BLM) and Pakoon Limestone (mostly PARA-BLM). Particularly notable are numerous examples of the large distinctive horn coral *Vesiculophyllum* at a PARA-NPS Redwall Limestone locality, observed during the 2020 field inventory (Figure 35). This genus commonly has a "woody" surface texture (particularly when weathered) and a cylindrical form, sometimes curved, that appears to consist of segments or stacked cones. Colonial rugose corals were also observed during the field inventory, in the lower Supai Group and Pakoon Limestone of PARA-BLM (Figures 36 and 37). Redwall Limestone rugose corals from PARA are described in Easton and Gutschick (1953) and McKee and Gutschick (1969). Pakoon Limestone rugose corals are reported in McKee (1982c).



Figure 35. Several examples of *Vesiculophyllum* weathering on a Redwall Limestone surface, PARA-NPS (NPS/2020 FIELD INVENTORY).

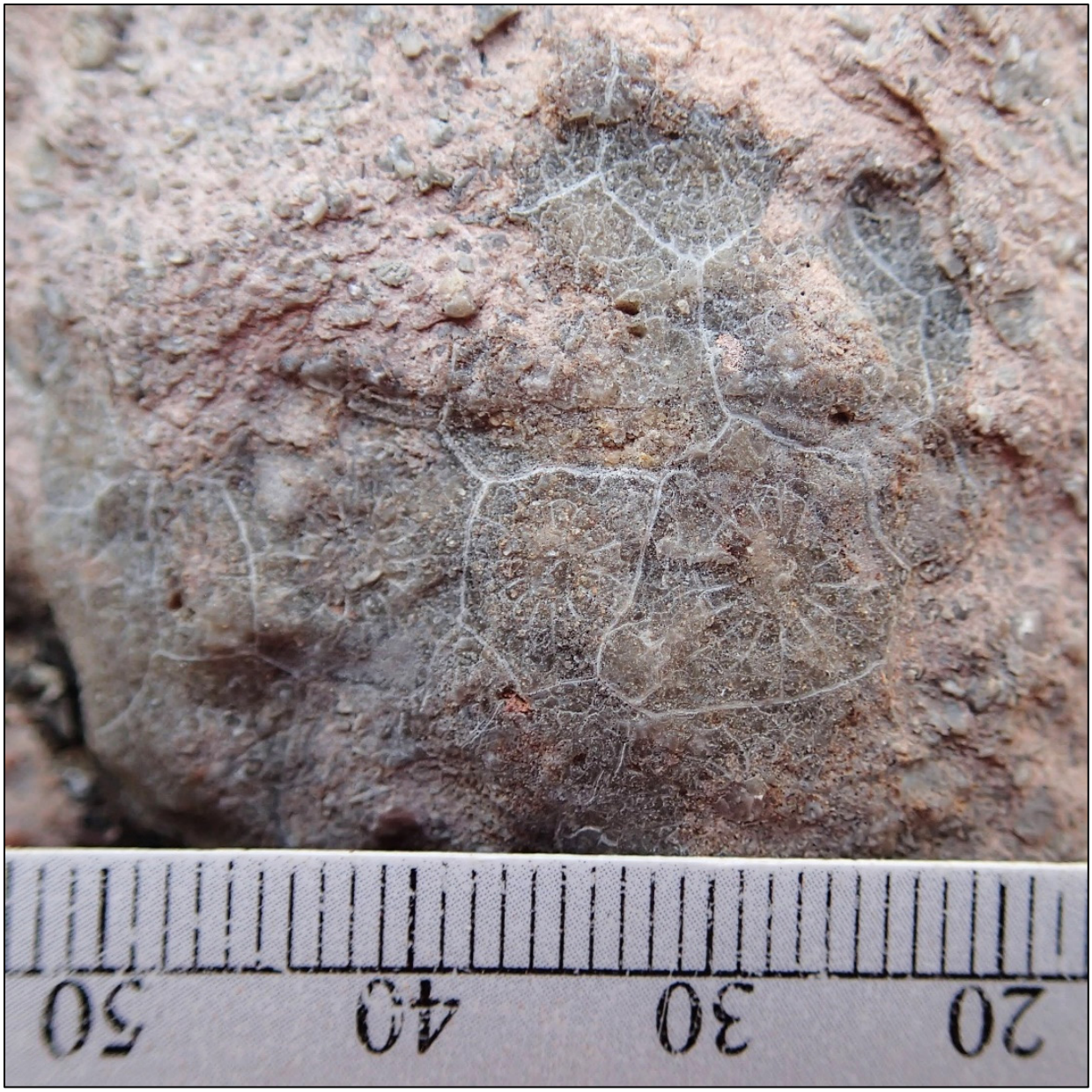


Figure 36. Corallites of a colonial rugose coral, Pakoon Limestone, PARA-BLM (NPS/2020 FIELD INVENTORY). Small septa are visible inside the polygonal corallites.



Figure 37. A colonial rugose coral in cross-section, Pakoon Limestone, PARA-BLM (NPS/2020 FIELD INVENTORY). This view shows a framework of corallites, septa (vertical plates in corallites), and tabulae (horizontal plates). Tabulate corals also have well-developed tabulae, but they lack well-developed septa and their corallites are smaller.

Phylum Bryozoa (moss animals)

Bryozoans are microscopic colonial animals that have a substantial fossil record. Their colonies are sometimes mistaken for coral colonies, but the living chambers of bryozoans are much smaller than those of corals (sub-millimeter scale versus millimeter to centimeter scale). Bryozoan colonies take on a variety of morphologies, such as stem- or branch-like (which can be mistaken for bones or plant fossils), domes, net-like, and irregular. Bryozoans have been reported from several formations within PARA-NPS and PARA-BLM, from the Redwall Limestone to the Kaibab Formation. Most of the diversity listed in Appendix A comes from the Redwall Limestone (primarily via McKee and Gutschick 1969) or Kaibab Formation, but this is misleading because bryozoans are difficult to classify to genus or species without making detailed study of microscopic structures in thin section, so observers will often only report either the general presence of bryozoans, or broad structural forms. Many of PARA's bryozoan fossils can be described as fenestrate, meaning they form colonies of lacy, net-like fronds (Figure 38). Others are thicker and branching (Figure 39). Cross-sections of bryozoan fronds and branches often appear as ovals or wavy features with internal layers and minute chambers (Figures 40 and 41).

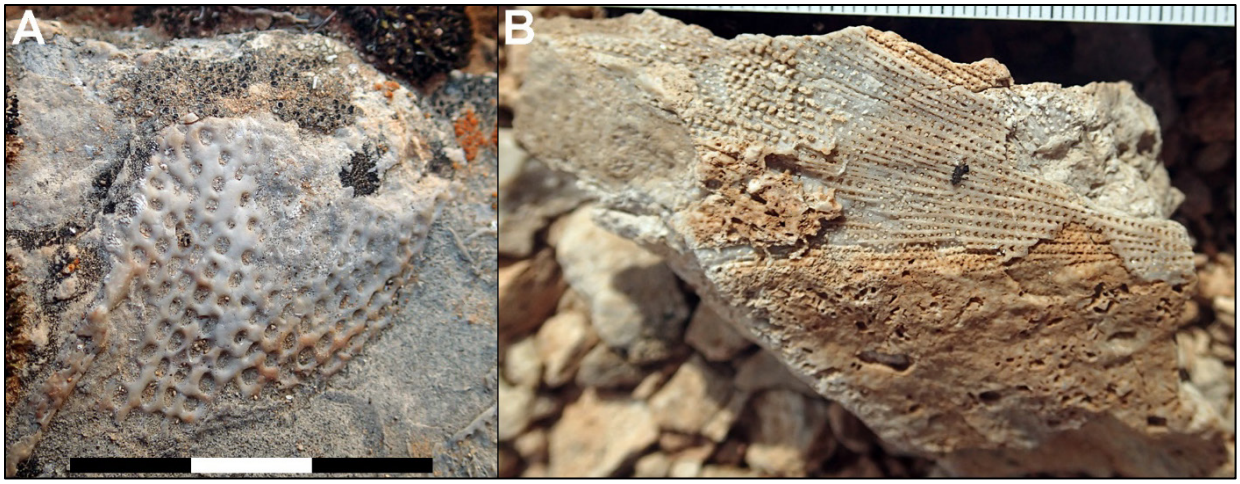


Figure 38. Two examples of typical fenestrate bryozoan fossils (NPS/2020 FIELD INVENTORY). **A.** Toroweap Formation, PARA-BLM. Scale bar is 3 cm. **B.** Kaibab Formation, PARA PAL 0016, PARA-BLM. Ruler marks are 1 mm each.



Figure 39. A colony of branching bryozoans exposed in relief, Pakoon Limestone, PARA-NPS (NPS/2020 FIELD INVENTORY).



Figure 40. Most of the fossils visible here are cross-sections of bryozoan fronds (the streak-like features). Pakoon Limestone, PARA-NPS (NPS/2020 FIELD INVENTORY).

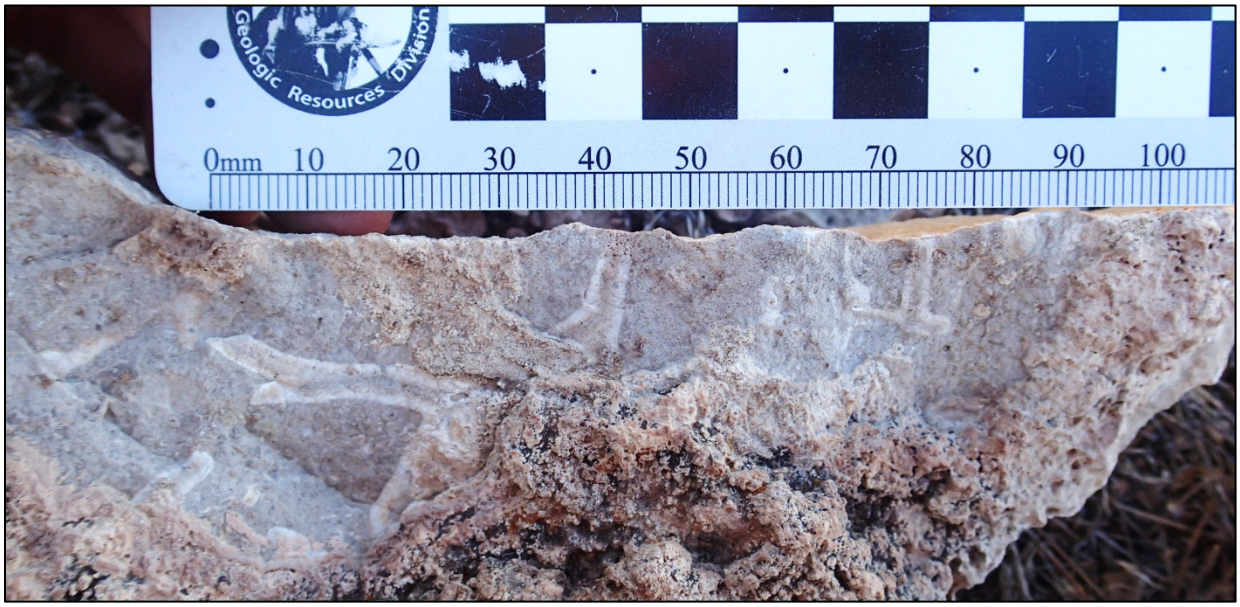


Figure 41. These cross-sections represent branching bryozoans, Kaibab Formation, PARA-NPS (NPS/2020 FIELD INVENTORY).

Phylum Brachiopoda (lamp shells)

Brachiopods are shelled, sessile, filter-feeding marine invertebrates that resemble bivalve mollusks, but have much different soft anatomies and valve articulations. Brachiopods feed using a tentacle-bearing organ called a lophophore, supported by a mineralized brachidium which is occasionally preserved in fossils (Figure 42). Their shells can generally be distinguished from bivalve mollusks by symmetry. A single brachiopod valve usually has a line of symmetry, but the two valves are usually different shapes and sizes and thus are not symmetric to each other. A single bivalve valve is usually clearly asymmetric (less obvious for some groups such as scallops), but the two valves are usually mirror images. Brachiopods are often informally separated into articulate and inarticulate forms based on shell composition and how the shells are hinged; articulate brachiopod shells are usually made of calcium carbonate, whereas inarticulate brachiopod shells are usually phosphatic.



Figure 42. A brachiopod fossil in cross-section with internal structures representing the brachidium. Pakoon Limestone, PARA-BLM (NPS/2020 FIELD INVENTORY).

Brachiopods are perhaps the most abundant and diverse type of body fossil found in the Paleozoic of PARA, for both PARA-NPS and PARA-BLM. Dozens of species have been reported, primarily from the Watahomigi Formation, Pakoon Limestone, Toroweap Formation, and Kaibab Formation (Appendix A). Although brachiopod taxonomy is very complex and the features used to distinguish different genera and species are not always apparent, several genera of Permian brachiopods can be distinguished by features that are usually visible on any well-preserved specimens:

Composita: Smooth shells, generally 2.5 cm (1.0 in) in greatest dimension; rounded to diamond-shaped or slightly pentagonal when viewed from above or below; prominent midline feature making a deep ridge (fold) on one valve and groove (sulcus) on the other (Figure 43A).

Derbyia: Broad D-shaped shells with well-developed fine ribbing radiating from the middle of the hinge line; hinge line is close to straight; relatively large, can exceed 5 cm (2 in) across (Figure 43B). Another brachiopod with a straight hinge line, *Dyoros* (*Chonetes* of older references), can be distinguished by size (half or less that of a full-sized *Derbyia*) and lack of strong ribbing.

Meekella: Large (up to at least 6.4 cm or 2.5 in across) with strong coarse radiating ribs resembling a ruffled potato chip (Figure 43C). Small specimens can be confused with *Phrenophoria* (*Pugnoides* or *Wellerella* of older references) or *Spiriferellina* (*Spiriferina* of older references). The latter can be distinguished by the presence of a small number of heavy ribs (4 to 6) on either side of the midline, becoming larger toward the midline, and a well-developed fold and sulcus, with noticeable gap between ribs on the valve with the fold.

Productids (*Peniculauris*, *Rugatia*): May exceed 8.5 cm (3.3 in) across; complete fossils composed of a bulbous and strongly curved valve and a flattened valve (Figure 43D); often seen as paired rounded lobes weathering in situ (Figure 44); parallel to slightly converging ribbing, coarser than *Derbyia* and finer than *Meekella*, and sometimes slightly knobby and irregular. Productids are among the most abundant and recognizable fossils of the Kaibab Formation. *Peniculauris* and *Rugatia* are generally similar, although *Rugatia* specimens are never as large as *Peniculauris*. They were formerly classified in the same genus (*Productus* or *Dictyoclostus*). In life, productids had numerous fine spines growing from the strongly curved valve, which are rarely preserved due to their fragility. These spines would have anchored the shell in the substrate while also raising it slightly above.

Detailed technical information and additional photos and figures for relevant brachiopods can also be found in Carter et al. (2014) (Redwall Limestone), Gordon (1982) (Watahomigi Formation), and McKee (1938) (Toroweap and Kaibab Formations).

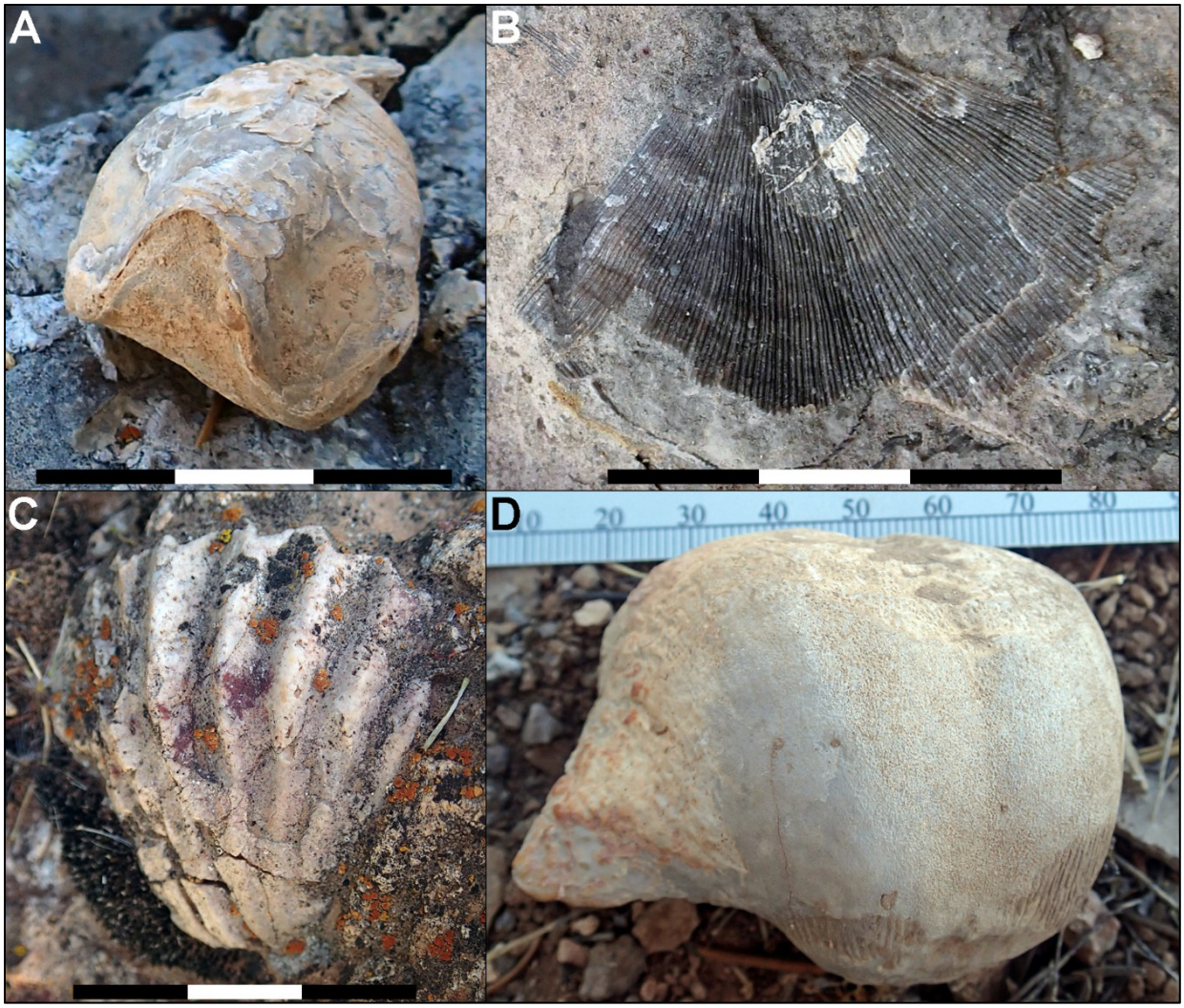


Figure 43. Various common Permian brachiopods (NPS/2020 FIELD INVENTORY). Scale bars are 3 cm. **A.** *Composita*, Kaibab Formation, PARA-BLM. **B.** *Derbyia*, Pakoon Limestone, PARA-BLM. **C.** *Meekella*, Kaibab Formation, PARA-BLM. **D.** Productid, Kaibab Formation, PARA-NPS.



Figure 44. A productid brachiopod partially exposed from rock, showing the characteristic bulbous lobed shape and knobby ribbing. Toroweap Formation, PARA-BLM (NPS/2020 FIELD INVENTORY).

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

Bivalves are familiar aquatic invertebrates today, but during the Paleozoic brachiopods filled many of the roles that would be taken by bivalves today. As noted above, most bivalves can be distinguished from brachiopods by their symmetry (asymmetric single valves, valves symmetric to each other), although there are exceptions. Pectinids (scallops), for example, are more like brachiopods by having nearly symmetric single valves. Bivalves have been found in most of the formations from the Redwall Limestone through the Moenkopi Formation within PARA, both in PARA-NPS and PARA-BLM, with the majority of the published diversity concentrated in the Watahomigi Formation (Gordon 1982; McKee 1982c). The 2020 field inventory observed additional taxa in the Toroweap, Kaibab, and Moenkopi Formations, primarily in PARA-BLM. The majority of the most identifiable specimens are pectinids, of which several genera can be distinguished in the Toroweap and Kaibab Formations: *Acanthopecten*, notable for curved markings resembling stereotypical drawings of ocean waves (Figure 45A); *Annuliconcha*, with a distinctive stair-step appearance (Figure 45D); and *Aviculopecten*, with numerous fine ribs that are "bundled" in pairs (Figure 45B). An interesting pectinid from the Kaibab Formation of PARA-BLM appears to show

nodes along some ribs, similar to *Pseudomonotis hawni* (Figure 45C). Another location had slabs with diminutive bivalves, indicative of a different facies (Figure 46). Several taxa of small bivalves can be recognized in the Moenkopi Formation as well (Figure 47). Additional technical information on Supai Group bivalves can be found in Gordon (1982) and McKee (1982b, 1982c), and on Toroweap and Kaibab Formation bivalves in McKee (1938) and Chronic (1952).

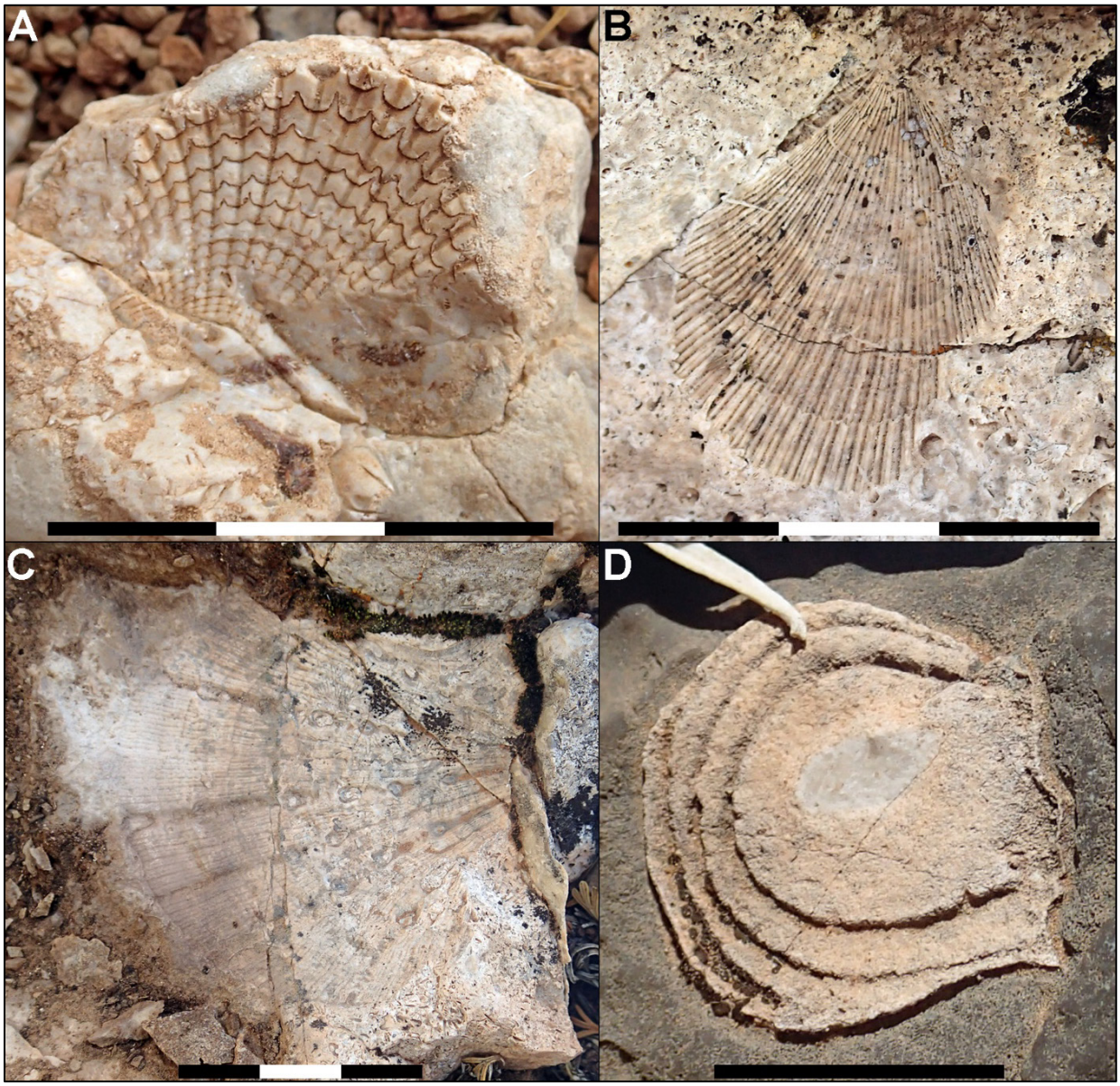


Figure 45. Pectinids, PARA-BLM, Kaibab Formation except D (Toroweap Formation) (NPS/2020 FIELD INVENTORY). Scale is 3 cm in A–C, 1 cm in D. **A.** *Acanthopecten*. **B.** *Aviculopecten*. **C.** cf. *Pseudomonotis hawni*. **D.** *Annuliconcha*.



Figure 46. A loose stone crowded with diminutive bivalves. Kaibab Formation, PARA-BLM (NPS/2020 FIELD INVENTORY).

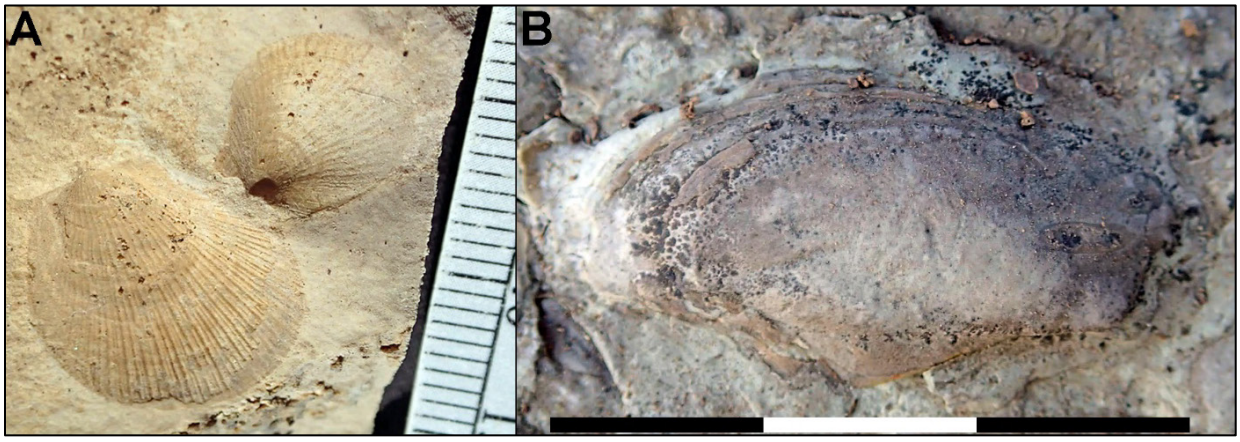


Figure 47. Moenkopi Formation bivalves, PARA-BLM (NPS/2020 FIELD INVENTORY). **A.** *Leptochondria*?. **B.** *Bakevellia* or *Unionites*. Scale bar is 3 cm.

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

Thus far cephalopods are a minor constituent of the upper Paleozoic invertebrate assemblages within PARA. There are several subclasses of cephalopods, but only one, the Nautiloidea, has been definitely reported from PARA, and these nautiloids have only been classified according to their basic configuration: orthoconic or coiled. Orthoconic nautiloids, now extinct, grew elongate straight or gently curved conical shells, divided into numerous internal chambers by walls called septa. Coiled nautiloids include shells resembling the modern chambered nautilus. They can be generally distinguished from comparably sized coiled ammonoid cephalopods by the simpler septa of nautiloid shells, which do not form the ornate patterns seen in some ammonoids. Nautiloid chambers also tend to be concave with respect to the opening of the shell, and the internal siphuncle is usually centered in the chambers rather than near the outer curve as in ammonoids. Undetermined orthoconic nautiloids have been reported from the Callville/Pakoon interval of PARA-NPS (LAKE collections) and the Manakacha (McKee 1982b) and Toroweap Formations (Schleh 1966) of PARA-BLM. Undetermined coiled nautiloids have only been reported from the Toroweap Formation of PARA-BLM (Schleh 1966). No definite cephalopods were observed during the 2020 field inventory.

Phylum Mollusca: Class Gastropoda (snails)

Gastropods are another group known from the Paleozoic that is very familiar today. Many Paleozoic snails had shells that resemble some modern forms. Most of the gastropod fossils of PARA have been found in the Callville/Pakoon interval, the Watahomigi Formation, or the Kaibab Formation, although there are a few reports, mostly from PARA-BLM, from the Redwall Limestone, Manakacha Formation, Wescogame Formation, and Toroweap Formation. Many of the gastropod shells can be placed in one of four basic shapes: shells coiled in a flat plane (planispiral) resembling coiled cephalopods or cinnamon rolls, exemplified by *Straparollus* (also known as *Euomphalus*) (Figure 48A); high-spired shells resembling the modern seashell *Turritella*, exemplified by *Meekospira* and *Murchisonia* (Figures 48B and 48D); bulbous planispiral shells coiling into themselves as if devouring the previous whorls, exemplified by *Bellerophon* (Figure 48C); and bulbous non-planispiral shells, exemplified by *Naticopsis*. Additional technical information on Supai Group gastropods can be found in Gordon (1982) and McKee (1982b, 1982c), and on Toroweap and Kaibab Formation gastropods in McKee (1938) and Chronic (1952). Although most of the fossils mentioned are either shells or mineralogically replaced shells, gastropods and other mollusks are frequently found as natural internal casts due to dissolution of the shells. These internal casts are known as steinkerns.

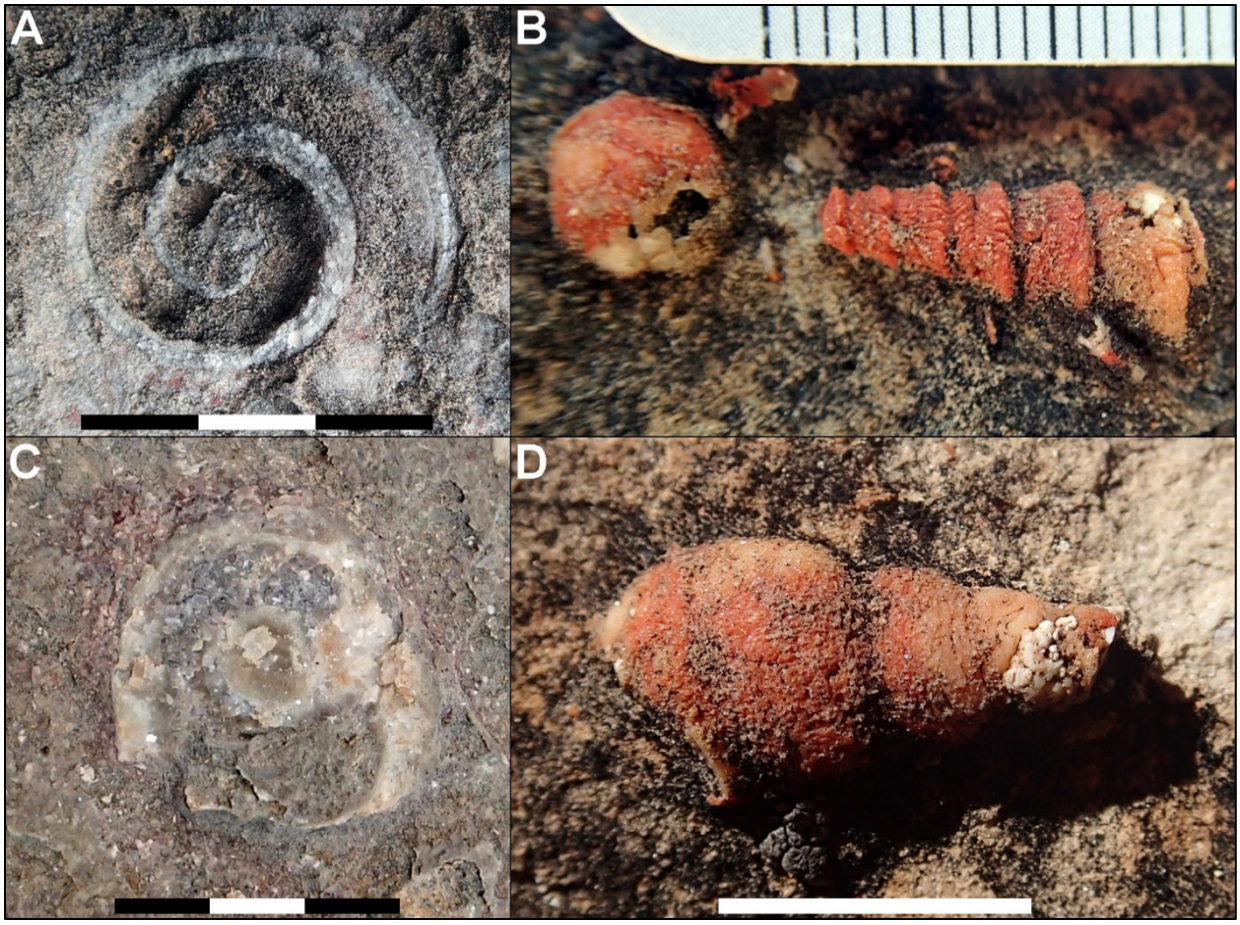


Figure 48. Various gastropods (NPS/2020 FIELD INVENTORY). **A.** *Straparollus*, Supai Group undivided, PARA-BLM. Scale bar is 3 cm. **B.** *Murchisonia* (plus a bulbous unidentified gastropod), Kaibab Formation, PARA-BLM. Ruler marks are 1 mm. **C.** Bellerophont cross-section, Redwall Limestone, PARA-NPS. Scale bar is 3 cm. **D.** *Meekospira*, Kaibab Formation, PARA-BLM. Scale bar is 1 cm.

Phylum Mollusca: Class Scaphopoda (tusk shells)

Like cephalopods, scaphopods are a minor constituent of the upper Paleozoic invertebrate assemblages within PARA. Scaphopods live buried in sediment. They are represented by generally small, gently curved or straight, tapering shells, sometimes with lengthwise ribbing. Their fossils can be confused with echinoid spines, which are similarly shaped. Unlike echinoid spines, scaphopod shells do not have a basal socket or complete tip at the apex (both ends are open), are fully hollow, and do not have smaller spines or nodes jutting from them. Echinoid spines, at least in the rocks of PARA, do not curve and may have a fusiform shape with tapering at both ends. Scaphopods or scaphopod-like fossils are known from the Callville/Pakoon interval of PARA-NPS (LAKE records) and the Kaibab Formation of PARA-BLM (Schleh 1966). Several examples of scaphopods were observed in the Kaibab Formation of PARA-BLM during the 2020 field inventory (Figure 49), and scaphopod-like fossils were seen in the Redwall Limestone of PARA-NPS (which would be the first report of scaphopods from this formation if accurate), the Pakoon Limestone of PARA-BLM, and the Kaibab Formation of both PARA-NPS and PARA-BLM.

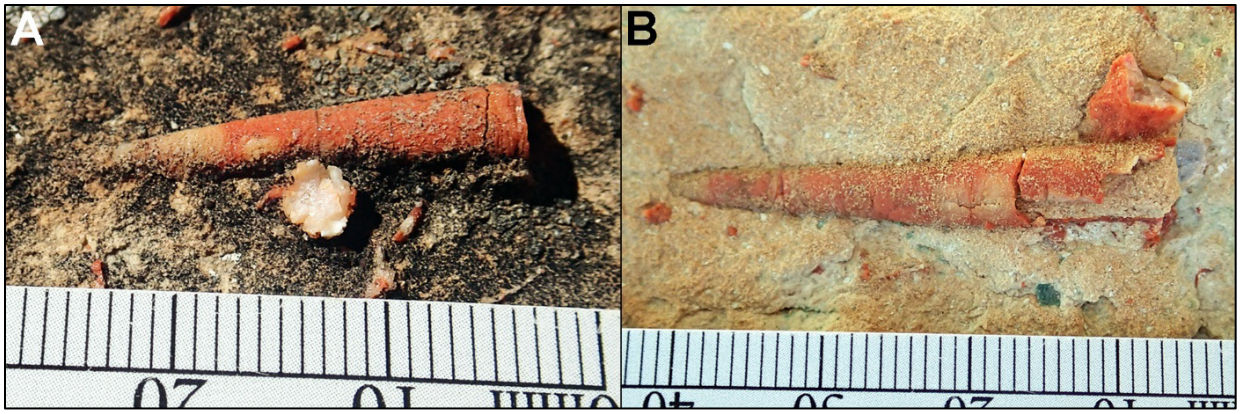


Figure 49. Two examples of scaphopods, Kaibab Formation, PARA-BLM. The red color is due to mineral replacement (NPS/2020 FIELD INVENTORY).

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

Echinoderms are a diverse group of animals known for five-fold symmetry and possession of a unique water vascular system. Asteroids (sea stars) and echinoids (sea urchins) are familiar modern echinoderms, but there are many other living and extinct groups of echinoderms with a wide variety of body plans. Two groups of echinoderms are known from PARA: crinoids, also known as sea lilies, and echinoids. Crinoids are present in most of the monument's formations from the Redwall Limestone to the Moenkopi Formation, represented by "stem" segments (columnals). Columnals are not generally diagnostic to genus or species, but there are exceptions, such as the star-shaped columnals of *Holocrinus* found in the Moenkopi Formation (Figure 50). Typical columnal shapes include simple thick-walled rings, gear- or sprocket-like, or rounded and bead-like (Figure 51).



Figure 50. Star-shaped crinoid columnals typical of *Holocrinus*. Moenkopi Formation, PARA-BLM (NPS/2020 FIELD INVENTORY).

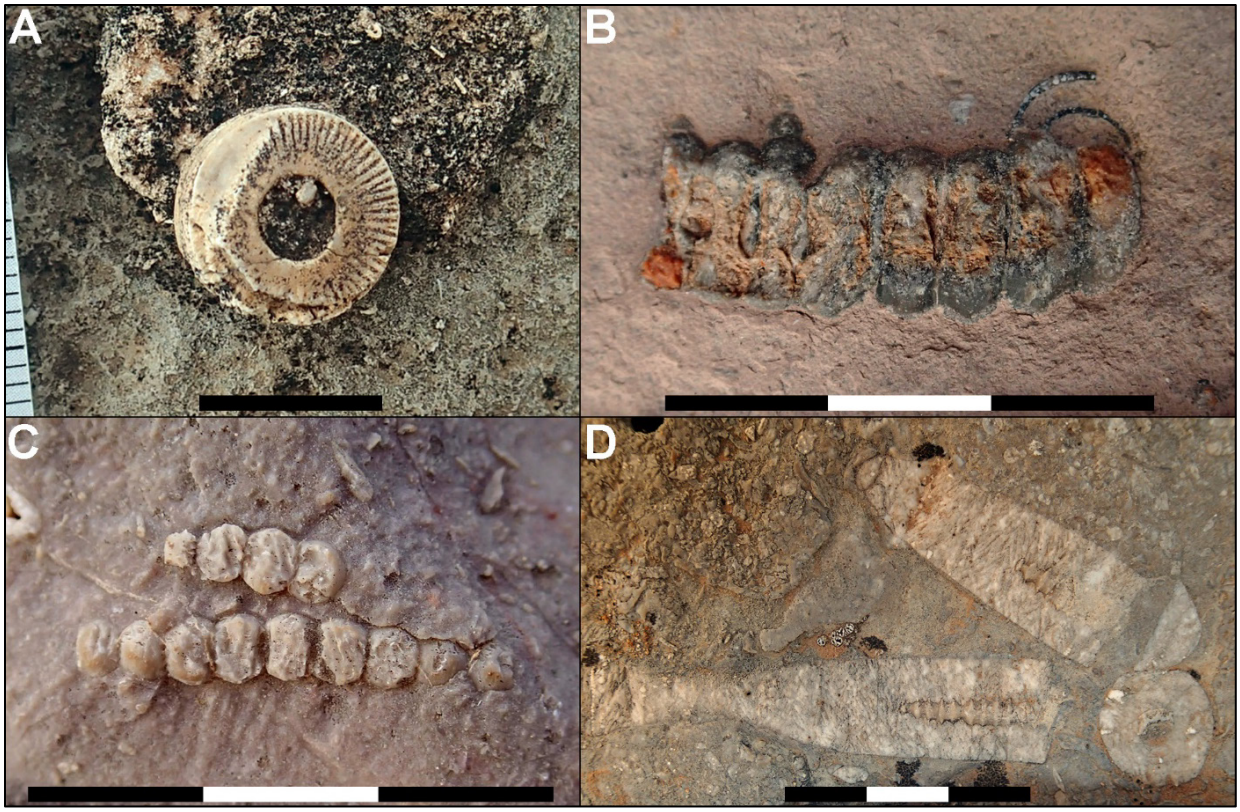


Figure 51. Various crinoid columnals (NPS/2020 FIELD INVENTORY). Scale bars are 3 cm in all but A (1 cm). **A.** A single flat cylindrical columnal, Pakoon Limestone, PARA-NPS. **B.** Several rounded columnals, undivided Supai Group, PARA-BLM. **C.** Bead-like columnals, Kaibab Formation, PARA-NPS. **D.** "Stems" in cross-section, Toroweap Formation, PARA-BLM.

PARA's echinoids are almost entirely represented by spines, which as mentioned above can be confused with scaphopod shells. Echinoid spines may feature smaller spines along their length, and/or a base with a socket (Figure 52). Echinoid fossils have been reported from the Watahomigi, Manakacha, Wescogame, Pakoon, Toroweap, Kaibab, and Moenkopi Formations.

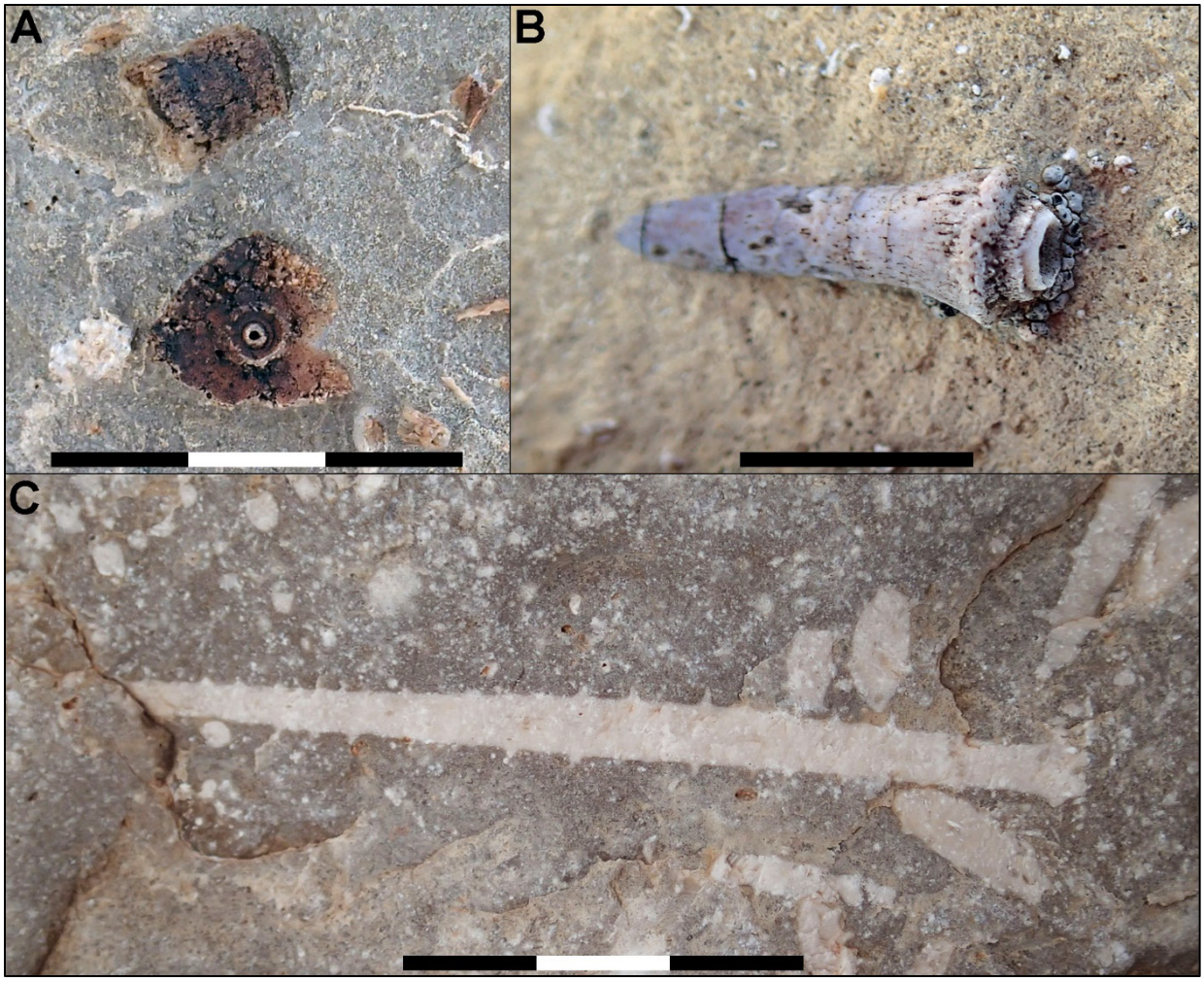


Figure 52. Echinoids (NPS/2020 FIELD INVENTORY). Scale bars are 3 cm in A and C, 1 cm in B. **A.** A socket for a spine, Pakoon Limestone, PARA-NPS. **B.** A spine showing the basal attachment, Kaibab Formation, PARA-BLM. **C.** A spine in cross-section, showing smaller points projecting from it, undivided Supai Group, PARA-BLM.

Other Invertebrates

Trilobites, among the most famous fossil invertebrates, are only represented in a few formations at PARA: *Griffithides* in the Kaibab Formation of PARA-BLM (Longwell 1928); *Paladin* in both PARA-NPS and PARA-BLM of the Watahomigi Formation and PARA-BLM of the Manakacha Formation (Gordon 1982; McKee 1982c); and undetermined trilobites in PARA-NPS of the Redwall Limestone (McKee and Gutschick 1969), both PARA-NPS and PARA-BLM of the Watahomigi Formation (McKee 1982b, 1982c), and PARA-BLM of the Kaibab Formation (Schleh 1966). They may also be present in the Bright Angel Shale and Muav Formation of PARA-NPS (Schenk 1938). No trilobites were observed during the 2020 field inventory.

Conodonts, extinct eel-like chordates known almost exclusively from their microscopic jaw elements and noted for their biostratigraphic utility, have been reported from the Callville Limestone and Watahomigi Formation of PARA-BLM (Pierce 1979).

A variety of interesting fossil fragments of undetermined taxonomic identity were observed during the 2020 field inventory. Most are probably poorly preserved or small pieces of known types of fossils, but a few are enigmatic, such as an irregular heavily perforate object (a sponge?) (Figure 53A) and a "wormy" object resembling a bryozoan in cross-section (Figure 53B).

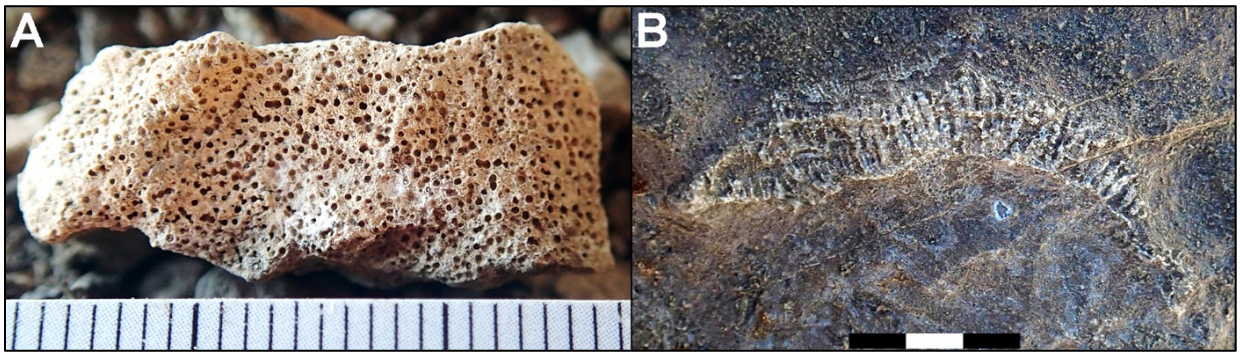


Figure 53. Examples of unidentified fossils (NPS/2020 FIELD INVENTORY). **A.** A finely perforate object, Kaibab Formation, PARA-NPS. **B.** A "wormy" object in cross-section, uncertain stratigraphy, PARA-BLM. Scale bar is 3 cm.

Fossil Vertebrates

The only pre-Quaternary vertebrate body fossils currently reported from PARA are teeth attributed to the cartilaginous fish *Deltodus* from the Watahomigi Formation of PARA-NPS and Wescogame Formation of PARA-BLM (McKee 1982c), although more such fossils are presumably present. No additional pre-Quaternary vertebrate specimens were observed during the 2020 field inventory.

Various late Quaternary vertebrates (reptiles, birds, mammals) are known from caves at PARA (e.g., Voyles 2008), but have not been scientifically described. A number of specimens were observed during the 2020 field inventory (Figure 54), and a subset was collected (see Appendix B).



Figure 54. A bat jaw from a cave deposit, PARA-BLM (NPS/2020 FIELD INVENTORY).

Ichnofossils

Trace fossils have been found in almost all of the formations exposed within PARA, from the Cambrian to the Quaternary. Plant trace fossils are represented by root traces in the Rainbow Gardens Formation of PARA-NPS and -BLM (Beard 1996; Lamb et al. 2018) and potentially the rocks of the Grand Wash Trough (or Hualapai Limestone) of PARA-BLM (Billingsley et al. 2004). Vertebrates are represented by packrat middens and dung in caves (Figures 55 and 56). Scratch marks inside one of the PARA-BLM cave sites are of unknown age, but at least some look recent.

Invertebrate trace fossils, primarily burrows and trails, have been found in practically all of the monument's formations, sometimes in great abundance (Figure 57). Of note are burrows observed in the Toroweap Formation (Figure 58), which appear to be the first trace fossils reported from this unit. The most impressive trace fossil documented during the field inventory is a block laced with trails attributable to the ichnogenus *Psammichnites* (cover image; Figures 59 and 60), interpreted as recording feeding by a subsurface animal using a siphon-like structure (Mángano et al. 2002).

Microbial trace fossils and sedimentary structures of microbial origin have also been reported in many formations. Among them are "algal laminations" in the Muav Formation of PARA-NPS (Brathovde 1986); stromatolites or potential stromatolites in several formations (Figure 61); and potential microbially induced sedimentary structures identified as *Rivularites*. Stromatolites and potential microbial features were identified in several formations during the 2020 field inventory.



Figure 55. A consolidated packrat midden, PARA-BLM (NPS/2020 FIELD INVENTORY).



Figure 56. An unconsolidated midden, PARA-STATE (NPS/2020 FIELD INVENTORY).



Figure 57. A heavily burrowed block from the Chinle Formation, Petrified Forest Member, PARA-BLM (NPS/2020 FIELD INVENTORY).

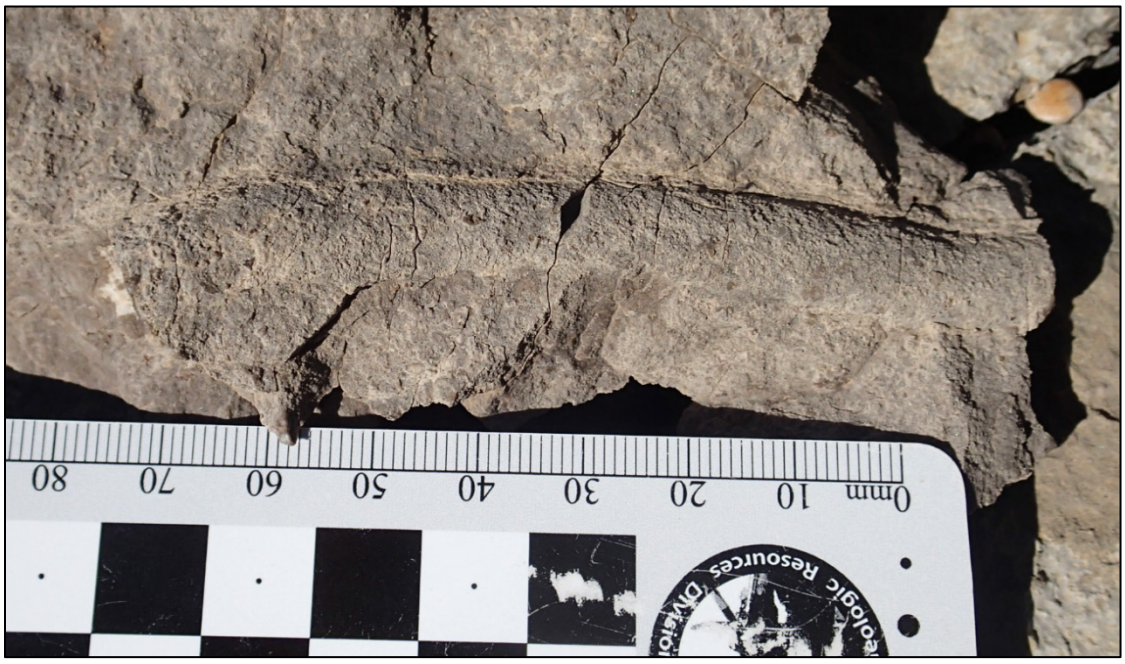


Figure 58. A burrow in the Toroweap Formation, PARA-BLM (NPS/2020 FIELD INVENTORY).



Figure 59. *Psammichnites* isp. trace fossils from the Wescogame? Formation, PARA-BLM (NPS/ ROSE WEEKS).



Figure 60. Detail of part of the *Psammichnites* trails, PARA-BLM (NPS/ ROSE WEEKS).



Figure 61. A stromatolite found at a Redwall Limestone locality, PARA-NPS (NPS/2020 FIELD INVENTORY).

Other Fossils

Some of the fossils found at PARA are taxonomically distinct from plants, invertebrates, vertebrates, or ichnofossils. The most diverse of these are foraminifera, a type of single-celled organism that can be described as “amoebas with shells”; the “shells” are known as “tests”. They have a long fossil record and are frequently used for biostratigraphy and paleoecological assessments. They are the best-documented type of Paleozoic microfossil known from PARA, found from both PARA-NPS and PARA-BLM, although given the difficulties inherent in microfossil study it is all but certain that microfossils are more abundant and diverse than presently known. Foraminifera have been found at PARA in the Redwall Limestone (Skipp et al. 1966; McKee and Gutschick 1969; Skipp 1969), the four formations of the Supai Group, the Callville Formation, and the Pakoon Limestone (McKee 1982b, 1982c). They are generally members of the extinct order Fusulinida, which flourished from the Mississippian to the Permian and are known for their relatively large tests, often resembling grass seeds or rice grains in size and shape (Figure 62). Two taxa have been named from the Redwall Limestone of PARA-BLM (Skipp 1969): *Endothyra eocompressa* and *Globoendothyra redwallensis*. There are also other microfossils, such as *Calcisphaera* from the Redwall Limestone of PARA-NPS (McKee and Gutschick 1969), as well as unidentified items.



Figure 62. Several fusulinid foraminifera are visible in this photo, the most characteristic being the example below the light-colored echinoid spine near the center. Layers of chambers are visible. Pakoon Limestone, PARA-BLM (NPS/2020 FIELD INVENTORY).

Paleontological Localities

Paleontological Localities Within PARA

During the 2020 field inventory, outcrops and other potential sources of paleontological resources were documented at 38 localities. Multiple locations were visited at some of these designated localities. Every formation or group from the Redwall Limestone up stratigraphically to the Navajo Sandstone was visited (the latter as part of a Quaternary rock shelter exploration), with the exceptions of the Surprise Canyon Formation and Coconino Sandstone. Both of these formations are of limited exposure and/or access in PARA; the Coconino Sandstone was observed on one occasion but not formally inventoried. Undivided Callville/Supai Group rocks were visited in several places without determining the exact stratigraphy. A few Cenozoic units and several caves and rock shelters with Quaternary resources were also visited. Sites included areas under NPS, BLM, and state management. Table 2 provides a brief overview. A small number of specimens were collected from a subset of the localities, primarily to serve as a voucher collection of typical fossils, but a few were collected for other reasons, such as unusual preservation or unique occurrences. These specimens are reposited at LAKE (see "Museum Collections and Paleontological Archives" below). A table of all specimens collected in 2020 is included in Appendix B. See also Figure 1 for general geographic reference. More detailed descriptions are included in the sensitive version of this report, and full details are on file at PARA and in the NPS Paleontology Archives.

Table 2. Capsule information for 2020 localities.

Locality #	Stratigraphy	Management
0001	Kaibab Formation	BLM
0002	Kaibab Formation	BLM
0003	Chinle Formation	BLM
0004	Chinle Formation	BLM
0005	Esplanade Sandstone	NPS
0006	Redwall Limestone	NPS
0007	Pakoon Limestone	NPS
0008	Esplanade Sandstone	State
0009	Redwall Limestone	NPS
0010	Quaternary alluvium with Toroweap Formation float	BLM
0011	Kaibab Formation	NPS
0012	Toroweap Formation	BLM
0013	Kaibab Formation	BLM
0014	Kaibab Formation	BLM
0015	Toroweap Formation	BLM
0016	Kaibab Formation	BLM
0017	Toroweap Formation	BLM

Table 2 (continued). Capsule information for 2020 localities.

Locality #	Stratigraphy	Management
0018	Quaternary in cave	BLM
0019	Quaternary in cave	BLM
0020	Quaternary in cave	BLM
0021	Cenozoic basalt, red dune sands, and limestone	BLM
0022	Chinle Formation	BLM
0023	Undivided Moenave/Kayenta Formations	BLM
0024	Moenkopi Formation	BLM
0025	Quaternary in cave	BLM
0026	Redwall Limestone	BLM
0027	Supai Group undivided	BLM
0028	Moenkopi Formation	BLM
0029	Gypsiferous facies of the Grand Wash Trough	BLM
0030	Rainbow Gardens Formation	NPS
0031	Kaibab Formation	NPS
0032	Quaternary in rock shelters	State
0033	Kaibab Formation	BLM
0034	Upper lower Supai Group	BLM
0035	Esplanade, Pakoon, and upper lower Supai Group	BLM
0036	Upper lower Supai Group	NPS
0037	Esplanade Sandstone and Hermit Formation	NPS
0038	Wescogame Formation and Pakoon Limestone?	BLM

Redwall Limestone

Sites in PARA-NPS

The 2020 field inventory team visited two Redwall Limestone localities within PARA-NPS: PARA PAL 0006 and 0009. The field team observed fossils both in situ and in float at the NPS localities, where they were generally sparse but locally abundant. These included horn corals, brachiopods, and crinoids. Horn corals were most abundant in what is likely the Thunder Springs Member, identified by the presence of chert lenses 2 to 3 m (7 to 10 ft) long (Figure 8). PARA PAL 0006 was notable for an exceptional horn coral site. Numerous examples of the large horn coral *Vesiculophyllum* are present here in situ, weathering out of the matrix (Figures 35 and 63). Smaller outcrops of fossiliferous Redwall Limestone were also documented at PARA PAL 0006 and included corals, brachiopods, scaphopods, and crinoids.



Figure 63. A fossiliferous Redwall Limestone “bench” at PARA PAL 0006 (PARA-NPS) with numerous rugose corals (*Vesiculophyllum*) eroding in relief (NPS/2020 FIELD INVENTORY).

All members of the Redwall Limestone were present at PARA PAL 0009. In the lower part of the formation there were horn coral beds with sporadic occurrences of other invertebrates, such as crinoids and brachiopods. Although horn corals were seen in great abundance at both PARA PAL 0006 and 0009, preservation differed greatly (Figure 64). At PARA PAL 0006, the corals appear cherty, dark, and stand out in relief from the limestone. At PARA PAL 0009, the corals show no relief and are white, making them harder to spot from even short distances.



Figure 64. Differing preservation in the Redwall Limestone (NPS/2020 FIELD INVENTORY). **A.** PARA PAL 0006 corals, PARA-NPS. **B.** PARA PAL 0009 corals, PARA-NPS.

In the literature, McKee and Gutschick (1969) described collections from several Redwall Limestone stratigraphic sections in PARA. The locality information is too vague to pinpoint the sections with any great precision. Combined records from two sections in PARA-NPS show bryozoans, brachiopods, crinoids, and trilobites in the Thunder Springs Member; corals, bryozoans, brachiopods,

crinoids, trilobites, and foraminifera in the Mooney Falls Member; and corals, brachiopods, bivalves foraminifera, and calcispheres in the Horseshoe Mesa Member (McKee and Gutschick 1969).

Sites in PARA-BLM

The field inventory visited one Redwall Limestone locality in PARA-BLM, PARA PAL 0026. This site had a typical Redwall assemblage of rugose corals, probable bryozoans, brachiopods, and crinoids.

McKee and Gutschick (1969) described fossils from a composite section along the Grand Wash Cliffs. The sections yielded foraminifera in the Whitmore Wash Member; bryozoans in the Thunder Springs Member; corals and foraminifera in the Mooney Falls Member; and corals and foraminifera in the Horseshoe Mesa Member. Skipp (1969) named two species of foraminifera from the Redwall Limestone of Snap Canyon: *Endothyranopsis eocompressa* and *Globoendothyra redwallensis*.

McKee and Gutschick (1969) also described a Redwall Limestone section from "Pakoon". The text describes the locality as "Pakoon, at Whitney Ridge, Virgin Mountains, T.36N.(?), R.16W., Ariz." (p. 7), which by township and range would be within PARA-BLM. The Redwall Limestone is mapped at the southern end of Whitney Ridge (Beard et al. 2007), but Whitney Ridge is within Nevada, albeit just on the other side of the state line. There are several geographic features with "Pakoon" in their names in or near T36N R16W in Arizona, including a high point designated "Pakoon" in T36N R16W section 24, on the Pakoon Cockscomb, but the Redwall Limestone is not mapped on this ridge or in the immediate vicinity (Billingsley et al. 2004). This leaves a conundrum: the specified combination of named geographic features, coordinates, and geology does not exist, so at least some part of the description is incorrect. Assuming that the geology would be the least likely part for a geologist to mistake, it seems most likely that the section was actually in the area of Redwall Limestone on the south end of Whitney Ridge, adjacent to the Arizona–Nevada state line on the Nevada side, and thus outside of PARA. Therefore, taxa reported from this section have been omitted. For completeness, the "Pakoon" section yielded corals, bryozoans, brachiopods, and crinoids in the Thunder Springs Member; corals, bivalves, gastropods, crinoids, and foraminifera in the Mooney Falls Member; and corals, foraminifera, and calcispheres in the Horseshoe Mesa Member (McKee and Gutschick 1969). Skipp et al. (1966) named the foraminifera *Septabrunsiina mckeei* from "Pakoon".

Supai Group, Undifferentiated

Sites in PARA-NPS

The 2020 field inventory documented three localities in PARA-NPS with Supai Group rocks: PARA PAL 0005 (Esplanade Sandstone), PARA PAL 0036 (upper lower Supai Group), and PARA PAL 0037 (Esplanade Sandstone). PARA PAL 0005 is actually two adjacent sites, featuring burrows.

PARA PAL 0036 is in an area mapped as undivided pre-Esplanade Supai Group in Billingsley and Wellmeyer (2003). Beard et al. (in press) mapped it as the Callville Formation and Pakoon Limestone, which may be more lithologically appropriate for the fossiliferous carbonate rocks documented here. Fossils, including crinoid elements and possible planispiral gastropods, are

uncommon at this locality and poorly preserved. Rocks at this locality include gray carbonates, and red and gray sandy carbonates and lime-cemented sandstones.

PARA PAL 0037 is from the same area as 0036, higher in section. It includes both the Esplanade Sandstone and Hermit Formation. The contact between the two is difficult to discern, and neither was found to be notably fossiliferous. The field inventory observed only a few invertebrate burrows in the Esplanade Sandstone.

McKee's Supai Group monograph (McKee 1982a) includes stratigraphic sections and fossil collections from several localities in PARA. Of these, the Whitmore Wash and Parashant Canyon sections are here interpreted as within PARA-NPS, but as with the Redwall Limestone sections in McKee and Gutschick (1969), the locality information is vague. Of interest, McKee (1982b) reported abundant impressions of the conifer *Walchia* in the Manakacha Formation in Parashant Canyon.

Sites in PARA-BLM

Four Supai Group sites in PARA-BLM were documented: PARA PAL 0027, PARA PAL 0034, PARA PAL 0035 (including the upper lower Supai Group, Pakoon Limestone, and Esplanade Sandstone), and PARA PAL 0038 (apparently including the Wescogame Formation and Pakoon Limestone).

PARA PAL 0027 (Figure 65) is of note because some of the fossils at this locality resemble the colorful fossils seen at some Kaibab Formation localities, having been replaced by red minerals (Figure 66). There are also beds laced with fossil fragments, including shell fragments and crinoid columnals. Lithologies include shell-hash light gray limestone, gray limestone (difficult to distinguish from the Redwall Limestone), and tan fine-grained sandstone.



Figure 65. Undivided Supai Group outcrop exhibiting planar bedding, undulations, and a silicified rugose coral below the scale bar, Grand Wash, PARA PAL 0027, PARA-BLM (NPS/2020 FIELD INVENTORY).



Figure 66. An unidentified silicified fossil fragment seen in rocks of the undivided Supai Group, PARA PAL 0027, PARA-BLM (NPS/2020 FIELD INVENTORY).

PARA PAL 0034 is mapped as upper lower Supai Group. Mixed lithology is evident here, and the interfingering Supai and Pakoon rocks make defining formations here arbitrary. Gray limestone is dominant, with many red chert lenses (Figure 67). There are also interfingering red sandstone beds, some of which are heavily burrowed (Figure 68).



Figure 67. An example of a large red chert lens in gray Supai Group limestone, PARA PAL 0034, PARA-BLM (NPS/2020 FIELD INVENTORY).



Figure 68. Extensive burrowing by large invertebrates in Supai Group sandstone at PARA PAL 0034, PARA-BLM (NPS/2020 FIELD INVENTORY).

PARA PAL 0035 also has mixed lithology and interfingering Supai and Pakoon rocks. Fossils observed here include corals, bryozoans, brachiopods, crinoids, echinoids, and fusulinid foraminifera.

PARA PAL 0038 includes both limestone beds with marine invertebrate fossils (notably echinoderms) (Figure 69) and underlying sandstone. Geologic maps of the locality show it to be near the contact of the undivided lower Supai Group and the undivided Pakoon Limestone and Esplanade Sandstone (Billingsley and Wellmeyer 2003), which suggests that the fossiliferous marine beds may belong to the Pakoon Limestone and the underlying sandstone to the Wescogame Formation, although a detailed stratigraphic study would be necessary to be certain for this gradational interval. This locality is notable for the large trace fossil block featured on the cover of this report (see also Figures 59 and 60). It is not in situ but likely originated in the immediate vicinity, as outcrops of the same lithology are present nearby.



Figure 69. Marine invertebrates in limestone at PARA PAL 0038, PARA-BLM, crowded with large and small crinoid fragments (NPS/2020 FIELD INVENTORY).

McKee described several Supai Group sections in PARA-BLM (McKee 1982a). He reported a number of fossils in each section, primarily in the Watahomigi Formation; identifiable fossils were much less abundant in the Manakacha Formation, Wescogame Formation, and Esplanade Sandstone, although sand-size fragments of fossils were present in each at the various sections. Identifiable fossils included specimens of the conifer *Walchia*, plant stems, tabulate and rugose corals, bryozoans, brachiopods, bivalves, nautiloids, gastropods, trilobites, crinoids, echinoids, conodonts, teeth of the cartilaginous fish *Deltodus*, invertebrate burrows, stromatolites, possible microbially induced sedimentary structures, “algae” and possible “algae”, and foraminifera (Gordon 1982; McKee 1982b, 1982c).

Sites in PARA-STATE

The field inventory also visited a site located on state land, PARA PAL 0008. Only infrequent burrows were observed here. However, the site does have some geological interest because the Queantoweap Sandstone was named by McNair (1951) for outcrops in this area (Johansen 1918).

Pakoon Limestone

Sites in PARA-NPS

The 2020 field inventory documented one Pakoon Limestone locality in PARA-NPS, PARA PAL 0007. The formation was very fossiliferous both here and at the PARA-BLM Pakoon Limestone sites, and the fossils were less fragmented than in other surveyed limestone units. The Pakoon Limestone at PARA PAL 0007 included examples of probable chaetetid sponges, corals, bryozoans, brachiopods, crinoids, and echinoids. The relative paucity of mollusks compared to some of the

Toroweap and Kaibab Formation localities indicates a different paleoenvironmental setting. Most of these fossils were observed in float, but Pakoon Limestone could be observed in place above the Esplanade Sandstone.

Sites in PARA-BLM

Three PARA-BLM localities including or potentially including the Pakoon Limestone were documented by the field inventory: PARA PAL 0034, 0035, and 0038. Because these localities also included the Supai Group, they were discussed above in the Supai Group section. As with PARA PAL 0007, the invertebrate faunas have relatively few mollusk specimens. All three share moderately abundant and diverse marine invertebrate fossils of moderate to good preservation.

McKee did not include any Pakoon Limestone rocks in the sections measured in eastern PARA, but did report a number of fossils from the PARA-BLM sections, again dominated by corals, bryozoans, brachiopods, crinoids, echinoids, and fusulinid foraminifera (McKee 1982b, 1982c).

Hermit Formation

Sites in PARA-NPS

PARA PAL 0037 presents a complete section of the Hermit Formation. The formation was found to be sparsely fossiliferous at this locality, with burrows (Figure 70). No plant fossils were observed, and there are more accessible sections elsewhere if someone is interested in seeing the Hermit Formation; it is mostly of interest for being in PARA-NPS. See the "Supai Group Undifferentiated" section above for discussion of the Esplanade Sandstone at this locality.

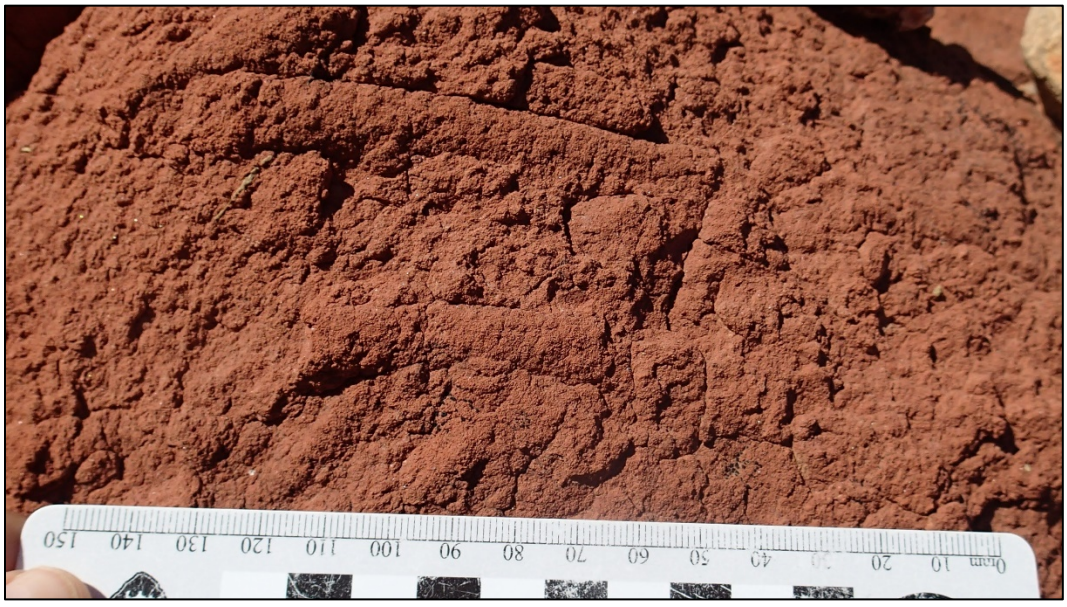


Figure 70. Burrows in the Hermit Formation, PARA PAL 0037, PARA-NPS (NPS/2020 FIELD INVENTORY).

Sites in PARA-BLM

The Hermit Formation was observed to have invertebrate burrows near the PARA-BLM locality PARA PAL 0010.

Toroweap Formation

Sites in PARA-NPS

Although the Toroweap Formation is certainly present in PARA-NPS, there are no specific reports of Toroweap Formation fossils from sites within PARA-NPS. However, there is a report in the literature for a PARA-NPS locality in undivided Toroweap–Kaibab rocks. Near the mouth of Grand Wash, on the north side of the Colorado River in the Grand Wash parcel of PARA-NPS, Longwell (1928) found bryozoans, brachiopods, and echinoids in the "Kaibab Formation", which then included the Toroweap Formation; it is possible that at least some of these fossils are actually from the Toroweap Formation.

Sites in PARA-BLM

The 2020 field inventory documented three Toroweap Formation localities within PARA-BLM (PARA PAL 0012, 0015, and 0017), and reported Toroweap Formation fossils as float at a fourth location (PARA PAL 0010).

PARA PAL 0010 is a locality where Quaternary deposits include blocks of characteristic light gray fossiliferous Toroweap Formation limestone. A transect through the Quaternary deposits showed a representative Toroweap Formation fossil assemblage in the float. Brachiopods and bryozoans were particularly evident at this locality, and corals (Figure 71) and crinoids were also present. Pseudofossils resembling petrified wood observed here are actually pieces of stylolites, irregular surfaces within rocks at which minerals have been dissolved (Figure 72). The geologic map of the area around PARA PAL 0010 shows broad plateaus of Kaibab Formation over the Toroweap Formation, with the Hermit Formation as the lowest unit in the valley (Billingsley and Wellmeyer 2003), so fossiliferous Kaibab Formation float may also be present.

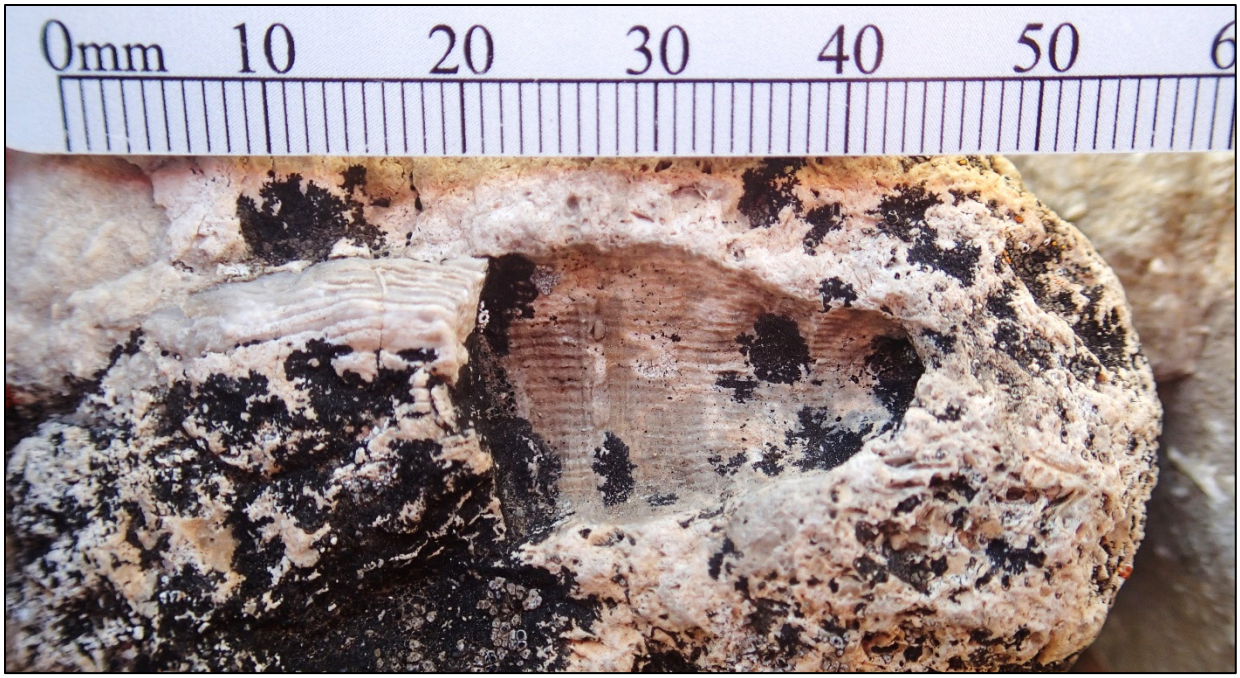


Figure 71. A horn coral preserved as mold and cast in a Toroweap Formation float cobble in Quaternary channel deposits, PARA PAL 0010, PARA-BLM (NPS/2020 FIELD INVENTORY).

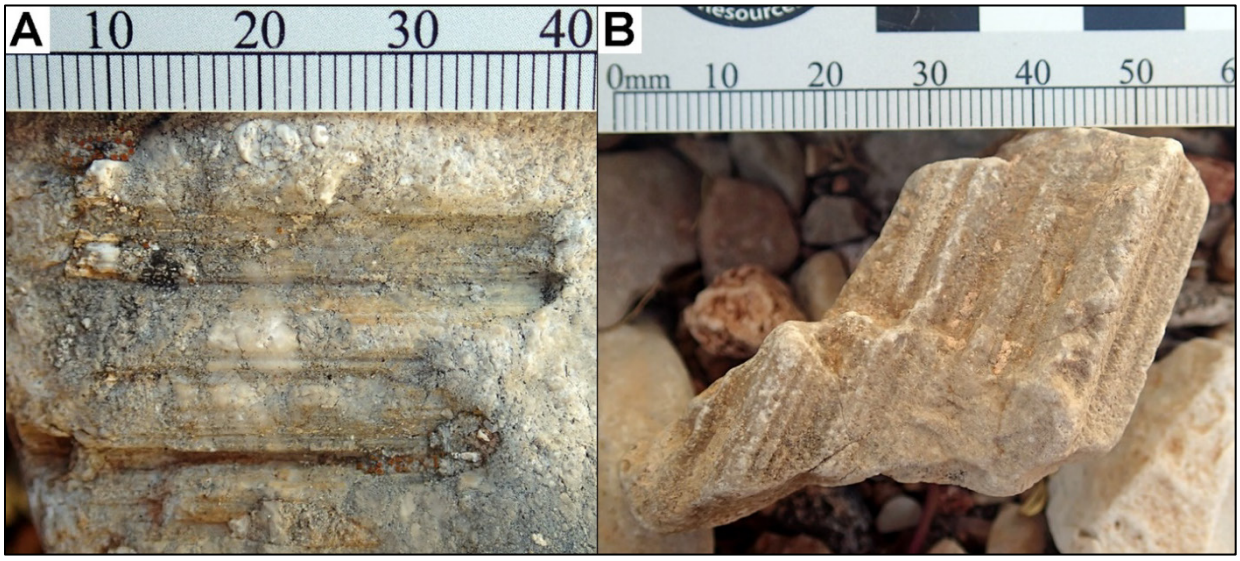


Figure 72. Pseudofossils (pieces of stylolites) with wood-like texture among Toroweap Formation float, PARA PAL 0010, PARA-BLM (NPS/2020 FIELD INVENTORY).

PARA PAL 0012 is in the Brady Canyon Member of the Toroweap Formation. Bryozoans, brachiopods, pectinid bivalves, crinoids, and echinoids are recognizable, and at least one burrow is present. The presence of burrows at PARA PAL 0010 and 0012 is of note because trace fossils are rarely if ever reported from the Toroweap Formation in the literature. They are frequently found in other marine formations, though, so their absence in the Toroweap Formation literature probably

owes more to lack of reporting than genuine absence. Strongly uneven surfaces with jigsaw-like markings can be seen at PARA PAL 0012, representing partially exposed stylolites (Figure 73A), and outcrops of the Coconino Sandstone (relatively uncommon in PARA) and the Hermit Formation are visible nearby.



Figure 73. Two views of in situ stylolites in the Toroweap Formation (NPS/2020 FIELD INVENTORY). **A.** A complex surface in the Brady Canyon Member, most likely a section through a stylolite, PARA PAL 0012, PARA-BLM. **B.** "Woody texture" at PARA PAL 0015, PARA-BLM, produced by weathering of a stylolite (NPS/2020 FIELD INVENTORY).

PARA PAL 0015 is also in the Brady Canyon Member of the Toroweap Formation. Fossils included bryozoans, crinoids, and echinoids. Otherwise, this site was most notable for weathered stylolites expressed as inorganic “woody” intervals with vertical corrugations in the steep wall of the exposure (Figure 73B).

PARA PAL 0017 is primarily in the Woods Ranch Member of the Toroweap Formation, with some underlying Brady Canyon Member. The presence of putative petrified wood is unusual. LAKE 33391 appears to be a heavily silicified section of a thick stem with irregular surficial scars (Figure 74). It was found as float, which opens the possibility that this petrified wood came from another formation, but there are no outcrops of formations known to produce petrified wood within the area currently draining into the site (Billingsley and Workman 2000). If it did actually derive from another unit better known for producing petrified wood, such as the Chinle Formation, its transport into the area must have predated the current drainage system (barring human transport). On the other hand, it is certainly not impossible for wood and other terrestrial items to be occasionally swept out to sea and deposited in marine settings, so it would not necessarily be surprising for there to be rare wood and other plant fossils in the Toroweap Formation.



Figure 74. LAKE 33391, an apparent piece of petrified wood from PARA PAL 0017, PARA-BLM (NPS/2020 FIELD INVENTORY).

Schleh (1966) described four stratigraphic sections of the Toroweap and Kaibab Formations within PARA-BLM. Bryozoans, brachiopods, bivalves, nautiloids, crinoids, and echinoids were observed in the Brady Canyon Member ("Toroweap Beta"), and a persistent shell bed of the bivalve *Schizodus* about 0.45 m (1.5 ft) thick was noted near the top of the Woods Ranch Member ("Toroweap Alpha"). The 2020 field inventory unsuccessfully attempted to locate occurrences of the *Schizodus* bed. Sorauf and Billingsley (1991) established a Toroweap Formation reference section north of the Parashant Canyon parcel of PARA-NPS. They observed numerous bryozoans, brachiopods, and crinoids in several beds of the Brady Canyon Member, and the *Schizodus* bed in the Woods Canyon Member.

Kaibab Formation

The Kaibab Formation is the most widely exposed bedrock formation in PARA, and is also among the most fossiliferous formations in the monument. Two NPS fossil sites and six BLM fossil sites were documented in the Kaibab Formation during the 2020 field inventory. Fossil preservation varied substantially from locality to locality. The Fossil Mountain Member was found to be more fossiliferous than the overlying Harrisburg Member, although it should be noted that the Harrisburg Member was only documented at two localities. Fossils observed in the Fossil Mountain Member during the 2020 field inventory include sponges, corals, branching and fenestrate bryozoans, brachiopods, bivalves (particularly pectinids), crinoids, echinoids, and rarer gastropods and scaphopods. Fossils are less abundant in the Harrisburg Member but no less diverse and include a greater abundance of gastropods, among them a possible new species of high-spired gastropod, as well as small globose gastropods, scaphopods, brachiopods, bivalves, and rarely corals and bryozoans. Sinkhole shelters created by gypsum dissolution are found in the Harrisburg Member.

Sites in PARA-NPS

Two Kaibab Formation localities were documented in PARA-NPS: PARA PAL 0011 and PARA PAL 0031. Several fossils were collected from PARA PAL 0011, apparently from the Fossil Mountain Member, although the Harrisburg Member may be present at the locality as well.

PARA PAL 0031 is a Fossil Mountain Member locality. At this locality, fossils are almost exclusively preserved in the abundant desert-varnished chert and not in the gray limestone (Figure 75). The limestone here reacts readily with acid, indicating that the absence of fossils in the limestone is not due to dolomitization. Crinoid columnals are a major exception to the lithology rule: They are easily spotted in the gray limestone. Crinoids are also more abundant at this locality than at other Kaibab Formation locations. Sponges are also seen here in both the chert and the limestone (Figure 76).



Figure 75. A Kaibab Formation brachiopod with desert varnish, PARA PAL 0031, PARA-NPS (NPS/2020 FIELD INVENTORY). Other specimens at this site are even more extensively varnished.



Figure 76. A weathered Kaibab Formation sponge with desert varnish, PARA PAL 0031, PARA-NPS (NPS/2020 FIELD INVENTORY).

Sites in PARA-BLM

PARA PAL 0001 is a Fossil Mountain Member site dominated by brachiopod fossils.

PARA PAL 0002 in the Harrisburg Member had fossils including brachiopods, bivalves, and gastropods.

PARA PAL 0013, interpreted as in the Fossil Mountain Member, had fairly diverse but poorly preserved fossils.

PARA PAL 0014, a Fossil Mountain Member locality, also had poor preservation. Fossils observed at this locality were mostly sponges, bryozoans, and brachiopods.

PARA PAL 0016, a Fossil Mountain Member site, was not unusual compared to the others, lithologically or paleontologically. Some good examples of weathering variations of invertebrate fossils were observed here (Figure 77), which are instructive for field observers who are unfamiliar with the various ways that weathering can affect fossils.

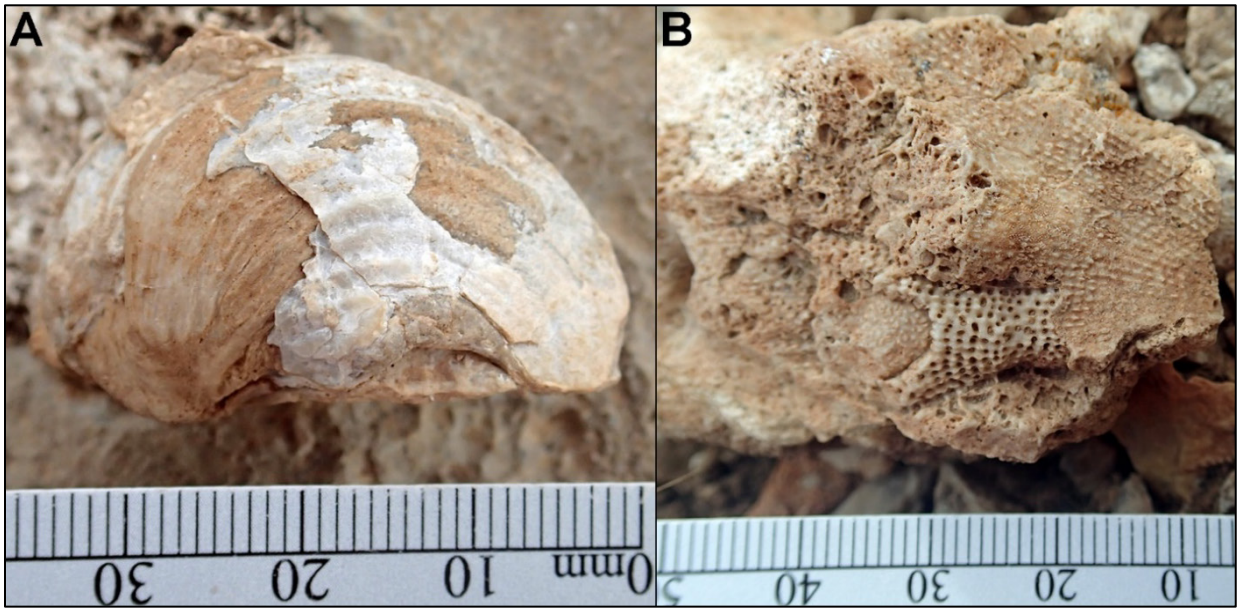


Figure 77. Fossil appearance is affected by weathering; PARA PAL 0016, PARA-BLM (NPS/2020 FIELD INVENTORY). **A.** A brachiopod that retains some original shell material. **B.** A bryozoan showing different surficial appearances based on the extent of weathering.

PARA PAL 0033 in the upper Harrisburg Member was sparsely fossiliferous, with only productid brachiopods observed.

A few PARA-BLM Kaibab Formation localities have been reported in the literature. Longwell (1928) found bryozoans, brachiopods, and trilobites at the top of a Kaibab Formation cliff. Schleh (1966) reported a number of fossils from four stratigraphic sections, mentioned above in the Toroweap Formation section. The Fossil Mountain Member ("Kaibab Beta") included sponges in chert, rugose corals, bryozoans, brachiopods, bivalves, crinoids, echinoids, and rare gastropods and

trilobites. The Harrisburg Member ("Kaibab Alpha") had more mollusks, and included bryozoans, brachiopods, bivalves, scaphopods, gastropods, crinoids, echinoids, and invertebrate burrows. Sorauf and Billingsley (1991) reported horn corals, bryozoans, brachiopods, and crinoids in the Fossil Mountain Member at their Kaibab reference section, also mentioned above.

Moenkopi Formation

Identifying Moenkopi Formation members at isolated outcrops can be difficult. The three red members in particular have very similar lithologies. Invertebrate burrows may be found in any of the members, while invertebrate body fossils are primarily found in the Virgin Limestone Member. Red bed members of the Moenkopi Formation often contain well-preserved examples of sedimentary structures, such as ripples, mud cracks, load casts, and various modes of bedding, which may be of interest for educational and interpretive purposes. No paleontological sites have been documented in the Moenkopi Formation of PARA-NPS, but two were documented in PARA-BLM during the 2020 field inventory.

Sites in PARA-BLM

PARA PAL 0024 included several members, possibly all members from the lower red member to the upper red member. Most fossils, primarily bivalves and star-shaped crinoid columnals, were found in the Virgin Limestone Member. A few bivalves and crinoids were found associated with the lower red member, but not in situ, leaving the original stratigraphic position uncertain. The lower red member and Virgin Limestone Member also had invertebrate burrows here.

PARA PAL 0028 is thought to represent the Shnabkaib Member and upper red member. The red beds had only invertebrate burrows, while the Shnabkaib Member had bivalves and a number of invertebrate traces (Figure 78).

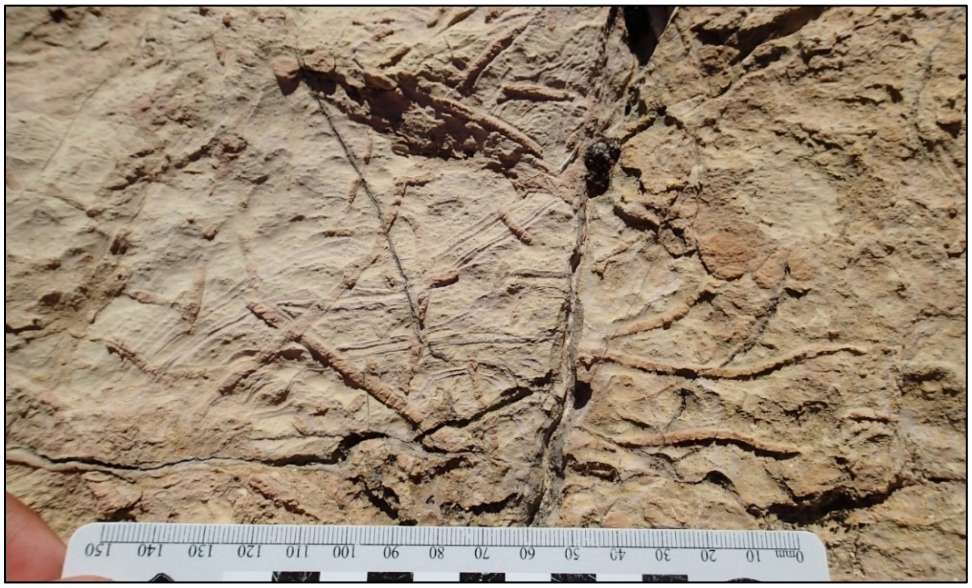


Figure 78. Moenkopi Formation trace fossils, PARA PAL 0028, PARA-BLM (NPS/2020 FIELD INVENTORY).

Chinle Formation (PARA-BLM Only)

Sites in PARA-BLM

Three Chinle Formation localities in PARA-BLM were documented as part of the 2020 field inventory. The only member definitely observed was the Petrified Forest Member. Petrified wood was found as float at all of these localities, but was not found in situ. Based on other reports of the large amount of petrified wood preserved in the Chinle Formation, it is assumed the petrified wood originated from the Chinle and not other neighboring formations. The more indurated beds showed abundant invertebrate burrows.

PARA PAL 0003 in the lower Chinle Formation had petrified wood in float and a few burrows.

PARA PAL 0004 had only petrified wood.

PARA PAL 0022 was notable for instances of extensively burrowed beds. Like the Moenkopi red bed members, this site also had numerous visually interesting sedimentary structures, including cross-bedding (Figure 79) and load casts or ball-and-pillow structures. The rocks at this locality also resemble the overlying undivided Moenave/Kayenta Formation at nearby PARA PAL 0023, but the area is mapped as the Chinle (Billingsley and Workman 2000), so this could simply be a Moenave/Kayenta-like interval in the Chinle Formation.

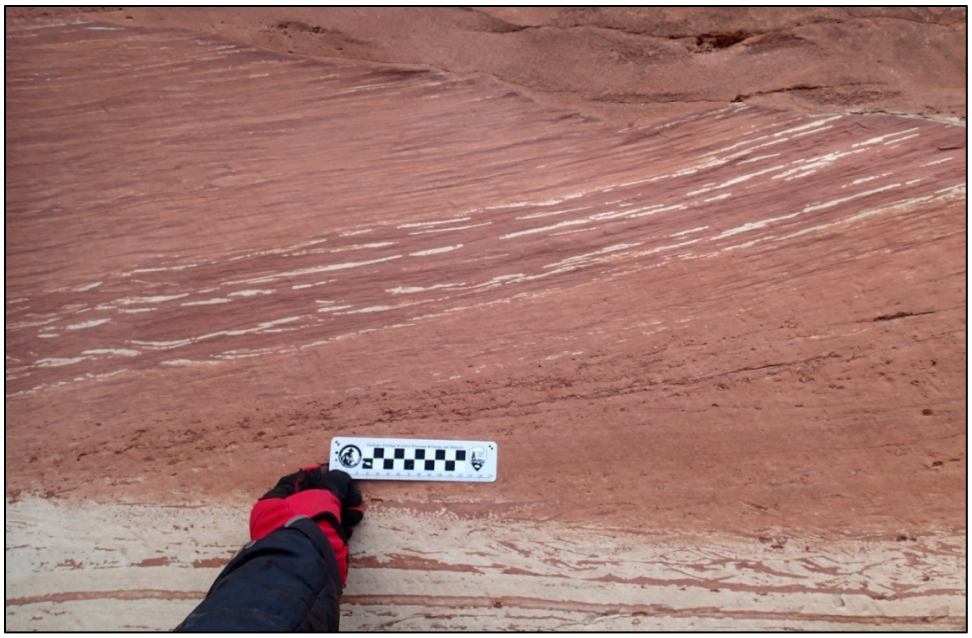


Figure 79. Color variations enhance Chinle Formation cross-bedding at PARA PAL 0022, PARA-BLM (NPS/2020 FIELD INVENTORY).

Moenave/Kayenta Formations, Undivided (PARA-BLM Only)

Sites in PARA-BLM

The 2020 field inventory included one site in the undivided Moenave/Kayenta Formation strata, PARA PAL 0023. Float pieces of petrified wood and in situ invertebrate burrows were observed at

this locality, which also had various sedimentary features similar to the underlying Chinle and Moenkopi Formations.

Rainbow Gardens Formation

Although the Rainbow Gardens Formation is exposed in both PARA-NPS and PARA-BLM, fossils have only been documented on NPS lands in PARA.

Sites in PARA-NPS

The 2020 field inventory documented one Rainbow Gardens Formation site, PARA PAL 0030. No fossils were observed during the field inventory, but fossils have been reported from this area in the past. This outcrop area was previously investigated by Longwell (1928, 1936) and Lamb et al. (2018). Longwell (1928) described it as a Moenkopi Formation locality, but by 1936 had recognized it was actually a different, much younger unit, with apparent plant stems. Lamb et al. (2018) measured a stratigraphic section and found examples of bioturbation in muddy siltstone, root traces, burrows, and undetermined tubular features.

Other Cenozoic Localities

Other Cenozoic fossils have only been documented from BLM lands in PARA.

Sites in PARA-BLM

PARA PAL 0021 is associated with a crater interpreted as a maar, a feature formed by the boiling of groundwater near or in contact with magma. The field team photographed burrows at this locality, and a variety of laminations that resemble microbial features such as stromatolites and oncoids. At least some of them are likely microbial in origin, but it can be difficult to be certain with such features because there are common inorganic methods of producing similar laminations. The site is of greater interest for its geologic features than its fossils.

PARA PAL 0029 is in an area mapped as the gypsum and gypsiferous facies of the rocks of the Grand Wash Trough (Billingsley and Wellmeyer 2003). No fossils were observed at the locality, and the field team considers it unlikely that fossils would be found elsewhere in this relatively widespread unit except as local occurrences.

Quaternary Caves and Rock Shelters

Mead (2003) provided a preliminary assessment of several caves and rock shelters within PARA-NPS and PARA-BLM.

Sites in PARA-BLM

Four cave sites in PARA-BLM were documented during the 2020 field inventory. The first three sites either have a bat gate at this time or are scheduled to receive one, while the fourth is scheduled to be sealed. At the moment, there is little known about the chronology of the caves, which presumably include a mix of late Pleistocene and Holocene materials. During the 2020 field inventory, McIntyre directed sampling for further analysis including radiocarbon dating, in addition to specimens collected for curation. These additional samples are currently at PARA. The cave sites are in fossiliferous bedrock (Kaibab Formation for the first three, and Redwall Limestone for the fourth), but no bedrock fossils were observed.

Voyles (2008) gave a brief description of a cave in PARA-BLM that included skeletal remains of at least one large bird and various mammals. Of note was a skeleton covered in calcite pool spar (Figure 80).



Figure 80. A spar-covered mammal skeleton (NPS/KYLE VOYLES).

Sites in PARA-STATE

The 2020 field inventory also investigated an area of rock shelters in a state land parcel within PARA-BLM.

Paleontological Localities Near PARA

Many of the most significant paleontological localities near PARA are in adjacent GRCA and LAKE. See Bonde et al. (2018; LAKE) and Santucci and Tweet (2020; GRCA) for further information on the paleontological resources of these NPS units.

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.

A common type of cultural association for this region is fossiliferous stone used for artifacts. For example, in the Southwest, petrified wood from the Chinle Formation was often used for points and other artifacts. The majority of parks in the neighboring Southern Colorado Plateau Network have examples of petrified wood artifacts (Tweet et al. 2009). PARA NPS archeological technician Greg Woodall has observed petrified wood used as hammer stones at sites on the east side of PARA, and reports that sometimes people would pick up fossil specimens or add them to shaman kits (pers. comm., October 2020).

In one of the caves visited in 2020 there is a coyote skull with attached atlas vertebra (Figure 81). It has been suggested that this specimen may have been brought into the sinkhole cave by humans, based on it having been found in the lower cave, comparable to cultural objects found in other caves, and the lower mandible still being attached.



Figure 81. A coyote skull and atlas vertebra, PARA-BLM (NPS/2020 FIELD INVENTORY).

Museum Collections and Paleontological Archives

Museum Collections and Curation

Monument Collections

PARA does not maintain a museum collections facility and receives curatorial support for fossils and other specimens or objects from the curator at LAKE. The majority of the fossils collected from PARA-NPS are reposited at LAKE, in Boulder City, Nevada. Most of these paleontological specimens were collected by Edward Schenk in the 1930s and pertain to his field work during the construction of Boulder Dam (now Hoover Dam) (accession 130; see Appendix Table B-2 for a list) (Figure 82). There are also five boxes of plant specimens, bones, owl pellets, and packrat midden material from the early phase of the Quaternary cave project begun by Mead and Voyles, which were transferred from Northern Arizona University (Flagstaff). The material was collected from seven caves, three in PARA-BLM, three on the BLM Arizona Strip, and one in GRCA that could only be accessed through PARA (E. Eichenberg, pers. comm., April 2021). The specimens collected during the 2020 field inventory were placed in LAKE collections (see Appendix Table B-1 for a list). The original plan was to reposit these fossils at the Museum of Northern Arizona, but during the project it was decided that it would be better to reposit them at LAKE.



Figure 82. A photo of LAKE/PARA-NPS specimens in LAKE collections, collected by Schenk in the 1930s (NPS/JUSTIN TWEET).

Collections in Other Repositories

Four other repositories have or had specimens from PARA: the GRCA Museum, the Museum of Northern Arizona (MNA; Flagstaff, Arizona), the National Museum of Natural History (USNM; Washington, D.C.), and the University of Nevada, Las Vegas (UNLV; Las Vegas, Nevada). See Appendix C for contact information.

The GRCA Museum reposits a group of paleontological and geological specimens collected by Edwin McKee from the Redwall Limestone stratigraphically up to the Kaibab Formation in Parashant Canyon; see Appendix Table B-3 for a list. Most or all of these specimens were probably obtained during the 1936–1937 collecting activities described in McKee (1937a). It is likely that at least some and perhaps all of the specimens came from the portion of the canyon administered under PARA-NPS. Of the stratigraphic units, the two lowest (the Redwall Limestone and Supai Group) are by far the best represented, with the Hermit Formation a distant third, and few specimens from the Coconino Sandstone, Toroweap Formation, and Kaibab Formation. The distribution suggests that McKee accessed the canyon from its mouth and worked up, which would be logical for field work focused on smaller canyons entering the Grand Canyon as described in McKee (1937a). The lower formations are most extensively exposed near the canyon's mouth, and the lower part of the canyon is within PARA-NPS. A PARA-NPS origin is also consistent with locality descriptions in McKee's publications (McKee and Gutschick 1969; McKee 1982a). Therefore, at least the specimens from the lower formations most likely originated from PARA-NPS rather than PARA-BLM.

The MNA has a small collection of PARA fossils, collected by David Gillette (MNA; now retired) under permits PARA-2012-SCI-0008 and PARA-2015-SCI-0007. Erin Eichenberg (TUSK integrated resources program manager; previously the LAKE museum specialist) and Jennifer Fox (PARA ecologist) visited the MNA in August 2017, where they viewed several collections including the paleontological material.

There are also some fossils in the collections of the USNM that came from PARA. These include the type specimens of two foraminifera collected from PARA-BLM (Skipp et al. 1966; Skipp 1969). Some of Schenk's fossils identified by USGS scientists for LAKE in the early 1960s were retained for USGS reference collections, and would now be in USNM collections, but none of the retained specimens came from localities now in PARA based on correspondence between Douglas B. Evans (LAKE) and Harold I. Saunders, July 10, August 14, and August 29, 1972.

The University of Nevada, Las Vegas has a small number of specimens from PARA. These were collected by Stephen Rowland (UNLV; now retired) under permit PARA-2012-SCI-0002. They consist of cave packrat midden material, catalogued as LAKE 31729, 31730, 31731, and 31732 under accession LAKE-00576. Per Rowland and Olsen (2016), these middens are of middle to late Holocene age.

Type Specimens

The type specimens of two fossil species are known to have been found at PARA-BLM localities (Table 3). Both are species of foraminifera from the Redwall Limestone.

Table 3. Fossil taxa named from specimens found within PARA-BLM.

Taxon	Publication	Holotype	Provenance	Notes
Endothyra eocompressa	Skipp 1969	USNM 641824 (641822 per USNM catalog)	Mississippian, Redwall	Foraminifera
Globoendothyra redwallensis	Skipp 1969	USNM 641763	Mississippian, Redwall	Foraminifera

Archives

NPS Paleontology Archives

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 monument-specific and servicewide information pertaining to paleontological resources documented throughout the NPS. If any resources are needed by NPS staff at PARA, or additional questions arise regarding paleontological resources, contact the NPS Senior Paleontologist & Paleontology Program Coordinator Vincent Santucci, vincent_santucci@nps.gov. Monument 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 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). There are a number of such files relevant to PARA. Most of them can be grouped under one of two projects: identifications of fossils collected by Schenk during the 1930s for LAKE; and identifications of fossils collected by McKee for his work on the stratigraphy of the Supai interval.

The Schenk collections were sent to the USGS for identification in 1960, and most of the work was completed in the early 1960s, but circumstances resulted in the project being shelved and forgotten until 1972, after an inventory of LAKE collections showed that the specimens were still out. The USGS then completed the identifications and sent the specimens back to LAKE, with the exception of a few items retained for USGS reference collections; none of the retained specimens was from a PARA locality. The work that culminated in McKee's Supai Group monograph (McKee 1982a) included two decades' worth of USGS memos identifying fossils. Most of the unpublished and preliminary identifications were superseded by identifications in the monograph, but the memos do

provide useful historical information about the creation of this monograph. Unfortunately, they do not greatly clarify his localities, which are vague in both the publication and the memos. In fact, the memos can be more difficult to interpret due to McKee's use of undefined field codes for localities.

Photographic Archives

More than 1,700 digital photos were taken during the 2020 field inventory, of which a subset of 1,320 is considered the "photos of record". Copies of these photos are held by PARA and the NPS Paleontology Archives. A photo index has been prepared, identifying the locality, geology, date, and subject of each in a spreadsheet format. There is also an annotated version of the index with additional comments on the taxonomic identifications of many of the subjects. For convenience, these photos are referred to by the last four digits of the file name, from 0001 to 1320. The photos not considered part of the "photos of record" generally show landscapes, plants or animals, camp settings, or one or more of the field party in action, and as such are valuable supplementary images documenting the project itself.

In addition to these photos, PARA has photos of fossils seen in the field by staff, interns, and others. These and the inventory photos should be integrated at some point to ensure that all relevant photos are in one digital location.

PARA Paleontological Research

Current and Recent Research

Beginning in 2000, when PARA was established, five permits have been issued for projects with a significant paleontological component within PARA-NPS. In some cases, paleontology was a secondary focus of the project. In descending chronological order, the permitted projects include the following ("principal investigator" is the person listed as such in the Research Permitting and Reporting System [https://irma.nps.gov/RPRS/]; projects may have many more investigators and associated institutions):

PARA-2012-SCI-0002, principal investigator Stephen Rowland of University of Nevada, Las Vegas, project "*Pilot Study of Packrat-Midden Paleoecology as a Proxy for Vegetation Change and Climate Change on the Shivwits Plateau, Parashant National Monument*", issued for 2012.

PARA-2012-SCI-0004, principal investigator Neil Marchington, independent researcher, project "*Grand Wash Cliffs Cave Inventory Within Selected Canyons*", issued for 2012.

PARA-2012-SCI-0008, principal investigator David Gillette of the Museum of Northern Arizona, project "*Inventory and Analysis of Fossil Resources Found Within* [site name redacted]", issued for 2013–2015; this project was continued in succeeding years under permit PARA-2015-SCI-0007 (2016–2018).

PARA-2020-SCI-0002, principal investigator Justin Tweet of the National Park Service, project "*Parashant National Monument Paleontological Inventory*", issued for 2020–2021. This report was supported by this permit.

Two permits issued for collection of material for interpretive purposes, which mentioned fossils as potential items for collection, were omitted from the list for two reasons: the absence of a research component, and the investigator annual reports did not mention collecting fossils (PARA-2013-SCI-0001 and PARA-2017-SCI-0013). Note that prior to 2012, research permits for the NPS lands in PARA were handled through LAKE, and the BLM state office is responsible for BLM lands. The project including Gillette's and Rowland's research was initiated with Jim Mead under a BLM permit. Rowland's collecting focused on packrat middens, while Gillette's focused on small vertebrate bones (J. Fox, PARA ecologist, pers. comm., April 2021).

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 2006, 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 F.

Recommended Research

Research topics that would follow from this inventory include the following, in rough stratigraphic order of topics from Quaternary to older:

- Dating of cave samples procured during the inventory
- Inventories of packrat midden sites and description of midden contents, which would also support interpretive interest in Quaternary climate and ecological change at PARA
- Surveys of the Moenkopi Formation
- Analysis of the striking color replacement of remineralized Kaibab Formation fossils
- Further surveys of lower Supai Group formations; one topic of interest is investigation for additional invertebrate trace fossil sites similar to PARA PAL 0038
- Visits to the few Surprise Canyon Formation outcrops; this formation is significantly fossiliferous elsewhere, including vertebrate fossils

Interpretation

At this time, PARA presents limited information about paleontology in their interpretation and education programs. The monument does not currently participate in National Fossil Day. Family visitation is affected by the distance and expense (including vehicle preparation) involved in reaching PARA (M. Wimmer, PARA BLM monument manager, pers. comm., October 2020). The monument does receive material such as NPS paleontology coloring books (A. Franklin, PARA interpretive ranger, pers. comm., October 2020). PARA has a rock box for interpretive purposes, but this does not include fossils, nor is there an interpretive collection of actual fossils, although photos of fossils are available (A. Franklin, pers. comm., October 2020). Some permits issued for collecting material for interpretive purposes mention the possibility of collecting fossils, but associated investigator annual reports show no fossils were collected. PARA outreach and education programs include school visits, brown bag lunch seminars, and a yearly Southern Paiute cultural camp (A. Franklin, pers. comm., October 2020).

Current Long Range Interpretive Plan

A long range interpretive plan was produced for PARA in 2012. Paleontology and geology are included but not fleshed out (A. Franklin, pers. comm., November 2020). The PARA foundation document (NPS 2016) includes an interpretive topic incorporating paleontology, "Rock of All Ages: Geology and Paleontology of Parashant". Themes under this topic include:

> *"The exposed stratigraphy and continuing natural processes within the monument reveals the progression of time and the natural history of the earth."*
>
> *"The vast acreage of clearly defined geological formations provides an unsurpassed classroom for geological and paleontological research."*
>
> *"Volcanic rocks, cinder cones, and basalt flows ranging in age from 9 million to only about 1,000 years old tell of ancient volcanic activity throughout the monument."*
>
> *"Parashant's robust fossil record, spanning early sea life to present-day plants and animals, contributes to our understanding of global forces and climate change."*

Recommended Interpretive Themes

I. General Paleontological Information

All of the following interpretation topics include a section instructing visitors how to be paleontologically aware while in the monument. The ranger will provide the visitor with advice on why fossils are important, how paleontologists look for fossils, what to do if fossils are found, and reminders to be aware that fossils exist and should be respected within monument boundaries.

- Fossils are non-renewable resources that possess scientific and educational information and provide insight into what Earth was like thousands and even hundreds of millions of years ago.
- When paleontologists survey for paleontological resources, the most important tool is a geologic map. Paleontological resources are more common in certain geologic units, so

knowing where those units are exposed is important for a successful search. Other tools that a paleontologist takes into the field include small picks and brushes, consolidants to stabilize fossils, GPS, camera, topographic maps, and appropriate First Aid and safety equipment. It might be helpful to provide examples of these items for visitors when giving an interpretive talk.

- If fossils are found in the monument by a visitor, the visitor should photograph it and notify a ranger of where the resource was found, but most importantly, they should leave the fossil where they found it. It is extremely important for scientific and resource management purposes for locational information to be preserved. Visitors should be informed that monument fossils are protected by law.

II. Fossils of PARA

- A program could be developed to educate the public on what types of fossils are present in PARA and what they tell scientists about Earth's dynamic history. The goal of this program is to increase visitors' understanding of local geology and paleontology. Therefore, information regarding fossils from the vicinity of PARA can be included as necessary.

III. Caves and Fossil Resources

- Resources for this interpretation theme are listed in the references section. The key reference is Santucci et al. (2001).

IV. Further Interpretation Themes

National Fossil Day is celebrated annually on Wednesday of the second full week in October, which is National Earth Science Week. For more information on this event visit: https://www.nps.gov/subjects/fossilday/index.htm. Conducting one of the suggested paleontology-focused talks on this day would be a perfect opportunity to not only increase public awareness about paleontological resources in PARA, but also connect with other parks and museums who are also participating in this national event. The NPS Geologic Resources Division can assist with planning for National Fossil Day activities and provide supplies for the Junior Paleontologist Program including activity booklets, badges, posters and other fossil-related educational resources (https://www.nps.gov/subjects/fossils/junior-paleontologist.htm).

Other Recommendations for Interpretation and Education

The relative lack of active paleontological content in interpretive and educational programs and materials means that there is an opportunity to produce new content. Staff provided a number of suggestions during interviews. PARA is in an unusual situation compared to many NPS areas. It is a remote, rugged area with few facilities, influencing the number of visitors and the kinds of activities they pursue. There is some apprehension about the wisdom of highlighting and promoting resources, not only from the standpoint of protecting that resource, but for protecting and conserving the monument's other resources, and to avoid encouraging unprepared visitors to get into situations where they may put their safety at risk. On the other hand, there is also a sense of wanting to bring the monument to visitors. Co-management by the NPS and BLM inevitably brings not only differences in laws and policies, but unwritten institutional differences in approaches to visitation,

use, and management. As with any resource, care must be taken when determining how much information can be given to the public. Staff do not feel that paleontology is currently a significant draw at PARA (fossils are mostly small marine invertebrates, not dinosaurs or other large vertebrates), but there is also the general sense that when resources are publicized at PARA, they disappear (G. Woodall, pers. comm., October 2020).

- In general, there is interest in more paleontological and geological information for physical media and the website. Suggestions for physical media include kiosks, waysides, signs, and exhibits.
- Several PARA staff interviewed for this project would like to see products that could be used to identify specimens. Photographs taken during the field inventory and composite figures of specimens prepared for this report could easily be combined with a small amount of text to give pointers on recognizing and distinguishing fossils at various taxonomic levels. Multiple products could be produced, e.g., material appropriate for visitors, and a "field guide" appropriate for interns and full-time staff to allow them to identify what they see in the field, improving documentation. Other topics that could be incorporated for staff include where fossils are found (geographically and geologically), descriptions of the rock units, how fossils are formed, and whether a certain type of fossil is expected or unusual. Much of this information can be drawn from this inventory report. Both physical (pamphlets, fliers, etc.) and digital (websites) products could be created for visitors.
- Documenting specimens with photogrammetry is recommended as an effective way to address multiple staff suggestions and resource management issues. For example, photogrammetric models of collected specimens can be used for interpretive/educational purposes. See for example the GRCA "virtual museum" at https://www.nps.gov/articles/series.htm?id=A9E62040-AC6F-A6D7-BE564A036F1D6146. Digitized specimens can also be printed using a 3D printer, making them more available for interpretive purposes. Photogrammetry of unusual specimens that cannot feasibly be removed from the field would make them available for study, interpretation, and management. The *Psammichnites* block is an ideal candidate due to its size and remoteness; photogrammetry would provide a quality model for study and interpretation, and could be used to document weathering at the site (a photo taken in March 2013 shows that visible weathering has occurred). Another area of interest is the in situ *Vesiculophyllum* "bench".
- The existing paleontology/geology presence on the PARA NPS website should be revised. There is a great deal of geologic information (see for example "Geologic Evolution of the Parashant", https://www.nps.gov/para/learn/nature/geologic-evolution-of-the-parashant.htm), but there are few illustrations to go with the text, and the long pages would benefit from being divided. Photos from the field inventory could be used to illustrate common fossil types and almost all of the significant bedrock units of the monument. See also the LAKE museum online fossil photos at https://www.nps.gov/features/lake/museum/fossils.html.
- Because of the challenges involved with on-site National Fossil Day events, PARA may consider the possibility of remote participation, or doing something in conjunction with a related unit such as GRCA, LAKE, or Zion National Park (ZION).

- Signage should be created incorporating paleontological resources and resource management laws and policy. Such signage would not be placed at paleontologically sensitive locations, e.g., cave sites or paleontological sites near roads. Interpretation of archeological resources may be used as a guide. Suggestions for paleontological or geological signs or waysides include descriptions of features, climate and ecological change (such as the change from woodlands to desert), maars, tectonic plates, continental seas, the boundary of the Basin and Range province, and the origin of the Grand Canyon.
- The Pleistocene cave material could be used as an exhibit focus.
- There is interest in assembling an interpretive collection of fossils, which could include specimens that have been produced by 3D printing from photogrammetric models.

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 423 official units of the National Park System, plus national rivers, national trails, and affiliated units that are not included in the official number. Of these, 283 are known to have some form of paleontological resources, and paleontological resources are mentioned in the enabling legislation of 18 units, including PARA. 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 F. 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, roadway construction or building excavation that inadvertently exhumes fossils 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 associated paleontological resource data.

Management of paleontological resources at PARA involves not only the NPS, but also the BLM. This dual management has the potential to create additional complexities. Under PRPA, the NPS and BLM have some differing mandates; in particular, the BLM is mandated to consider casual collecting, while collecting is prohibited on NPS lands. However, although the BLM does permit casual collecting of common plant and invertebrate fossils on some of the lands it manages, it does not permit collecting within the lands it manages at PARA. Under the Resource Management Plan (U.S. Department of the Interior 2008), decision MA-GL-03 states "The collection of any objects in the Monument, including paleontological resources (such as fossils or track ways) or rock specimens will not be authorized, except by permit for scientific research or use." Paleontological decisions from the Resource Management Plan are included here for reference as Table 4.

Table 4. Paleontological decisions from the PARA Resource Management Plan (U.S. Department of the Interior 2008: Table 2.2 [table structure has been adapted for this document]).

Category	Decision #	Decision Text
Desired Future Conditions	DFC-GL-01	Paleontological resources will be managed for their scientific, educational, and recreational values.
	DFC-GL-02	Geological and paleontological Monument objects will be protected. These may include all vertebrate or uncommon invertebrate fossils or localities and relevant and highly visible geological features and formations.
Land Use Allocations	LA-GL-01	Areas will be classified according to their potential to contain vertebrate fossils or noteworthy occurrences of invertebrate or plant fossils. These Paleontological Sensitivity Classes are: **Class 1 (Low sensitivity):** Igneous and metamorphic geologic units and sedimentary geologic units where vertebrate fossils or uncommon non-vertebrate fossils are unlikely to occur. **Class 2 (Moderate sensitivity):** Sedimentary geologic units that are known to contain or have unknown potential to contain fossils that vary in significance, abundance, and predictable occurrence. **Class 3 (Moderate sensitivity):** Areas where geologic units are known to contain fossils but have little or no risk of human-caused adverse impacts and/or low risk of natural degradation. **Class 4 (High sensitivity):** Areas where geologic units regularly and predictably contain vertebrate fossils and/or uncommon non-vertebrate fossils, and are at risk of natural degradation and/or human-caused adverse impacts.
Management Actions	MA-GL-01	BLM and NPS will identify and protect significant fossils and allow for scientific research at paleontological sites, in accordance with permitting procedures.
	MA-GL-02	Should paleontological resources be discovered within the Monument, the sites will be evaluated for sensitivity. The sites will then be classified and managed consistent with the land use allocation classifications described above.
	MA-GL-03	The collection of any objects in the Monument, including paleontological resources (such as fossils or track ways) or rock specimens will not be authorized, except by permit for scientific research or use.

Table 4 (continued). Paleontological decisions from the PARA Resource Management Plan (U.S. Department of the Interior 2008: Table 2.2 [table structure has been adapted for this document]).

Category	Decision #	Decision Text
Management Actions (continued)	MA-GL-04	Prior to authorizing land uses in any Class 4 areas, a records search and paleontological survey and/or monitoring will be required so that impacts to vertebrate fossils and/or uncommon invertebrate fossils can be minimized or mitigated.
	MA-GL-05	Adverse impacts to vertebrate and/or uncommon invertebrate paleontological resources will be mitigated.

As noted in the PARA foundation document (NPS 2016), paleontological resources in PARA are vulnerable to looting because collecting may be legal in some areas nearby or adjacent to the monument. There can be genuine confusion about the permissibility of collecting within the monument, as well as feigned confusion (i.e., people can "play dumb"; M. Sims, PARA chief ranger, pers. comm., October 2020). The vast size, small staff, and sparse visitation of PARA also contribute to this issue. Unauthorized collection of fossils on BLM lands is occurring in the area around PARA. For example, there is a confiscated fossil held at the information center in St. George, Utah (A. Franklin, pers. comm., October 2020), collected from BLM land in Utah outside of PARA (J. Fox, pers. comm., April 2021).

Cave localities are in a distinct class for management due to the close connection with archeological resources and unique issues affecting cave resources. See Santucci et al. (2001) for additional discussion of paleontological resources in cave settings.

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 such a large task at PARA. Active recruitment of paleontological research scientists should also be used as a management strategy.

Baseline Paleontology Resource Data Inventories

A baseline inventory of paleontological resources is critical for implementing effective management strategies, as it provides information for decision-making. This inventory report has compiled information on previous paleontological research done in and near PARA, taxonomic groups that have been reported within PARA 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 MOJN completed by Tweet et al. (2016) and the references cited within were important baseline paleontological resource data sources for this PARA-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 staff, would be scheduled for more frequent visits than a less productive or less threatened site.

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?

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. A standard locality condition form as used during the 2020 field inventory at PARA is included in Appendix D. 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 at the locality as well as the probability of being recognized as a fossil-rich area by non-paleontologists, which could lead to 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).

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 sediments 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, including 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. A foundation document is intended to provide basic guidance about a park for planning and management. It briefly describes a given park and its purpose, significance, fundamental resources and values, other importance resources and values, and interpretive themes. Mandates and commitments are also identified, and the state of planning is assessed. Foundation documents may include paleontological information, and are also useful as a preliminary assessment of what a park's staff know about their paleontological resources, the importance they place on these resources, and the present state of these non-renewable resources. A foundation document for PARA has been published (NPS 2016), as well as for LAKE (NPS 2015). This inventory can be regarded as fulfilling the medium-priority natural resources data need "paleontological survey of marine fossils" in the PARA foundation document.

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. An RSS has not yet been published for PARA, but a LAKE RSS has been published (NPS 2014) and does address paleontological resources.

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 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. The NPS Geologic Resources Inventory (GRI) has been digitizing existing maps of NPS units and making them available to parks for resource management.

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). Whenever possible, page-sized geologic maps derived from GRI files are included in paleontological resource inventory reports for reference, but it is recommended that GRI source files be downloaded from IRMA for use. The source files can be explored in much greater detail and incorporated into the park GIS database. GRI maps have not been produced specifically for PARA, but the two NPS parcels are documented in the GRCA map (Parashant Canyon parcel;

https://irma.nps.gov/DataStore/Reference/Profile/2203644) and LAKE map (Grand Wash parcel; https://irma.nps.gov/DataStore/Reference/Profile/2202839). 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. A PARA-specific report does not exist at this time, nor has one been completed for related LAKE.

Paleontological Resource Potential Maps

A paleontological resource potential map is included in this report (Figure 83). The map shows the distribution of geologic units within PARA that are known to have yielded fossils within the monument (green on Figure 83), have not yielded fossils within the monument 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.).

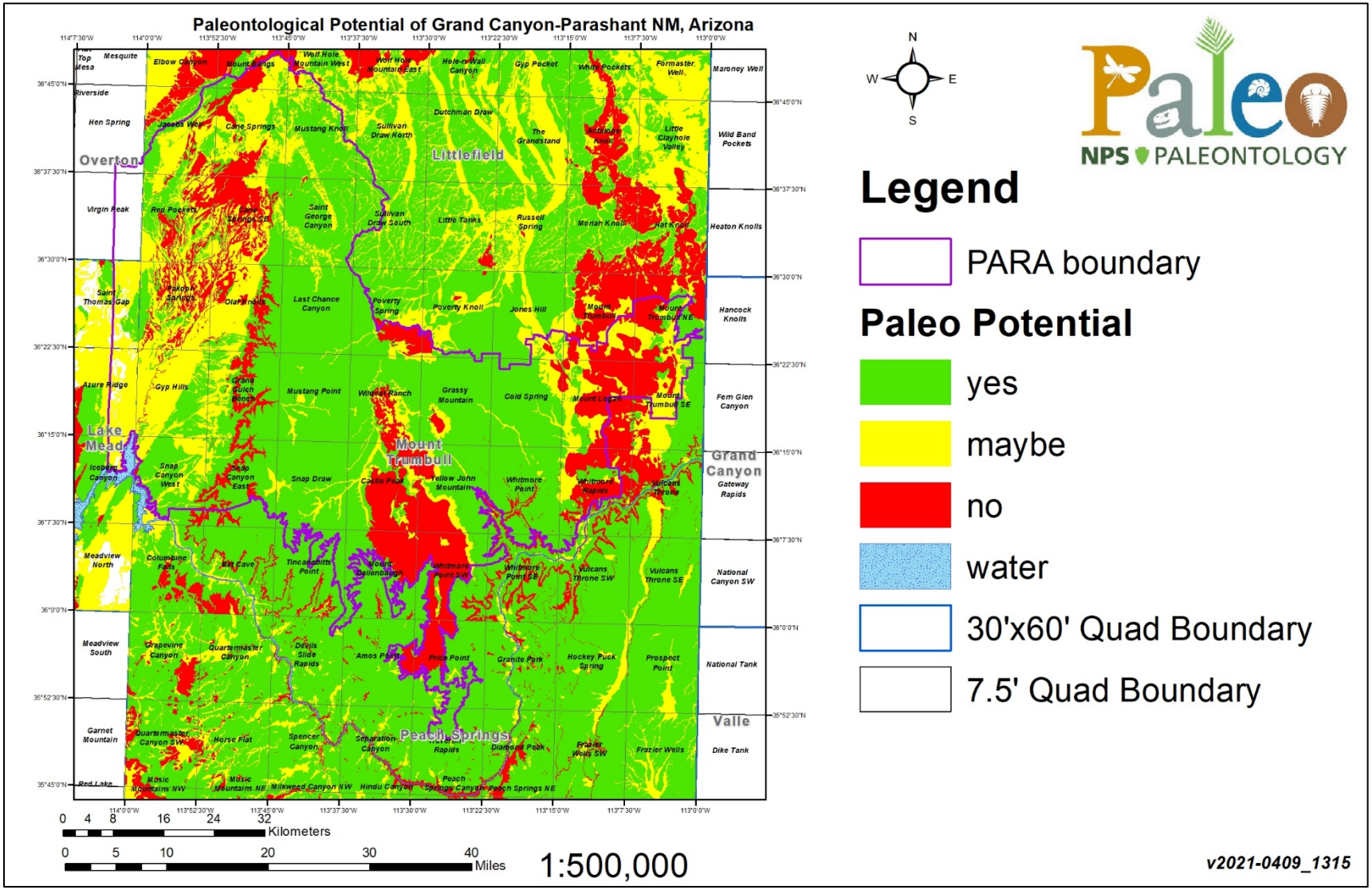


Figure 83. Paleontological potential map of PARA.

Paleontological Resource Management Recommendations

The paleontological resource inventory at PARA has documented rich and previously unrecognized paleontological resources within monument boundaries. This report captures the scope, significance, and distribution of fossils at PARA as well as provides recommendations to support the management and protection of the monument's non-renewable paleontological resources. Given the fact that PARA's enabling legislation specifically identifies paleontological resources as significant for the monument, the following recommendations would be beneficial to monument staff for the management and stewardship of the monument's important non-renewable paleontological resources.

- PARA staff should participate in paleontological resource training. This training could include specific discussions such as how to recognize and document paleontological resources, and BLM and NPS policies for paleontological resource management. Paleontological resource training was mentioned in most of the staff interviews and therefore should be considered a high priority.
- PARA staff should be encouraged to observe exposed rocks and sedimentary deposits for fossil material while conducting their usual duties. To promote this, staff should receive guidance 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 should take advantage of them, if funding and time permit.
- PARA staff should photo-document and monitor any occurrences of paleontological resources that may be observed in situ. 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.
- Fossil theft is one of 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. When possible, the incident should be fully documented and the information submitted for inclusion in the annual law enforcement statistics.
- Fossils found in a cultural context should be documented like other fossils, but 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 (i.e., subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.
- The monument may fund and recruit paleontology interns as a cost-effective means of enabling some level of paleontological resource support. The Scientists in Parks program (Geoscientists-in-the-Parks before 2021) is an established program for recruitment of geology and paleontology interns, and was utilized to provide support for this inventory.

- This inventory should be utilized by PARA staff to inform their observations while performing other duties. Sightings of fossils not mentioned in this report are of great interest because they may not yet be known within PARA.
- People working in the field for PARA under any capacity should be briefed on what to do if they find fossils while in the field. Trail maintenance crews and firefighters especially see locations infrequently or never visited by even seasoned monument staff.
- Building on the previous two items, informal observations should be archived and integrated with the information recorded during this inventory. For example, locality numbers should be assigned as necessary, with a corresponding locality form prepared, and relevant photos should be archived.
- A monitoring schedule should be prepared for the investigated sites based on this inventory. PARA currently has a database of ARPA-sensitive sites with monitoring intervals. This system could be adapted for paleontological sites.
- Preparing a geospatial layer of sensitive paleontological sites would not only improve site monitoring, but also show areas to avoid during placement and repair of trailheads, campsites, and other infrastructure.
- Further archiving should be conducted on the inventory photo collection. The current numbering system is workable, but more indicative file names incorporating locality numbers would be more robust (e.g., a format such as "PARA_PAL_0001_0001", with a photo number at the end). If this is undertaken, it must be done with great care. A separate column must be made in the photo guide spreadsheet for the new file names, to preserve a record of the original numbering.
- The specimens collected as part of the Quaternary cave studies are currently at three institutions (LAKE, MNA, and UNLV). In order to have formal record of these specimens and accountability for their care, the specimens at LAKE and MNA need to be cataloged and identified, and the specimens at UNLV need loan paperwork.
- The far southwest part of PARA, the area of the Grand Wash parcel adjacent to the Colorado River, was not visited in this project. This area would be a good choice for a future visit. The rocks are accessible from the river and include units that are known to be significantly fossiliferous, such as the Redwall Limestone, Pakoon Limestone, Toroweap Formation, and Kaibab Formation, so for resource management it would be useful to establish a baseline in this area. In addition, the monument's most extensive outcrops of Cambrian and Devonian formations are in this area, and these units were not visited during the field inventory.
- Several PARA staff interviewed for this project would like to see products that could be used to identify specimens. Photographs taken during the field inventory and composite figures of specimens prepared for this report could easily be combined with a small amount of text to give pointers on recognizing and distinguishing fossils at various taxonomic levels. Multiple products could be produced, e.g., material appropriate for visitors, and a "field guide" appropriate for interns and full-time staff to allow them to identify what they see in the field, improving documentation. Other topics that could be incorporated for staff include where

fossils are found (geographically and geologically), descriptions of the rock units, how fossils are formed, and whether a certain type of fossil is expected or unusual. Much of this information can be drawn from this inventory report. The GRCA (Santucci and Tweet 2020) and LAKE (Bonde et al. 2018) paleontological inventories also contain useful information because they document nearby areas with similar geology and paleontology. Both physical (pamphlets, fliers, etc.) and digital (websites) products could be created for visitors.

- Documenting specimens with photogrammetry is recommended as an effective way to address multiple staff suggestions and resource management issues. For example, photogrammetric models of collected specimens can be used for interpretive/educational purposes. See for example the GRCA "virtual museum" at https://www.nps.gov/articles/series.htm?id=A9E62040-AC6F-A6D7-BE564A036F1D6146. Digitized specimens can also be printed using a 3D printer, making them more available for interpretive purposes. Photogrammetry of unusual specimens that cannot feasibly be removed from the field would make them available for study, interpretation, and management. The *Psammichnites* block is an ideal candidate due to its size and remoteness; photogrammetry would provide a quality model for study and interpretation, and could be used to document weathering at the site (a photo taken in March 2013 shows that visible weathering has occurred). A Technical Assistance Request has been submitted by PARA for photogrammetry of this block. Another area of interest is the in situ *Vesiculophyllum* "bench".
- If the opportunity to add staff arises, it would be useful to add someone with a focus on geological and paleontological resources, as well as additional interpretation staff.
- Contact the NPS Paleontology Program for technical assistance with paleontological resource management issues.

If fossil specimens are found by PARA 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 PARA and position in the outcrop, if applicable. If the relevant USGS 7.5' quadrangle, Township-Range-Section, or similar are known, these should be recorded. If possible, revisit the site when a GPS unit is available.
- Record associated data, such as rock type, general description of the fossil, type of fossil if identifiable, general location in PARA, 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.
- Do not remove the fossil unless it is loose in a heavily visited area, such as a public trail, and is at risk of being taken or destroyed. If the fossil is removed, be sure to wrap in soft material, such as tissue paper, and place in a labeled plastic bag with associated notes.
- If fossil resources are found, alert staff at PARA to allow for proper documentation.

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Appendix A: Paleontological Species

The following tables (Appendix Table A-1 through A-9) document the fossil species found at PARA in stratigraphic context, as reported in the literature, in museum collections, and through personal observations. Because of the large number of stratigraphic units and the relatively large number of fossil taxa, it was necessary to divide the tables into more manageable segments. The divisions are as follows:

- Appendix Table A-1: Paleobotanical taxa
- Appendix Table A-2: Pre-Supai Group fossil invertebrate taxa
- Appendix Table A-3: Supai Group fossil invertebrate taxa
- Appendix Table A-4: Post-Supai Group fossil invertebrate taxa
- Appendix Table A-5: Fossil vertebrate taxa
- Appendix Table A-6: Pre-Supai Group and Supai Group ichnofossils
- Appendix Table A-7: Post-Supai Group ichnofossils
- Appendix Table A-8: Foraminifera taxa
- Appendix Table A-9: Other fossils

Within each table, the rows are organized systematically, placing taxa of the same broad groups together (first column), with summary rows for particularly diverse groups. The columns are organized by formation, which are presented in ascending order (oldest to youngest) left to right. The columns also include the taxon (second column) and references (last column; included in "Literature Cited" above). The reference column includes records from the Grand Canyon National Park museum (GCM; Edwin McKee's collections), the Lake Mead National Recreational Area museum (LMM; Edward Schenk's collections from the 1930s), and USGS internal memos if no other report of a particular taxon from a particular formation exists in the literature. There are also numerous reports from the 2020 paleontological inventory, referenced as "PI20". These are based on field identifications made by Flora, Weeks, and others, which were cross-checked by Tweet from their photos. A few of the Kaibab Formation taxa were also identified by Robert Blodgett.

Stratigraphic abbreviations are as follows, in descending order (youngest to oldest). They follow the maps used for this report, except where no abbreviation existed. In those cases, an appropriate equivalent was created. In the interest of space, each table only includes those units that have a record of the type of fossil documented in that table.

- Q = Quaternary
- Tu = unnamed Cenozoic, Locality 21
- Tgl = Rocks of the Grand Wash Trough, limestone facies, which is thought to be equivalent to the Hualapai Limestone
- Ths = Rainbow Gardens Formation

- TRkm = undivided Moenave and Kayenta Formations
- TRc = Chinle Formation
- TRm = Moenkopi Formation
- Pk = Kaibab Formation
- Pt = Toroweap Formation
- Pc = Coconino Sandstone
- Ph = Hermit Formation
- Pq = Queantoweap Sandstone
- Pe = Esplanade Sandstone
- Pp = Pakoon Limestone
- IPMs = undivided lower Supai Group (including one or more of the Wescogame, Manakacha, and Watahomigi Formations, and potentially the Callville Formation)
- IPwe = Wescogame Formation
- IPm = Manakacha Formation
- IPMwa = Watahomigi Formation
- IPMc = Callville Formation
- Mr = Redwall Limestone
- Dtb = Temple Butte Formation
- Cn = Nopah Formation
- Cfm = Frenchman Mountain Dolostone
- Cm = Muav Formation
- Cba = Bright Angel Shale

If a taxon is present in a given formation at a locality that can be placed within PARA, the corresponding stratigraphic cell is marked with a code:

- B = reported from both BLM and NPS lands
- ?BLM = within PARA, possibly BLM land
- BLM = Bureau of Land Management
- ?NPS = within PARA, possibly NPS land
- NPS = National Park Service
- S = State land
- Y = present, but not enough information to determine management

Two additional codes are included to give information about the occurrence. “R” after an ownership code indicates a reworked fossil, and “U” indicates uncertain stratigraphy. This occurs in connection with older records that do not divide certain units (the Toroweap and Kaibab Formations, or the Callville Formation and Pakoon Limestone). A null record is marked “–”.

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, particularly McKee (1982b, 1982c) versus Gordon (1982), which include several taxa of similar but slightly different designation from the same collections; their Watahomigi Formation bryozoan records have been combined. In addition, some of the taxa have undergone name changes since the publication of the referenced record. It was not feasible to track down all potential name changes, nor to determine which was the best name, so as a compromise, name changes have been limited to those changes reflected in the paleontological literature of the Grand Canyon region. In some cases, outdated names have been retained because it is not possible to determine a modern translation (e.g., *Producta* sp.). Changes used here are as follows, with the name in use being the right-most name:

- Bellerophontaceae = Bellerophontida
- *Callipteris conferta = Autunia conferta*
- *Caninophyllum incrassatum = Vesiculophyllum incrassatum*
- *Chonetes kaibabensis = Dyoros kaibabensis*
- *Cruziana*-like traces (Tweet et al. 2016) = *Psammichnites* isp.
- *Dictyoclostus bassi = Peniculauris bassi*
- *Dictyoclostus ivesi = Squamularia ivesi = Peniculauris ivesi*
- *Echinocrinus = Archaeocidaris*
- *Endothyra* (*Globoendothyra*) *redwallensis = Globoendothyra redwallensis*
- *Homalophyllites subcrassus = Sychnoelasma subcrassus*
- *Lithostrotion* (*Diphyphyllum*)? *inconstans = Dorlodotia inconstans*
- *Marginifera lasallensis = Kutorginella lasallensis*
- Orthoceratida = Orthocerida
- *Productus montpelierensis = Pustula montpelierensis = Waagenoconcha montpelierensis = Bathymyonia nevadensis*
- *Productus occidentalis = Rugatia occidentalis*
- *Productus semireticulatus = Dictyoclostus semireticulatus*
- *Pugnoides pinguis = Phrenophoria pinguis*
- *Pustula subhorrida = Echinauris subhorrida*
- *Spirifer occidentalis = Spirifer occiduus = Anthracospirifer occiduus*

- PARA specimens listed as *Syringopora aculeata* in Easton and Gutschick (1953) may include those transferred to *S. surcularia* in Sando (1969)
- *Triplophyllites* (*Homalophyllites*) *paucicinctus* specimens from PARA in Easton and Gutschick (1953) might be *subcrassus*, per Sando (1969) (several specimens transferred)
- *Zaphrentis persimilis = Triplophyllites persimilis = Zaphrentites persimilis = Amplexizaphrentis persimilis*

Appendix Table A-1. Paleobotanical taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	lPm	Pe	Ph	Pt	TRc	TRkm	Ths	Q	Reference
"Seed ferns"	*Autunia conferta*	–	–	NPS	–	–	–	–	–	GCM
	Gigantopteris americana	–	–	NPS	–	–	–	–	–	McKee 1937a; GCM
	Supaia sp.	–	–	NPS	–	–	–	–	–	GCM
	Supaia thinnfeldioides	–	–	NPS	–	–	–	–	–	GCM
Pinopsida	Pine cone?	–	–	–	–	–	–	–	BLM	PI20
	Walchia sp.	NPS	BLM	–	–	–	–	–	–	McKee 1982b, 1982c
Other plants	Petrified wood	–	–	–	BLM	BLM	BLM	–	BLM	E. McIntyre, pers. obs.; PI20
	Plant stems	–	BLM	–	–	–	–	–	–	McKee 1982c
	Possible plant molds	–	–	–	–	–	–	NPS	–	Longwell 1936
	Undetermined plants	–	–	?NPS	–	–	–	–	–	Schenk 1938
	Undetermined plants?	–	–	NPS	–	–	–	–	–	PI20

Appendix Table A-2. Pre-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Cba	Cm	Dtb	Mr	Reference
Cnidaria: Anthozoa: Tabulata	*Syringopora* aff. *S. surcularia*	–	–	–	NPS	McKee and Gutschick 1969
	Syringopora sp.	–	–	–	B	McKee and Gutschick 1969; PI20
	Syringopora sp.?	–	–	–	NPS	PI20
	Syringopora surcularia	–	–	–	NPS	McKee and Gutschick 1969
	Auloporidae undetermined	–	–	–	BLM	McKee and Gutschick 1969
Cnidaria: Anthozoa: Rugosa	*Amplexizaphrentis* cf. *A. persimilis*	–	–	–	NPS	GCM
	Amplexizaphrentis persimilis	–	–	–	NPS	Sando E&R 1963/10/14
	Dorlodotia cf. *D. arizelum*	–	–	–	BLM	McKee and Gutschick 1969
	Dorlodotia inconstans	–	–	–	NPS	Easton and Gutschick 1953; McKee and Gutschick 1969
	Ekvasophyllum sp.	–	–	–	BLM	McKee and Gutschick 1969
	Streptelasma sp.	–	–	?NPS	–	Schenk and Wheeler 1942 (might be in GRCA)
	Sychnoelasma subcrassus (small)?	–	–	–	NPS	Easton and Gutschick 1953?; McKee and Gutschick 1969
	Vesiculophyllum incrassatum	–	–	–	B	Easton and Gutschick 1953; McKee and Gutschick 1969
	Vesiculophyllum sp.	–	–	–	NPS	PI20
	Vesiculophyllum sp.?	–	–	–	NPS	PI20
	Undetermined horn corals	–	–	–	B	McKee and Gutschick 1969; PI20
	Rugosa undetermined	–	–	–	B	GCM; PI20
Bryozoa	Medium mesh *Fenestella*	–	–	–	NPS	McKee and Gutschick 1969
	Moderately coarse mesh *Fenestella*	–	–	–	NPS	McKee and Gutschick 1969
	Penniretepora sp.	–	–	–	NPS	McKee and Gutschick 1969
	Polypora sp.	–	–	–	NPS	McKee and Gutschick 1969
	Undetermined rhomboporoid	–	–	–	NPS	GCM

Appendix Table A-2 (continued). Pre-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Cba	Cm	Dtb	Mr	Reference
Bryozoa (continued)	Fenestellidae undetermined	–	–	–	NPS	McKee and Gutschick 1969
	Bryozoa undetermined	–	–	–	NPS	GCM
	Bryozoa undetermined?	–	–	–	BLM	PI20
Brachiopoda	*Chonetes* sp.	–	–	–	NPS	GCM
	Derbyia sp.	–	–	–	NPS	GCM
	Marginatia burlingtonensis	–	–	–	BLM	Carter et al. 2014
	Spirifer sp.	–	–	–	NPS	McKee and Gutschick 1969
	Productida undetermined	–	–	–	NPS	PI20
	Brachiopoda undetermined	–	–	NPS?	B	Schenk 1938; McKee and Gutschick 1969; PI20
	Tolmatchoffia keokuk	–	–	–	NPS	Carter et al. 2014
Mollusca: Bivalvia	Bivalvia undetermined	–	–	–	NPS	McKee and Gutschick 1969
Mollusca: Gastropoda	Bellerophontida undetermined?	–	–	–	NPS	PI20
	Gastropoda undetermined	–	–	–	NPS	PI20
Mollusca: Scaphopoda	Scaphopoda undetermined?	–	–	–	NPS	PI20
Arthropoda: Trilobita	Trilobita undetermined	NPS?	NPS?	–	NPS	Schenk 1938; McKee and Gutschick 1969
Echinodermata: Crinoidea	Crinoidea undetermined	–	–	–	B	McKee and Gutschick 1969; PI20
	Long crinoid columnals	–	–	–	NPS	McKee and Gutschick 1969
Invertebrata	“Branching coral-like structures”	–	NPS?	–	–	Schenk 1938
	Undetermined invertebrate fossil	–	–	–	BLM	PI20

Appendix Table A-3. Fossil invertebrate taxa reported from the Supai Group and associated units of PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	IPMc	IPMwa	IPm	IPwe	IPMs	Pp	Pe	Reference
Porifera	*Chaetetes* sp.	BLM	–	–	–	–	–	–	Brill 1963; Pierce 1979
	Probable chaetetid-type sponge	–	–	–	–	–	NPS	–	PI20
Cnidaria: Anthozoa	**Corals overall**	**BLM; NPS, U**	**B**	**BLM**	**BLM**	**BLM**	**B**	**BLM, U**	**–**
	Columellate coral	–	–	–	–	–	BLM	–	McKee 1982c
	Coral bioclasts	–	–	–	–	–	BLM, U	BLM, U	McKee 1982c
	Large complex tubular colonial coral	–	–	–	–	–	BLM	–	McNair 1951
	Undetermined colonial coral	–	NPS	–	–	–	BLM	–	McKee 1982b; GCM; PI20
	Undetermined coral	NPS, U	BLM	–	–	BLM	B	–	Schenk 1938; McKee 1982b; PI20
Cnidaria: Anthozoa: Tabulata	*Favosites* sp.	–	–	–	–	–	BLM	–	McKee 1982b; PI20
	Syringopora (type 1)	–	–	–	–	–	BLM	–	McKee 1982c
	Syringopora (type 2) (*S. multattenuata*)	–	–	–	BLM	–	BLM	–	McKee 1982c
	Syringopora sp.	–	NPS	BLM	BLM	–	BLM	–	McKee 1979, 1982b, 1982c; Gordon 1982
Cnidaria: Anthozoa: Rugosa	*Caninia* sp.	–	–	BLM	BLM	–	–	–	McKee 1982c
	Diphyphyllum sp.	–	–	–	–	–	BLM	–	McKee 1982c
	Durhamina sp.	–	–	–	–	–	BLM	–	McKee 1982c
	Heintzella sp.	–	–	–	–	–	BLM	–	McKee 1982c
	Kleopatrina sp.	–	–	–	–	–	BLM	–	McKee 1982c
	Lithostrotionella sp.	–	–	–	–	–	BLM	–	McKee 1982c

Appendix Table A-3 (continued). Fossil invertebrate taxa reported from the Supai Group and associated units of PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	IPMc	IPMwa	IPm	IPwe	IPMs	Pp	Pe	Reference
Cnidaria: Anthozoa: Rugosa (continued)	*Michelinia* sp.	–	–	–	–	–	BLM	–	PI20
	Thysanophyllum sp.	–	–	–	–	–	BLM	–	McKee 1982c
	Zaphrentis sp.	–	–	–	–	–	BLM	–	Hill 1914
	Undetermined horn corals	BLM; NPS, U	Y	BLM	–	BLM	BLM; NPS, U	–	McNair 1951; Sando E&R 1963/10/14; McKee 1982c; Tweet et al. 2016; LMM; PI20
	Undetermined colonial Rugosa	–	–	–	–	BLM	–	–	PI20
	Rugosa undetermined	–	–	–	–	BLM	BLM	–	McKee 1982b; PI20
Bryozoa	*Rhombopora lepidodendroides*	–	–	–	–	BLM, U	BLM, U	–	Longwell 1928
	Stenopora sp.	–	–	–	–	BLM, U	BLM, U	–	Longwell 1928
	Tabulipora sp.	–	–	BLM	–	–	–	–	McKee 1982c
	Bifoliate fistuliporoid bryozoan	–	NPS	–	–	–	–	–	Gordon 1982
	Stenoporoid bryozoan	–	NPS	–	–	–	–	–	GCM
	Massive stenoporoid bryozoan	–	NPS	–	–	–	–	–	Gordon 1982
	Ramose trepostome bryozoan	–	B	–	–	–	–	–	Gordon 1982
	Stenolaemata undetermined	–	–	–	BLM, U	BLM	BLM	–	PI20
	Undetermined fenestrate bryozoan	–	–	–	–	–	B	–	PI20
	Undetermined rhomboporoid	–	–	BLM	–	–	–	–	McKee 1982c
	Bryozoan bioclasts	–	B	B	BLM	–	B, U	B, U	McKee 1982c
	Bryozoa undetermined	–	BLM	–	–	–	B	–	McKee 1982b, 1982c; PI20
	Bryozoa undetermined?	–	NPS	–	–	BLM	BLM	–	GCM; PI20

Appendix Table A-3 (continued). Fossil invertebrate taxa reported from the Supai Group and associated units of PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	IPMc	IPMwa	IPm	IPwe	IPMs	Pp	Pe	Reference
Brachiopoda	**Brachiopoda overall**	**B**	**B**	**BLM**	**BLM, U**	**BLM**	**B**	**–**	**–**
	Anthracospirifer occiduus	–	BLM	BLM	–	–	–	–	Gordon 1982; McKee 1982c
	Anthracospirifer cf. *A. occiduus*	NPS, U	–	–	–	–	NPS, U	–	LMM
	Anthracospirifer tanoensis	–	B	BLM	–	–	–	–	Gordon 1982; McKee 1982c
	Anthracospirifer tanoensis?	–	NPS	–	–	–	–	–	GCM
	Antiquatonia sp.	NPS, U	–	–	–	–	NPS, U	–	LMM
	Buxtonia sp.	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Cleiothyridina sp. or *Neophricadothyris* sp.	NPS, U	–	–	–	–	NPS, U	–	LMM
	Composita cf. *C. argentea*	–	NPS	–	–	–	–	–	GCM
	Composita gibbosa	–	B	–	–	–	–	–	Gordon 1982; McKee 1982c
	Composita ovata	–	B	–	–	–	–	–	Gordon 1982; McKee 1982c
	Composita subtilita	–	BLM	–	–	BLM, U	BLM	–	Hill 1914; Longwell 1928; Gordon 1982; McKee 1982c
	Composita sp. *C. subtilita*	NPS, U	–	–	–	–	NPS, U	–	LMM
	Composita sp.	NPS, U	BLM	BLM	–	–	BLM; NPS, U	–	Gordon 1982; McKee 1982b, 1982c; GCM; LMM
	Derbyia sp.	–	NPS	–	–	–	–	–	McKee 1982c; GCM
	Derbyia sp. A	–	NPS	–	–	–	–	–	Gordon 1982
	Derbyia sp. or *Streptorhynchus* sp.	NPS, U	–	–	–	–	NPS, U	–	LMM
	Derbyia-like?	–	–	–	–	–	BLM	–	PI20

Appendix Table A-3 (continued). Fossil invertebrate taxa reported from the Supai Group and associated units of PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	IPMc	IPMwa	IPm	IPwe	IPMs	Pp	Pe	Reference
Brachiopoda (continued)	*Dielasma*? sp.	–	–	–	–	–	BLM	–	Hill 1914
	Echinoconchus sp.	NPS, U	–	–	–	–	NPS, U	–	LMM
	Flexaria? sp.	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Linoproductus nodosus	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Linoproductus pumilus	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Linoproductus sp. A	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Martinia sp.	NPS, U	–	–	–	–	NPS, U	–	LMM
	Meekella-like	–	–	–	–	–	NPS	–	PI20
	Neospirifer cf. *N. cameratus*	BLM	–	–	–	–	–	–	McNair 1951
	Neospirifer sp.	NPS, U	BLM	BLM	–	–	NPS, U	–	McKee 1982b; LMM
	Orbiculoidea cf. *O. missouriensis*	–	BLM	–	–	–	–	–	Gordon 1982
	Orbiculoidea sp.	–	BLM	–	–	–	–	–	McKee 1982c
	Orbiculoidea? sp.	–	BLM	–	–	–	–	–	McKee 1982b
	Orthotetes keokuk	NPS, U	–	–	–	–	NPS, U	–	LMM
	Phricodothyris sp.	–	–	BLM	–	–	–	–	McKee 1982b
	Productus sp.	–	–	–	–	–	BLM	–	Hill 1914; Longwell 1928
	Pugnax utah	–	–	–	–	–	BLM	–	Hill 1914
	Pulchratia? *pictus*	–	BLM	–	–	–	–	–	Gordon 1982
	Pulchratia? sp.	–	BLM	–	–	–	–	–	McKee 1982c
	Punctospirifer transversus	–	NPS	–	–	–	–	–	Gordon 1982; McKee 1982c

Appendix Table A-3 (continued). Fossil invertebrate taxa reported from the Supai Group and associated units of PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	IPMc	IPMwa	IPm	IPwe	IPMs	Pp	Pe	Reference
Brachiopoda (continued)	*Punctospirifer* sp.	–	–	BLM	–	–	–	–	McKee 1982b
	Pustula nebraskensis	–	–	–	–	BLM, U	BLM, U	–	Longwell 1928
	Reticulariina gonionota	–	NPS	–	–	–	–	–	McKee 1982c
	?*Reticulariina gonionota*	–	NPS	–	–	–	–	–	Gordon 1982
	Schizophoria altirostris	–	BLM	–	–	–	–	–	McKee 1982c
	Schizophoria altirostris?	–	BLM	–	–	–	–	–	Gordon 1982
	Schizophoria sp.	–	–	BLM	–	–	–	–	McKee 1982c
	Spirifer sp.	NPS, U	NPS	–	–	–	NPS, U	–	GCM; LMM
	Squamularia perplexa?	–	–	–	–	–	BLM	–	Hill 1914
	Streptorhynchus sp.	–	NPS	–	–	–	–	–	GCM
	Orthotetida undetermined	NPS, U	–	–	–	–	NPS, U	–	LMM
	Productida undetermined	–	–	–	–	BLM	B	–	PI20
	Productoid	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Small ribbed brachiopod	–	–	–	–	–	BLM	–	PI20
	Spiriferida undetermined	NPS, U	BLM	–	–	–	NPS, U	–	McKee 1982b; LMM
	Strophomenid-like	–	BLM	–	–	–	–	–	McKee 1982b
	Undetermined chonetid	–	–	–	–	–	BLM	–	McKee 1982c
	Brachiopoda undetermined	NPS, U	B	BLM	BLM, U	BLM	B	–	Schenk 1938; Pierce 1979; McKee 1982b; PI20
Mollusca	**Mollusca overall**	**NPS, U**	**B**	**BLM**	**BLM**	**BLM**	**B**	**–**	**–**

Appendix Table A-3 (continued). Fossil invertebrate taxa reported from the Supai Group and associated units of PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	IPMc	IPMwa	IPm	IPwe	IPMs	Pp	Pe	Reference
Mollusca: Bivalvia	**Bivalvia overall**	**NPS, U**	**B**	**BLM**	**–**	**–**	**NPS, U**	**–**	**–**
	Acanthopecten? sp.	–	BLM	–	–	–	–	–	Gordon 1982
	Aviculopecten gravidus	–	B	–	–	–	–	–	McKee 1982c
	Aviculopecten sp. A	–	BLM	–	–	–	–	–	Gordon 1982
	Aviculopecten sp. B	–	NPS	–	–	–	–	–	Gordon 1982
	Aviculopecten sp.	NPS, U	B	–	–	–	NPS, U	–	Gordon 1982; McKee 1982c; LMM
	Leptodesma sp.	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Myalina (*Myalina*) sp. A	–	BLM	–	–	–	–	–	Gordon 1982
	Myalina (*Myalina*) sp. B	–	NPS	–	–	–	–	–	Gordon 1982
	Myalina sp.	–	B	–	–	–	–	–	McKee 1982b, 1982c
	Nuculopsis sp.	–	–	BLM	–	–	–	–	McKee 1982c
	Oriocrassatella? sp.	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Permophorus sp.	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Promytilus sp.	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Schizodus amplus	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Schizodus sp. A	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Schizodus sp. B	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Schizodus sp.	–	–	BLM	–	–	–	–	McKee 1982c
	Selenimyalina? sp.	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Septimyalina sp. B	–	BLM	–	–	–	–	–	Gordon 1982
	Septimyalina sp.	–	BLM	–	–	–	–	–	McKee 1982c
	Wilkingia terminalis	–	BLM	–	–	–	–	–	Gordon 1982

Appendix Table A-3 (continued). Fossil invertebrate taxa reported from the Supai Group and associated units of PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	IPMc	IPMwa	IPm	IPwe	IPMs	Pp	Pe	Reference
Mollusca: Bivalvia (continued)	*Wilkingia* sp.	–	BLM	–	–	–	–	–	McKee 1982c
	Myalinidae undetermined	NPS, U	NPS	–	–	–	NPS, U	–	Gordon 1982; McKee 1982c; LMM
	Bivalvia undetermined	NPS, U	BLM	–	–	–	NPS, U	–	Gordon 1982; LMM
Mollusca: Cephalopoda	Orthocerida undetermined	NPS, U	–	–	–	–	NPS, U	–	LMM
	Nautiloidea undetermined (orthoconic)	–	–	BLM	–	–	–	–	McKee 1982b
	Cephalopoda undetermined	NPS, U	–	–	–	–	NPS, U	–	LMM
Mollusca: Gastropoda	*Bellerophon* (*Bellerophon*) n. sp.	–	–	BLM	–	–	–	–	McKee 1982c
	Bellerophon (*Bellerophon*) sp.	–	BLM	–	–	–	–	–	Gordon 1982
	Bellerophon sp.	NPS, U	BLM	–	–	–	NPS, U	–	McKee 1982c; LMM
	Euconospira sp.	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Naticopsis? sp.	–	–	–	–	–	BLM	–	Hill 1914
	Naticopsis-like	–	BLM	–	–	–	–	–	McKee 1982b
	Retispira sp.	–	NPS	–	–	–	–	–	McKee 1982c
	Straparollus (*Euomphalus*) sp.	–	NPS	–	–	–	–	–	Gordon 1982
	Straparollus (*Euomphalus*)-like	–	–	–	–	BLM	–	–	PI20
	Straparollus sp.	–	B	–	–	–	–	–	McKee 1982c
	Bellerophontida undetermined	NPS, U	NPS	–	–	–	NPS, U	–	Gordon 1982; LMM
	Low-spired gastropod	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c

Appendix Table A-3 (continued). Fossil invertebrate taxa reported from the Supai Group and associated units of PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	IPMc	IPMwa	IPm	IPwe	IPMs	Pp	Pe	Reference
Mollusca: Gastropoda (continued)	Subulitidae undetermined	–	BLM	–	–	–	–	–	Gordon 1982; McKee 1982c
	Gastropoda undetermined	NPS, U	NPS	BLM	BLM	–	BLM; NPS, U	–	McKee 1982b; LMM; PI20
	Gastropoda undetermined?	–	–	–	–	NPS	NPS	–	PI20
Mollusca: Scaphopoda	Scaphopoda undetermined	NPS, U	–	–	–	–	NPS, U	–	LMM
	Scaphopoda undetermined?	–	–	–	–	–	BLM	–	PI20
Arthropoda: Trilobita	*Paladin* sp.	–	B	BLM	–	–	–	–	Gordon 1982; McKee 1982c
	Trilobita undetermined	NPS, U	B	–	–	–	NPS, U	–	Grant E&R 1963/10/16; McKee 1982b, 1982c
Echinodermata	*Archaeocidaris* sp.	–	–	–	–	–	BLM	–	Hill 1914
	Crinoidea undetermined	NPS, U	B	BLM	BLM	B	B	–	Schenk 1938; McKee 1982b; LMM; PI20
	Echinoidea undetermined	NPS, U	BLM	BLM	BLM, U	BLM	B	–	Grant E&R 1963/10/16; Gordon 1982; McKee 1982b; PI20
	Pelmatozoan bioclasts	–	B	B	B	–	B, U	B, U	McKee 1982c
	Echinodermata undetermined	NPS, U	BLM	–	–	–	NPS, U	–	McKee 1982b; LMM
Conodonta	Conodonta undetermined	BLM	BLM	–	–	–	–	–	Pierce 1979; McKee 1982c
Invertebrata	Brachiopod or bivalve bioclasts	–	B	B	B	–	B, U	B, U	McKee 1982c
	Flared fossil	–	–	–	–	BLM	–	–	PI20
	Triradiate fragment	–	–	–	–	–	BLM	–	PI20
	Undetermined shell	–	–	–	–	–	BLM	–	PI20
	Wormy fossil	–	–	–	BLM, U	–	BLM, U	–	PI20
	Undetermined invertebrate fossil	–	–	–	–	BLM	NPS	–	PI20

Appendix Table A-4. Post-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Pc	Pt	Pk	TRm	Tu	Q	Reference
Porifera	*Actinocoelia maeandrina*?	–	–	B	–	–	–	PI20
	Porifera undetermined	–	–	B	–	–	–	Schleh 1966; PI20
	Porifera undetermined?	–	–	NPS	–	–	–	PI20
Cnidaria: Anthozoa	Undetermined coral	–	–	BLM	–	–	–	PI20
	Rugosa undetermined	–	–	BLM	–	–	–	Schleh 1966; PI20
	Undetermined horn corals	–	BLM	B	–	–	–	Sorauf and Billingsley 1991; PI20
Bryozoa	*Batostomella* sp.	–	NPS, U	NPS, U	–	–	–	Longwell 1928
	Cystodictya sp.	–	–	BLM	–	–	–	Longwell 1928
	Fistulipora sp.	–	–	BLM	–	–	–	Longwell 1928
	Leptopora n. sp.	–	–	BLM	–	–	–	Longwell 1928
	Phyllopora n. sp.	–	–	BLM	–	–	–	Longwell 1928
	Undetermined fenestrate bryozoan	–	BLM	B	–	–	–	Schleh 1966; Sorauf and Billingsley 1991; PI20
	Undetermined ramose bryozoan	–	BLM	BLM	–	–	–	Schleh 1966; Sorauf and Billingsley 1991
	Fenestrida undetermined	–	BLM	B	–	–	–	PI20
	Stenolaemata undetermined	–	BLM	B	–	–	–	PI20
	Bryozoa undetermined	–	BLM	BLM	–	–	–	Sorauf and Billingsley 1991; PI20
	Bryozoa undetermined?	–	–	BLM	–	–	–	PI20
Brachiopoda	**Brachiopoda overall**	**–**	**BLM; NPS, U**	**B**	**BLM**	**–**	**–**	**–**
	Avonia or *Composita*	–	BLM	–	–	–	–	PI20
	Avonia sp.	–	–	NPS?	–	–	–	GCM
	Bathymyonia nevadensis	–	NPS, U	NPS, U	–	–	–	Longwell 1928

Appendix Table A-4 (continued). Post-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Pc	Pt	Pk	TRm	Tu	Q	Reference
Brachiopoda (continued)	*Camarotoechia* sp.	–	BLM	–	–	–	–	Sorauf and Billingsley 1991
	Chonetes sp.	–	–	BLM	–	–	–	Schleh 1966
	Composita arizonica	–	BLM	–	–	–	–	Schleh 1966
	Composita sp.	–	BLM	BLM	BLM[1]	–	–	Schleh 1966; Sorauf and Billingsley 1991; Billingsley et al. 2000; PI20
	Composita subtilita	–	B, U	B, U	–	–	–	Longwell 1928
	Derbyia sp.	–	BLM	BLM	–	–	–	Longwell 1928; Schleh 1966; Sorauf and Billingsley 1991; PI20
	Derbyia sp.?	–	BLM	BLM	–	–	–	PI20
	Derbyia-like	–	BLM	–	–	–	–	PI20
	Dictyoclostus semireticulatus	–	–	BLM	–	–	–	Longwell 1928
	Dyoros kaibabensis	–	–	BLM	–	–	–	Schleh 1966
	Echinauris subhorrida	–	–	BLM	–	–	–	Longwell 1928
	Enteletes? n. sp.	–	–	BLM	–	–	–	Longwell 1928
	Kutorginella lasallensis	–	–	BLM	–	–	–	Longwell 1928
	Marginifera sp.	–	–	BLM	–	–	–	Schleh 1966
	Meekella or *Phrenophoria*	–	–	BLM	–	–	–	PI20
	Meekella sp.	–	BLM	BLM; NPS?	–	–	–	Schleh 1966; GCM; PI20
	Meekella sp.?	–	–	BLM	–	–	–	PI20
	Meekella-like	–	BLM	BLM	–	–	–	PI20

[1] *Composita* is a Paleozoic genus; identification of it from the Moenkopi Formation in Billingsley et al. (2000) therefore requires caution. *Protogusarella* is a Moenkopi Formation brachiopod that can resemble *Composita*, especially if only partially exposed or poorly preserved.

Appendix Table A-4 (continued). Post-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Pc	Pt	Pk	TRm	Tu	Q	Reference
Brachiopoda (continued)	*Peniculauris* or *Rugatia*	–	BLM	–	–	–	–	PI20
	Peniculauris bassi	–	–	BLM	–	–	–	Schleh 1966
	Peniculauris ivesi	–	BLM; NPS, U	BLM; NPS, U	–	–	–	Longwell 1928; Schleh 1966
	Peniculauris sp.	–	BLM	–	–	–	–	PI20
	Peniculauris sp.?	–	–	BLM	–	–	–	PI20
	Phrenophoria pinguis	–	BLM	BLM	–	–	–	Schleh 1966
	Rhynchopora n. sp.	–	–	BLM	–	–	–	Longwell 1928
	Rugatia occidentalis	–	NPS, U	BLM; NPS, U	–	–	–	Longwell 1928
	Squamularia aff. *S. guadalupensis*	–	–	BLM	–	–	–	Longwell 1928
	Strongly ribbed brachiopod	–	–	BLM	–	–	–	PI20
	Undetermined “dictyoclostids”	–	BLM	BLM	–	–	–	Sorauf and Billingsley 1991
	Productida undetermined (large)	–	–	BLM	–	–	–	McNair 1951
	Productida undetermined (small)	–	BLM	BLM	–	–	–	Schleh 1966
	Productida undetermined	–	BLM	B	–	–	–	PI20
	Productida undetermined?	–	BLM	–	–	–	–	PI20
	Brachiopoda undetermined (small)	–	–	BLM	–	–	–	PI20
	Brachiopoda undetermined	–	BLM	B	–	–	–	Sorauf and Billingsley 1991; PI20
	Brachiopoda undetermined?	–	–	–	BLM	–	–	PI20

Appendix Table A-4 (continued). Post-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Pc	Pt	Pk	TRm	Tu	Q	Reference
Mollusca	**Mollusca overall**	**NPS**	**BLM**	**B**	**BLM**	**BLM**	**BLM**	**–**
	"Molds of mollusks"	NPS[2]	–	–	–	–	–	GCM
	Mollusca undetermined	–	–	BLM	–	BLM	–	PI20; PARA 2021
Mollusca: Bivalvia	*Acanthopecten* sp.	–	BLM	BLM	–	–	–	PI20
	Acanthopecten sp.?	–	–	BLM	–	–	–	PI20
	Annuliconcha sp.?	–	BLM	–	–	–	–	PI20
	Aviculopecten or *Deltopecten*	–	BLM	–	–	–	–	PI20
	Aviculopecten sp.	–	–	BLM	–	–	–	PI20
	Bakevellia or *Unionites*	–	–	–	BLM	–	–	PI20
	Eumorphotis sp.?	–	–	–	BLM	–	–	PI20
	Leptochondria sp.	–	–	–	BLM	–	–	PI20
	Leptochondria sp.?	–	–	–	BLM	–	–	PI20
	Nuculana-like	–	–	BLM	–	–	–	PI20
	Pleurophorus sp.?	–	–	BLM	–	–	–	PI20
	cf. *Pseudomonotis hawni*	–	–	BLM	–	–	–	PI20
	Schizodus sp.	–	BLM; NPS?	–	–	–	–	Sorauf and Billingsley 1991; GCM
	Pectinida undetermined	–	–	BLM	–	–	–	PI20
	Undetermined pectinoid	–	–	BLM	–	–	–	Schleh 1966
	Undetermined small pectinoid bivalves	–	BLM	–	–	–	–	Schleh 1966

[2] This record may pertain to the Seligman Member of the Toroweap Formation instead.

Appendix Table A-4 (continued). Post-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Pc	Pt	Pk	TRm	Tu	Q	Reference
Mollusca: Bivalvia (continued)	Bivalvia undetermined, non-Pectinida	–	–	–	BLM	–	–	PI20
	Bivalvia undetermined	–	BLM	BLM	BLM	–	–	Schleh 1966; PI20
Mollusca: Nautiloidea	Nautiloidea undetermined (coiled)	–	BLM	–	–	–	–	Schleh 1966
	Nautiloidea undetermined (orthoconic)	–	BLM	–	–	–	–	Schleh 1966
Mollusca: Gastropoda	*Meekospira*-like	–	–	BLM	–	–	–	PI20
	Murchisonia sp.	–	–	BLM	–	–	–	PI20
	Murchisonia-like	–	–	BLM	–	–	–	PI20
	Naticopsis sp.	–	–	BLM	–	–	–	PI20
	Naticopsis-like	–	–	BLM	–	–	–	PI20
	Straparollus (*Euomphalus*) sp.	–	–	BLM	–	–	–	PI20
	Warthia sp.	–	–	BLM	–	–	–	PI20
	Small high-spired gastropods	–	–	BLM	–	–	–	Schleh 1966
	Small planicoiled gastropods	–	BLM	BLM	–	–	–	Schleh 1966
	Bellerophontida undetermined	–	–	BLM	–	–	–	Schleh 1966; PI20
	Subulitidae undetermined	–	–	BLM	–	–	–	PI20
	Gastropoda undetermined	–	–	BLM	–	–	BLM	Sorauf and Billingsley 1991; PI20
Mollusca: Scaphopoda	Scaphopoda undetermined	–	–	BLM	–	–	–	Schleh 1966; PI20
	Scaphopoda undetermined?	–	–	B	–	–	–	PI20
Arthropoda: Trilobita	*Griffithides* sp.	–	–	BLM	–	–	–	Longwell 1928
	Trilobita undetermined	–	–	BLM	–	–	–	Schleh 1966
Echinodermata	Echinodermata undetermined	–	BLM	–	–	–	–	Sorauf and Billingsley 1991; LMM

Appendix Table A-4 (continued). Post-Supai Group fossil invertebrate taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Pc	Pt	Pk	TRm	Tu	Q	Reference
Echinodermata: Crinoidea	*Holocrinus* sp.	–	–	–	BLM	–	–	PI20
	Giant crinoid columnals	–	–	BLM	–	–	–	McNair 1951
	Crinoidea undetermined	–	BLM	B	BLM	–	–	McNair 1951; Schleh 1966; Sorauf and Billingsley 1991; PI20
Echinodermata: Echinoidea	*Archaeocidaris* sp.	–	NPS, U	NPS, U	–	–	–	Longwell 1928
	Miocidaris sp.?	–	–	–	BLM	–	–	PI20
	Echinoidea undetermined	–	BLM	B	–	–	–	Schleh 1966; Sorauf and Billingsley 1991; PI20
Invertebrata	Brachiopod or bivalve	–	BLM	NPS	BLM	–	–	PI20
	Echinoid-like fossil	–	–	BLM	–	–	–	PI20
	Punctate fossil	–	–	NPS	–	–	–	PI20
	Replaced shell	–	–	BLM	–	–	–	PI20
	Undetermined shell	–	–	BLM	BLM	–	–	PI20
	Undetermined invertebrate fossil	–	–	–	BLM	–	–	PI20

Appendix Table A-5. Fossil vertebrate taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	IPMwa	IPwe	Q	Reference
Chondrichthyes	*Deltodus* sp.	NPS	BLM	–	McKee 1982c
Reptilia	Serpentes undetermined	–	–	BLM	E. McIntyre, pers. obs.
	Testudines undetermined	–	–	BLM	E. McIntyre, pers. obs.
Aves	Condor-like bird	–	–	BLM	E. McIntyre, pers. obs.
	Trochilidae undetermined	–	–	BLM	E. McIntyre, pers. obs.
	Aves undetermined (large)	–	–	BLM	Voyles 2008
Mammalia	Rodentia undetermined	–	–	BLM	PI20
	Lepus sp.	–	–	BLM	PI20
	Chiroptera undetermined	–	–	BLM	PI20
	Chiroptera undetermined?	–	–	BLM	PI20
	Canidae undetermined	–	–	BLM	E. McIntyre, pers. obs.; PI20
	Canis latrans	–	–	BLM	PI20
	Felidae undetermined	–	–	BLM	E. McIntyre, pers. obs.; PI20
	Equus sp.	–	–	BLM	E. McIntyre, pers. obs.
	Oreamnos harringtoni	–	–	BLM	E. McIntyre, pers. obs.
	Bovidae undetermined?	–	–	BLM	PI20
	Mammalia undetermined	–	–	BLM	Voyles 2008; PI20
Vertebrata	Vertebrata undetermined	–	–	S	PI20

Appendix Table A-6. Supai and older ichnofossils reported from PARA in stratigraphic context. References are provided where appropriate.

Taxon	Cm	Cfm	Cn	Mr	IPMwa	IPm	IPwe	IPMs	Pp	Pe	Reference
“Algal” laminations	NPS	–	–	–	–	–	–	–	–	–	Brathovde 1986
Bioturbation	–	–	–	–	–	NPS	NPS	–	–	NPS	Johansen 1981
Escape traces?	–	–	–	–	–	–	–	–	–	NPS	PI20
“Fucoidal structures”	–	–	–	–	NPS	–	–	–	–	–	GCM
Invertebrate burrows	–	–	BLM?	–	–	–	–	BLM	BLM	NPS, S	Seager 1966; Johansen 1981; PI20
Possible “algal” structures	–	–	–	–	–	–	NPS	–	NPS	BLM	Johansen 1981; McKee 1982b
Possible microbially induced sedimentary structures	–	–	–	–	–	–	–	BLM	–	–	PI20
Psammichnites isp.	–	–	–	–	–	–	BLM	–	–	–	Tweet et al. 2016; PI20
Rivularites sp.	–	–	–	–	–	–	–	–	–	BLM	McKee 1982b, 1982c
Stromatolites	–	NPS	–	NPS	BLM	BLM	–	–	–	NPS	McKee 1982b, 1982c; Brathovde 1986; PI20
Stromatolites?	–	–	–	–	–	–	BLM, U	–	BLM, U	–	PI20
“Worm borings”	–	–	–	–	–	–	–	–	–	BLM	McKee 1982b, 1982c

Appendix Table A-7. Post-Supai ichnofossils reported from PARA in stratigraphic context. References are provided where appropriate.

Taxon	Pq	Ph	Pt	Pk	TRm	TRc	TRkm	Ths	Tgl	Tu	Q	Reference
Bat guano	–	–	–	–	–	–	–	–	–	–	BLM	E. McIntyre, pers. obs.
Bioturbation	–	–	–	–	–	–	–	NPS	–	–	–	Lamb et al. 2018
Invertebrate burrows	BLM	B	BLM	BLM	BLM	BLM	BLM	B	–	BLM	–	Schleh 1966; Beard 1996; Johansen 1981; Lamb et al. 2018; PI20
Invertebrate trails	–	–	–	–	BLM	–	–	–	–	–	–	PI20
Neotoma droppings	–	–	–	–	–	–	–	–	–	–	B, S	[component of packrat middens]
Oncoids or inorganically coated grains	–	–	–	–	–	–	–	–	–	BLM	–	PI20
Packrat middens	–	–	–	–	–	–	–	–	–	–	B, S	Covington 2003; Mead 2003; Rowland and Olsen 2016; PI20
Possible invertebrate burrows	–	NPS	–	–	–	–	–	–	–	–	–	Schenk 1938
Possible microbial laminations	–	–	–	–	–	–	–	–	–	BLM	–	PI20
Possible microbially induced sedimentary structures	–	–	–	–	BLM	–	–	–	–	–	–	PI20
Rivularites sp.	–	NPS	–	–	–	–	–	–	–	–	–	GCM
Root traces/rhizoliths	–	–	–	–	–	–	–	B	? BLM	–	–	Beard 1996; Billingsley et al. 2004; Lamb et al. 2018
Stromatolites?	–	–	–	NPS	–	–	–	–	–	BLM	–	PI20
Unspecified trace fossils	–	–	–	–	–	–	–	–	–	–	BLM	E. McIntyre, pers. obs.

Appendix Table A-8. Foraminifera taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Taxon	Mr	lPMc	lPMwa	lPm	lPwe	Pp	Pe	Reference
Bradyina sp.	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30
Brunsiina? sp.	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Climacammina sp.	–	–	–	–	–	BLM	–	McKee 1979; McKee 1982c
Cornuspira? sp.	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Earlandia perparva	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30
Earlandia sp.	B	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra baileyi	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra baileyi?	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra eospiroides	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra media	–	–	–	B	–	–	–	McKee 1982c
Endothyra nordvikensis?	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra plectogyra	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra teres	–	–	–	B	–	–	–	McKee 1982c
Endothyra torquida	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra torquida?	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra trachida	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra trachida?	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra aff. *E. pauciseptata*	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Endothyra sp.	NPS	–	–	–	BLM	–	–	Henbest E&R 1964/7/30; McKee and Gutschick 1969
Endothyranopsis eocompressa	BLM	–	–	–	–	–	–	McKee and Gutschick 1969; Skipp 1969
Eomillerella banffensis?	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Eomillerella cf. *E. banffensis*	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Eomillerella scitula	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Eomillerella spiroides	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Eoschubertella sp.	–	–	–	B	–	–	–	McKee 1982b, 1982c

Appendix Table A-8 (continued). Foraminifera taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Taxon	Mr	lPMc	lPMwa	lPm	lPwe	Pp	Pe	Reference
Eoschubertella sp. or juvenarium of larger fusulinid	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30
Fusulinella sp.	–	–	–	BLM	NPS, R	–	–	McKee 1982b, 1982c
Globivalvulina sp.	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30
Globivalvulina sp.?	–	–	–	–	–	BLM	–	Douglass E&R 1974/08/14
Globoendothyra redwallensis	BLM	–	–	–	–	–	–	McKee and Gutschick 1969; Skipp 1969
Hyperammina (two sp.)	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30
Millerella sp. cf. *M. marblensis*	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30
Monodiexodina sp.	–	–	–	–	–	BLM	–	McKee 1979, 1982c
Ozawainella? sp.	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30; McKee 1982c
Paracaligella? sp. B	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Profusulinella sp.	–	–	–	BLM	–	–	–	McKee 1982c
Pseudoschwagerina sp.	–	–	–	–	–	BLM	–	McNair 1951; McKee 1979, 1982c
"*Rugofusulina*" sp.	–	–	–	–	–	BLM	–	McNair 1951
Schubertella sp.	–	–	–	–	BLM	BLM	–	McKee 1979, 1982c
Schawgerina cf. *S. complexa*	–	–	–	–	–	BLM	–	Brill 1963
Schwagerina sp.	–	–	–	–	–	BLM	–	McNair 1951; McKee 1979, 1982c
Septabrunsiina mckeei	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Septaglomospiranella primaeva	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Septaglomospiranella primaeva noda	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Septatournayella henbesti?	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Septatournayella sp.	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Staffella sp.	–	–	–	BLM	–	–	–	McKee 1982c
Tetrataxis sp. cf. *T. millsapensis*	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30

Appendix Table A-8 (continued). Foraminifera taxa reported from PARA in stratigraphic context. References are provided where appropriate.

Taxon	Mr	lPMc	lPMwa	lPm	lPwe	Pp	Pe	Reference
Tournayella aff. *T. subangulata*	BLM	–	–	–	–	–	–	McKee and Gutschick 1969
Tournayella discoidea	B	–	–	–	–	–	–	McKee and Gutschick 1969
Tournayella sp.	NPS	–	–	–	–	–	–	McKee and Gutschick 1969
Triticites beedei	–	BLM	–	–	–	–	–	Brill 1963
Triticites pygmaeus	–	BLM	–	–	–	–	–	Brill 1963
Triticites cf. *T. hobblensis*	–	BLM	–	–	–	–	–	Brill 1963
Triticites cf. *T. plummeri*	–	BLM	–	–	–	–	–	Brill 1963
Triticites sp.	–	BLM	–	–	BLM	BLM	NPS	McNair 1951; McKee 1979, 1982c
Triticites?	–	BLM	–	–	–	–	–	Brill 1963
Tuberitina sp.	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30
Undetermined minammodytid	–	–	–	–	BLM	–	–	Henbest E&R 1964/7/30
Fusulinida undetermined	–	BLM	–	BLM	–	BLM	–	Pierce 1979; McKee 1982b; PI20
Textulariida undetermined	–	–	–	–	–	BLM	–	Douglass E&R 1974/08/14
Foraminifera bioclasts	–	–	B	B	B	B, U	B, U	McKee 1982c

Appendix Table A-9. Other fossils reported from PARA in stratigraphic context. References are provided where appropriate.

Group	Taxon	Cn	Mr	lPMwa	lPwe	Pp	Pe	Pt	Pk	Ths	Tgl	Reference
"Algal" fossils	Possible "algae"	–	–	BLM	–	–	–	–	–	–	–	McKee 1982b
	Unspecified "algae"	–	–	BLM	–	–	–	–	–	–	?BLM	McKee 1982c; Billingsley et al. 2004
Calcispheres	*Calcisphaera* sp.	–	NPS	–	–	–	–	–	–	–	–	McKee and Gutschick 1969
Undetermined (not necessarily fossils)	Fossil debris	BLM?	–	–	–	BLM	–	–	BLM	–	–	Seager 1966; McKee 1982b; Sorauf and Billingsley 1991; PI20
	Fossil molds	–	–	NPS	–	–	–	–	–	–	–	GCM
	Fragments of unspecified marine fossils	–	–	–	B	–	B	–	–	–	–	McKee 1982c
	Tubular features	–	–	–	–	–	–	–	–	NPS	–	Lamb et al. 2018
	Tubular fossil	–	–	–	–	–	–	–	BLM	–	–	PI20
	Unspecified or undetermined fossil	–	NPS	BLM	–	BLM	–	–	–	–	–	McKee 1982b; GCM; PI20

Appendix B: Museum Collections Data

2020 Collections

Appendix Table B-1 lists the specimens collected during the 2020 paleontological inventory. "Turritella" was used by the collectors as shorthand for high-spired gastropod shells of *Meekospira* or *Murchisonia* form. In addition to the specimens listed below, a small quantity of packrat midden material and similar material was collected from cave and rock shelter sites for later analysis.

Fm = Formation; Ls = Limestone; Mbr = Member; Mtn = Mountain; Ss = Sandstone

Detailed locality information can be found in the sensitive version of this report. Full information is kept in PARA and NPS Paleontology archives.

Appendix Table B-1. Specimens collected during the 2020 paleontological inventory.

Catalog #	Field #	Locality	Stratigraphy	Land Manager	Description
LAKE 33361	2020-09-28-001	PARA PAL 0001	Kaibab Fm, Fossil Mtn Mbr	BLM	*Composita* brachiopod
LAKE 33362	2020-10-06-002	PARA PAL 0005	Esplanade Ss	NPS	Burrow
LAKE 33363	2020-10-13-003	PARA PAL 0009	Redwall Ls	NPS	Stromatolite
LAKE 33364	2020-10-13-004	PARA PAL 0009	Redwall Ls	NPS	Crinoids
LAKE 33365	2020-10-13-005	PARA PAL 0009	Redwall Ls	NPS	Horn coral
LAKE 33366	2020-10-13-006	PARA PAL 0009	Redwall Ls	NPS	Horn coral
LAKE 33367	2020-10-13-007	PARA PAL 0009	Redwall Ls	NPS	Horn coral
LAKE 33368	2020-10-13-008	PARA PAL 0009	Redwall Ls	NPS	Fenestrate bryozoan
LAKE 33369	2020-10-13-009	PARA PAL 0009	Redwall Ls	NPS	Small loose horn corals and bryozoan in cobble
LAKE 33370	2020-10-17-010	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	Spiral gastropod shell
LAKE 33371	2020-10-17-011	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	Three gastropod shells
LAKE 33372	2020-10-17-012	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	*Derbyia*-like brachiopod
LAKE 33373	2020-10-17-013	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	Three small clams
LAKE 33374	2020-10-17-014	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	Small “turritella”
LAKE 33375	2020-10-17-015	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	Malachite in shell impressions
LAKE 33376	2020-10-17-016	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	“Turritella”
LAKE 33377	2020-10-17-017	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	“Turritella”
LAKE 33378	2020-10-17-018	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	Long “turritella”; prepared with acid
LAKE 33379	2020-10-17-019	PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	BLM	Multiple shells including large “turritella” prepared from block with acid
LAKE 33380	2020-10-19-020	PARA PAL 0010	Toroweap Fm, Brady Canyon Mbr	BLM	*Derbyia*-like brachiopod
LAKE 33381	2020-10-19-021	PARA PAL 0010	Toroweap Fm, Brady Canyon Mbr	BLM	*Meekella*-like brachiopod shell
LAKE 33382	2020-10-19-022	PARA PAL 0010	Toroweap Fm, Brady Canyon Mbr	BLM	Productid brachiopod
LAKE 33383	2020-10-20-023	PARA PAL 0011	Kaibab Fm, Fossil Mtn Mbr	NPS	Echinoid spines?

Appendix Table B-1 (continued). Specimens collected during the 2020 paleontological inventory.

Catalog #	Field #	Locality	Stratigraphy	Land Manager	Description
LAKE 33384	2020-10-20-024	PARA PAL 0011	Kaibab Fm, Fossil Mtn Mbr	NPS	Three productid brachiopods
LAKE 33385	2020-10-20-025	PARA PAL 0011	Kaibab Fm, Fossil Mtn Mbr	NPS	Productid brachiopod cross-section
LAKE 33386	2020-10-26-026	PARA PAL 0012	Toroweap Fm, Brady Canyon Mbr	BLM	Echinoid spine? and other fossils in stone
LAKE 33387	2020-10-26-027	PARA PAL 0012	Toroweap Fm, Brady Canyon Mbr	BLM	Fenestrate bryozoan
LAKE 33388	2020-10-26-028	PARA PAL 0012	Toroweap Fm, Brady Canyon Mbr	BLM	Productid brachiopod
LAKE 33389	2020-10-27-029	PARA PAL 0013	Kaibab Fm, Fossil Mtn Mbr	BLM	Sponge?
LAKE 33390	2020-11-02-030	PARA PAL 0016	Kaibab Fm, Fossil Mtn Mbr	BLM	*Acanthopecten*
LAKE 33391	2020-11-02-031	PARA PAL 0017	Toroweap Fm, Woods Ranch Mbr	BLM	Petrified wood?
LAKE 33392	2020-11-03-032	PARA PAL 0018	Quaternary	BLM	Rabbit skull
LAKE 33393	2020-11-11-033	PARA PAL 0024	Moenkopi Fm, Virgin Ls Mbr	BLM Wilderness	*Holocrinus* columnals
LAKE 33394	2020-11-17-034	PARA PAL 0025	Quaternary	BLM	Skeleton assemblage, probably bat
LAKE 33395	2020-11-17-035	PARA PAL 0025	Quaternary	BLM	Fox skeleton
LAKE 33396	2020-11-17-036	PARA PAL 0025	Quaternary	BLM	Small fox mandible
LAKE 33397	2020-11-19-037	PARA PAL 0028	Moenkopi Fm, Shnabkaib Mbr?	BLM	Bivalves (*Leptochondria*?)
LAKE 33398	2020-12-01-038	PARA PAL 0032	Quaternary	State lands	Modern skeletal elements including mouse and rabbit bones from carnivore den

Pre-2020 LAKE Collections

Some of the specimens collected by Edward Schenk for LAKE in the 1930s came from localities that are within the Grand Wash parcel of LAKE/PARA-NPS (Appendix Table B-2).

Appendix Table B-2. Pre-2020 specimens from PARA localities in LAKE collections (after Bonde et al. 2018).

LAKE Locality #	LAKE Catalog #	Taxa	Age	Formation
LAKE loc 0019	1410–1422, 2515	Coral, brachiopods (Spiriferida, *Composita* sp.), gastropods *(Bellerophon* sp.), crinoid	Late Mississippian–early Permian	Pakoon Limestone / Callville Formation
LAKE loc 0020	1423–1571	Brachiopods (*Composita* cf. *C. subtilita*, *Spirifer* cf. *S. occidentalis*, *Cleiothyridina* or *Neophricadothyris,* Orthotetida)*,* bivalves (myalinid, *Aviculopecten* sp.), gastropods (bellerophontid)	Late Mississippian–early Permian	Pakoon Limestone / Callville Formation
LAKE loc 0021	1572–1615	Brachiopods (*Spirifer* cf. *S. occidentalis*, Orthotetida, *Composita* cf. *C. subtilita*), bivalves (myalinid)	Late Mississippian–early Permian	Pakoon Limestone / Callville Formation
LAKE loc 0022	1729–1760	Brachiopods (*Martinia* sp., *Composita* sp., *Echinoconchus* sp.*, Spirifer* sp., *Derbyia* sp. or *Streptorhynchus* sp.), bivalves (*Aviculopecten* sp.*, Allorisma* sp.), cephalopods (Orthoceratida), crinoid	Late Mississippian–early Permian	Pakoon Limestone / Callville Formation
LAKE loc 0023	1761–1800	Brachiopods (*Orthotetes keokuk*, *Antiquatonia* sp.*, Neospirifer* sp., *Spirifer* cf. *S. occidentalis*), bivalves, cephalopods, gastropods (*Bellerophon* sp.), scaphopod, echinoderm spines and plates	Late Mississippian–early Permian	Pakoon Limestone / Callville Formation
LAKE loc 0036	1801–1846	Corals (*Vesiculophyllum incrassatum*, *Zaphrentites persimilis*)	Late Mississippian–early Permian [Mississippian instead]	Pakoon Limestone / Callville Formation [accepted as Redwall instead per W. Sando, USGS, pers. comm. to LAKE, October 1963]

GRCA Collections

GRCA museum collections include a group of specimens collected by Edwin McKee from Parashant Canyon (Appendix Table B-3). The exact area of collection (or areas, given the varied stratigraphy) in the canyon is unclear. Based on the distribution of geologic units in Parashant Canyon, McKee's likely access from the canyon mouth, and references in McKee's publications, at least some and perhaps all of the specimens came from what is now LAKE/PARA-NPS (see also discussion under "Collections in Other Repositories" above). Lithological specimens are included in the table for completeness and also because it is possible that some of them are fossiliferous to a minor extent. Some of the specimens, particularly rock samples and some of the Supai Group brachiopods, have gone missing and/or have been deaccessioned. Typographical errors in taxonomic names in the following table have been corrected. Notable specimens include two samples described as limestone from the Coconino Sandstone with mollusk molds (GRCA 5899 and 6541; see discussion under "Coconino Sandstone" above).

Appendix Table B-3. Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 3091	*Callipteris conferta*	Hermit Formation, base
GRCA 3092	*Supaia*	Hermit Formation, base
GRCA 3093	*Supaia*	Hermit Formation, base
GRCA 3094	*Supaia*	Hermit Formation, base
GRCA 3095	Unknown	Hermit Formation; missing
GRCA 3096	Unknown	Hermit Formation; missing
GRCA 3097	*Supaia thinnfeldioides*	–
GRCA 3098	*Gigantopteris americana*	Hermit Formation
GRCA 3099	Unknown	Hermit Formation
GRCA 3100	Unknown	Hermit Formation
GRCA 3101	*Supaia thinnfeldioides*	–
GRCA 3102	*Supaia*	Hermit Formation, base
GRCA 3103	*Callipteris conferta*	Hermit Formation
GRCA 3104	*Callipteris conferta*	Hermit Formation; deaccessioned
GRCA 3105	*Rivularites*	Hermit Formation
GRCA 3106	*Rivularites*	Hermit Formation
GRCA 4650	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4651	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4652	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4653	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4654	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4655	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4656	*Derbyia*	Base of Supai Group (Watahomigi Formation?)

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 4657	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4658	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4659	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4660	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4661	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4662	Unknown	Base of Supai Group (Watahomigi Formation?)
GRCA 4663	*Spirifer*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Anthracospirifer tanoensis* S & H?"
GRCA 4664	*Spirifer*	Base of Supai Group (Watahomigi Formation?); notes with specimen read "*Reticulariina gonionota* (Meek)" and "*Punctospirifer*".
GRCA 4665	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 4666	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 4667	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 4668	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 4669	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 4670	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4671	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4672	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4673	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4674	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4675	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4676	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4677	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4678	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4679	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4680	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4681	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 4682	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4683	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4684	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4685	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4686	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4687	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4688	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4689	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4690	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4691	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4692	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4693	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4694	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4695	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4696	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4697	*Straparollus (Euomphalus)*	Base of Supai Group (Watahomigi Formation?)
GRCA 4698	*Straparollus (Euomphalus)*	Base of Supai Group (Watahomigi Formation?)
GRCA 4699	*Straparollus (Euomphalus)*	Base of Supai Group (Watahomigi Formation?)
GRCA 4700	*Straparollus (Euomphalus)*	Base of Supai Group (Watahomigi Formation?)
GRCA 4701	*Straparollus (Euomphalus)*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4702	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4703	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4704	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4705	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4706	*Derbyia*	Base of Supai Group (Watahomigi Formation?)

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 4707	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4708	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4709	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4710	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4711	Unknown	Base of Supai Group (Watahomigi Formation?)
GRCA 4712	*Derbyia*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Aviculopecten gravidus* Gordon & Pojeta"
GRCA 4713	Unknown	Base of Supai Group (Watahomigi Formation?)
GRCA 4714	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4715	Unknown	Base of Supai Group (Watahomigi Formation?)
GRCA 4716	Unknown	Base of Supai Group (Watahomigi Formation?)
GRCA 4717	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4718	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4719	*Composita*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4720	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4721	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4722	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4723	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4724	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4725	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4726	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4727	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4728	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4729	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4730	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 4731	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 4732	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4733	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4734	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4735	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 4736	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4737	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4738	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4739	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4740	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4741	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4742	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4743	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4744	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4745	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 4749	*Spirifer*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Anthracospirifer tanoensis* S & H?"
GRCA 4750	*Spirifer*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Anthracospirifer tanoensis* S & H?"
GRCA 4751	*Spirifer*	Base of Supai Group (Watahomigi Formation?).
GRCA 4752	*Spirifer*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 5307	Limestone	Muav Formation limestone sample, Parashant Tongue
GRCA 5547	Limestone	Limestone sample; missing
GRCA 5548	Limestone	Redwall Limestone sample with crinoids, "A" Member; missing
GRCA 5549	Limestone	Redwall Limestone sample with corals, bryozoans and brachiopods, "B" Member; missing
GRCA 5550	Chert	Redwall Limestone chert sample with bryozoans and crinoids, "B" Member; deaccessioned
GRCA 5551	Chert	Redwall Limestone chert sample with bryozoans and crinoids, "B" Member; deaccessioned
GRCA 5552	Limestone	Redwall Limestone sample, "B" Member
GRCA 5553	Conglomerate	Redwall Limestone conglomerate samples, "B" Member
GRCA 5554	Conglomerate	Redwall Limestone conglomerate samples, "B" Member
GRCA 5555	Conglomerate	Redwall Limestone conglomerate samples, "B" Member
GRCA 5640	Siltstone	Supai Group siltstone sample; missing
GRCA 5641	Sandstone	Esplanade Sandstone sample; missing.
GRCA 5642	Sandstone	Esplanade Sandstone sample; missing.
GRCA 5643	Mudstone	Supai Group mudstone sample; missing

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 5644	Siltstone	Supai Group siltstone sample; missing
GRCA 5645	Sandstone	Supai Group sandstone sample; missing
GRCA 5646	Siltstone	Supai Group siltstone sample; missing
GRCA 5647	Sandstone	Supai Group sandstone sample; missing
GRCA 5648	Siltstone	Supai Group siltstone sample; missing
GRCA 5649	Siltstone	Supai Group siltstone sample; missing
GRCA 5650	Siltstone	Supai Group siltstone sample; missing
GRCA 5651	Sandstone	Supai Group sandstone sample; missing
GRCA 5652	Siltstone	Supai Group siltstone sample; missing
GRCA 5653	Siltstone	Supai Group siltstone sample; missing
GRCA 5654	Siltstone	Supai Group siltstone sample; missing
GRCA 5655	Siltstone	Supai Group siltstone sample; missing
GRCA 5656	Siltstone	Supai Group siltstone sample; missing
GRCA 5657	Limestone	Supai Group limestone sample; missing (except possibly small fragment)
GRCA 5658	Limestone	Supai Group limestone sample; missing
GRCA 5659	Limestone	Supai Group limestone sample; missing
GRCA 5660	Limestone	Supai Group limestone sample; missing
GRCA 5661	Limestone	Supai Group limestone sample; missing
GRCA 5662	Limestone	Supai Group limestone sample; missing
GRCA 5663	Limestone	Supai Group limestone sample; missing
GRCA 5664	Limestone	Supai Group limestone sample; missing
GRCA 5665	Limestone	Supai Group limestone sample; missing
GRCA 5666	Limestone	Supai Group limestone sample; missing
GRCA 5667	Limestone	Supai Group limestone sample with fossil molds; missing
GRCA 5668	Limestone	Supai Group limestone sample with crinoids; missing
GRCA 5669	Limestone	Supai Group limestone sample with abundant “fucoidal structures” and fossils (including *Composita* and *Streptorhynchus*); missing
GRCA 5670	Limestone	Supai Group limestone sample; missing
GRCA 5671	Claystone	Supai Group claystone sample; missing?
GRCA 5795	Sandstone	Hermit Formation sandstone sample
GRCA 5796	Siltstone	Hermit Formation siltstone sample
GRCA 5797	Siltstone	Hermit Formation siltstone sample
GRCA 5798	Mudrock	Hermit Formation mudrock sample with *Rivularites*
GRCA 5799	Shale	Hermit Formation shale sample with plant fossils
GRCA 5800	Siltstone	Hermit Formation siltstone sample

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 5801	Sandstone	Hermit Formation sandstone sample
GRCA 5898	Sandstone	Coconino Sandstone sample
GRCA 5899	Limestone	Coconino Sandstone limestone sample, “moulds of Mollusca very common”
GRCA 5900	Limestone	Coconino Sandstone limestone sample
GRCA 6504	Limestone	Supai Group limestone sample with abundant “fucoidal structures” and fossils (including *Composita* and *Streptorhynchus*); missing
GRCA 6505	Claystone	Supai Group claystone sample; missing
GRCA 6517	Siltstone	Hermit Formation siltstone sample
GRCA 6541	Limestone	Coconino Sandstone limestone sample, “moulds of Mollusca very common”
GRCA 6723	Tuff	Tuff sample
GRCA 6724	Tuff	Tuff sample
GRCA 8102	Conglomerate	Redwall Limestone conglomerate sample; deaccessioned
GRCA 9939	*Avonia*	Kaibab Formation; missing
GRCA 9940	*Avonia*	Kaibab Formation; missing
GRCA 9941	*Avonia*	Kaibab Formation; missing
GRCA 9942	*Avonia*	Kaibab Formation; missing
GRCA 9943	*Avonia*	Kaibab Formation; missing
GRCA 9944	*Avonia*	Kaibab Formation; missing
GRCA 9945	*Meekella*	Base of Kaibab Formation
GRCA 9953	*Schizodus*	Toroweap Formation
GRCA 9954	*Schizodus*	Toroweap Formation
GRCA 10924	Unknown	Redwall Limestone, float at base from upper part of lower massive unit
GRCA 10925	*Chonetes*	Redwall Limestone, upper part of lower massive unit
GRCA 10926	*Vesiculophyllum incrassatum*	Redwall Limestone, upper part of lower massive unit
GRCA 10927	*Vesiculophyllum incrassatum*	Redwall Limestone, upper part of lower massive unit
GRCA 10928	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit
GRCA 10929	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit
GRCA 10930	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit
GRCA 10931	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit
GRCA 10932	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit
GRCA 10933	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit
GRCA 10934	*Triplophyllites* cf. *T. persimilis*	Redwall Limestone, upper part of lower massive unit
GRCA 10935	*Triplophyllites* cf. *T. persimilis*	Redwall Limestone, upper part of lower massive unit

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 10996	*Vesiculophyllum incrassatum*	Redwall Limestone
GRCA 10997	*Syringopora surcularia*	Redwall Limestone
GRCA 10998	Unknown	Redwall Limestone
GRCA 10999	*Vesiculophyllum incrassatum*	Redwall Limestone
GRCA 11000	*Vesiculophyllum incrassatum*	Redwall Limestone
GRCA 11001	Rugosa	Redwall Limestone
GRCA 11002	Rugosa	Redwall Limestone
GRCA 11003	Rugosa	Redwall Limestone
GRCA 11004	Unknown	Redwall Limestone; missing
GRCA 11005	*Vesiculophyllum incrassatum*	Redwall Limestone
GRCA 11006	Rugosa	Redwall Limestone
GRCA 11007	Rugosa	Redwall Limestone
GRCA 11008	Rugosa	Redwall Limestone
GRCA 11009	*Vesiculophyllum incrassatum*	Redwall Limestone
GRCA 11010	Rugosa	Redwall Limestone
GRCA 11011	Fossil unknown	Redwall Limestone
GRCA 11012	Rugosa	Redwall Limestone
GRCA 11013	Rugosa	Redwall Limestone
GRCA 11014	Rugosa	Redwall Limestone
GRCA 11015	Rugosa	Redwall Limestone
GRCA 11016	Rugosa	Redwall Limestone
GRCA 11017	Rugosa	Redwall Limestone
GRCA 11018	Rugosa	Redwall Limestone
GRCA 11019	*Vesiculophyllum incrassatum*	Redwall Limestone
GRCA 11020	*Dorlodotia inconstans*	Redwall Limestone (top)
GRCA 11099	*Derbyia*	Redwall Limestone
GRCA 11222	*Derbyia*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Aviculopecten gravidus* Gordon & Pojeta"
GRCA 11223	Unknown	Base of Supai Group (Watahomigi Formation?)
GRCA 11224	*Derbyia*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Aviculopecten gravidus* Gordon & Pojeta"
GRCA 11303	Bryozoa	Supai Group
GRCA 15233	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15234	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15235	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 15236	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15237	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15238	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15239	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15240	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15241	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15242	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15243	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15244	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15245	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15246	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15247	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15248	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15249	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15250	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15251	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 15252	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15253	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15254	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 15255	*Composita*	Base of Supai Group (Watahomigi Formation?)
GRCA 16790	Rhomboporoid bryozoan	Redwall Limestone, upper part of lower massive unit
GRCA 17349	Rhomboporoid bryozoan	Redwall Limestone, upper part of lower massive unit
GRCA 20239	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20435	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit
GRCA 20436	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit
GRCA 20437	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit
GRCA 20514	Unknown	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Aviculopecten* sp. B"

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 20515	Unknown	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita* cf. *C. argentea* Shepard"
GRCA 20516	Unknown	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita* cf. *C. argentea* Shepard"
GRCA 20517	Unknown	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita* cf. *C. argentea* Shepard"
GRCA 20518	Unknown	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita* cf. *C. argentea* Shepard"
GRCA 20519	Unknown	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita* cf. *C. argentea* Shepard"
GRCA 20520	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20521	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20522	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20523	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20524	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20525	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20526	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20527	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20528	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20529	*Composita*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Composita gibbosa* Mather"
GRCA 20530	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20531	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20532	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20533	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20534	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20535	*Derbyia*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Aviculopecten gravidus* Gordon & Pojeta?"
GRCA 20536	*Derbyia*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Aviculopecten* sp. A"
GRCA 20537	*Derbyia*	Base of Supai Group (Watahomigi Formation?)

Appendix Table B-3 (continued). Parashant Canyon specimens in GRCA collections.

Catalog #	Identification	Comments
GRCA 20538	*Derbyia*	Base of Supai Group (Watahomigi Formation?); note with specimen reads "*Aviculopecten gravidus* Gordon & Pojeta"
GRCA 20539	Unknown	Base of Supai Group (Watahomigi Formation?); note with specimen reads "Stenoporoid"
GRCA 20540	Colonial coral	Supai Group
GRCA 20541	Colonial coral	Supai Group
GRCA 20577	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20578	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20579	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20580	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20581	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20582	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20583	*Derbyia*	Base of Supai Group (Watahomigi Formation?)
GRCA 20595	*Derbyia*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 20812	*Spirifer*	Base of Supai Group (Watahomigi Formation?); missing
GRCA 111099	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit (largest cliff)?
GRCA 111100	*Syringopora surcularia*	Redwall Limestone, upper part of lower unit (largest cliff)?

Appendix C: Repository Contact Information

Institutions known to have collections from PARA are listed below. Addresses, phone numbers, links, and email addresses to departments are included as available. Hyperlinks are subject to change without warning.

Grand Canyon National Park Museum Collection
2C Albright Ave
Grand Canyon Village, AZ 86023
(928) 638-7769
https://www.nps.gov/grca/learn/historyculture/muscol.htm

Lake Mead National Recreation Area
601 Nevada Way
Boulder City, NV 89005
(702) 293-8990
https://www.nps.gov/lake/index.htm

Museum of Northern Arizona
3101 N Fort Valley Rd
Flagstaff, AZ 86001
(928) 774-5213
https://musnaz.org/

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

University of Nevada, Las Vegas
Department of Geoscience
Lilly Fong Geoscience Building
4505 Maryland Parkway
Las Vegas, NV 89154
(702) 895-3262
https://geoscience.unlv.edu/

Appendix D: Selected Paleontological Locality Data

The following information is derived from the locality forms prepared during the 2020 PARA paleontological inventory. A transcription of a blank form is included below, followed by a table of basic information recorded during the field observations (Appendix Table D-1), and lists of taxa identified from the localities. The fields included in the appendix table are not the same as the fields on the form, because many fields have been omitted here to protect the localities. The sensitive version of this report has much more detail, and complete documentation is maintained by PARA and the NPS Paleontology Archives. Field activities were conducted under Permit PARA-2020-SCI-0002.

Several terms in the tables have been abbreviated for space:

- Fm = Formation
- Ls = Limestone
- Mbr = Member
- Mgmt. = land management
- Mtn = Mountain
- Ss = Sandstone

Paleontological Locality Form, Parashant National Monument

Locality Number: PARA PAL (text field)

Locality Name: (text field)

Field Number: (text field)

Other Number: (text field)

1. Type of Locality; (choices below)
    - ☐ Invertebrate
    - ☐ Plant
    - ☐ Vertebrate
    - ☐ Trace
    - ☐ Other (text field)
2. Group: (text field)

   Formation: (text field)

   Member: (text field)
3. Age: Period: (text field)
4. Location of Outcrop: (text fields below)

   UTM Zone 12N (text field)

   mE (text field)

   mN (text field)

   Datum (text field)

   Accuracy (text field)

   Elevation (text field)

   Elevation Accuracy (text field)
5. Position source: (choices below)
    - ☐ GPS
    - ☐ File
    - ☐ Derived from topography
    - ☐ Estimated from memory
6. USGS Quad Name: (text field)

   Scale: (text field)

   Edition: (text field)
7. County: Mohave

   State: AZ

8. Lithology (rock type, depositional environment, thickness, strike-and-dip, etc.): (text field)
9. Ownership (choices below):
    - ☐ NPS
    - ☐ BLM
    - ☐ Private
    - ☐ Other (text field)
10. Field notes reference: (text fields below)

    Name (text field)

    Date (text field)
11. Photographs: (choices below)
    - ☐ Digital: Folder name (text field)
    - ☐ Optical: Location (text field)
12. Repository(s) for Collected Specimens: (text fields below)

    Name (text field)

    Place (text field)

    Contact name/number (text field)
13. Locality Recorded by: (text field)

    Date: (text field)
14. Principal Investigator: (text field)

    Permit #: (text field)
15. Site Access: (choices below)
    - ☐ Easy
    - ☐ Moderate
    - ☐ Difficult
16. Locality Condition: (choices below)
    - ☐ Unconsolidated/erodes quickly
    - ☐ Erosion/fossil exposure w/in a couple years
    - ☐ Erosion/fossil exposure slow
17. Fossil Occurrence: (choices below)
    - ☐ Low
    - ☐ Moderate
    - ☐ High
18. Fossil Condition/Preservation: (choices below)

- ☐ Poor
- ☐ Good
- ☐ Excellent

19. Specimens Observed/Collected: (text fields below, attach list if necessary)

    Field # (text field)

    Taxon (text field)

    Element (text field)

    In situ/float (text field)

    Collected: (choices below)

    - ☐ Yes
    - ☐ No

20. Additional Comments (i.e., mitigation required, site disturbance, etc.): (text field)

LOCALITY CONDITION FORM

Date Locality Investigated: (text field)

Locality Number: PARA-PAL- (text field)

Investigator: (text field)

Locality Name: (text field)

Locality Significance: (choices below)

- ☐ Historical
- ☐ Research
- ☐ Museum Collections
- ☐ Interpretive
- ☐ Other Land Management (text field)

LOCALITY RATING

Disturbance Rating: (number from 0 to 20, scale described below)

0: Poor: The fossils erode rapidly/High level of illegal removal

10: Moderate: Above normal erosion/Occasional illegal removal

20: Outstanding: Normal erosion/No illegal removal

Disturbance Mitigation: (number from 0 to 15, scale described below)

0: No action

15: Erosion stopped or illegal removal of fossils reduced

Fragility Rating: (number from 0 to 20, scale described below)

0: High: Easily eroded

10: Moderate: Erodes 1–3 years

20: Low: Erodes slowly

Fragility Mitigation: (number from 0 to 15, scale described below)

0: No action

15: Fossils are collected and documented regularly

Fossil Abundance Rating: (number from 0 to 20, scale described below)

0: High: Large number of fossils/easily spotted

10: Moderate: Fossils present over large area/must search to locate

20: Low: Occur sporadically/not easily recognized

Loss Rating: (number from 0 to 20, scale described below)

0: High: Noticeable disappearance yearly

10: Moderate: Reduced by small amount yearly

20: Low: No significant change yearly

Loss Mitigation: (number from 0 to 20, scale described below)

0: No action

10: Monitored

20: Collected and documented

Locality Access Rating: (number from 0 to 20, scale described below)

0: High: Close to roads and trails

10: Moderate: Relatively inaccessible

20: Low: Difficult to locate

Locality Access Mitigation: (number from 0 to 20, scale described below)

0: No action

5: Monitored by staff

10: Actively patrolled, collected on occasion, protected by a barrier, or cyclic monitoring

20: Active law enforcement, surveillance, or ongoing collection by researchers

TOTAL SCORE FOR LOCALITY CONDITION (number)

Recommendations: (text field)

Appendix Table D-1. Basic information for localities recorded during 2020 paleontological inventory.

Locality #	Stratigraphy	Lithology	Mgmt.	Fossils Observed
PARA PAL 0001	Kaibab Fm, Fossil Mtn Mbr	Limestone with chert nodules, marine paleoenvironment.	BLM	Brachiopods, bryozoans, crinoids, corals
PARA PAL 0002	Kaibab Fm, Harrisburg Mbr	~1 m thick beds of white gypsum; unfossiliferous, laminated, shell-rich orange limestone; and a cap of fossiliferous, cherty, massive, very-fine-grained, orange, sandy limestone. Copper is present and some fossils exhibit copper replacement.	BLM	Brachiopods, bryozoans, crinoids, corals, gastropods (incl. turritella-like), scaphopods
PARA PAL 0003	Chinle Fm, Petrified Forest Mbr	Fluvial facies: channel sandstones, fine- to coarse-grained, mostly immature; with trough cross bedding, cross bedding, ripple lamination, and massive sedimentary structures. Small pebble conglomerate lenses present. Thin- to thick-bedded mudstones and siltstones. 1 prominent 0.5 m thick carbonate layer towards bottom of formation.	BLM	Petrified wood
PARA PAL 0004	Chinle Fm, Petrified Forest and Shinarump Mbrs	Sandstones and pebble conglomerates	BLM	Petrified wood
PARA PAL 0005	Esplanade Ss	Sandstone	NPS	Burrows
PARA PAL 0006	Redwall Ls, Thunder Springs, Mooney Falls, and Horseshoe Mesa Mbrs	Limestone, some chert lenses (~0.3 m x 5 m) and nodules.	NPS	Horn corals, brachiopods, crinoids, scaphopods
PARA PAL 0007	Pakoon Ls	Thin bed (~<1 m) thick bed of limestone.	NPS	Bryozoans, brachiopods, crinoids, corals, scaphopods
PARA PAL 0008	Esplanade Ss	Sandstone	State lands	Burrows
PARA PAL 0009	Redwall Ls, all mbrs	Limestone	NPS	Stromatolite, bryozoans, crinoids, brachiopods, rugose corals
PARA PAL 0010	Quaternary alluvium	This area is a Quaternary wash / alluvial sediments, with Permian Toroweap fossils in float. Most float blocks are <30 cm and >0.5 cm and all are limestone. Most blocks are gray. Some have red coloring. We assessed the fossils via a 30 m x 1 m transect.	BLM	Lobey and winged brachiopods, molluscs, fenestrate and branching bryozoans, rugose corals, crinoid discs, a woody textured fossil that might be a tabulate coral(?)

Appendix Table D-1 (continued). Basic information for localities recorded during 2020 paleontological inventory.

Locality #	Stratigraphy	Lithology	Mgmt.	Fossils Observed
PARA PAL 0011	Toroweap Fm, Brady Canyon Mbr	Cliff-forming limestone	BLM	Lobey, winged brachiopods; scaphopods; branching and fenestrate bryozoan, rugose corals, crinoid discs, reef hash, biologic-shaped chert, echinoderm(?), *Archimedes*, perforated texture that may or may not be biologic
PARA PAL 0012	Kaibab Fm, Fossil Mtn Mbr?	Yellow, red, gray sandy limestone with gray, purple, red, and white chert nodules. One bed appears to be laminated sandstone. We also observed a dark, purple-gray, conglomerate in the area.	BLM	Brachiopods, bryozoans (fenestrate and branching), crinoids, corals, scaphopods, echinoderm spine (?), burrow
PARA PAL 0013	Kaibab Fm, Fossil Mtn Mbr	Limestone	BLM	Brachiopods, bryozoans (fenestrate and branching and *Archimedes*), crinoids, corals, scaphopods, bivalve
PARA PAL 0014	Toroweap Fm, Brady Canyon Mbr	Limestone, 137 m thick	BLM	Brachiopods, sponges, crinoids, bivalves, scaphopods, bryozoan, and gastropods
PARA PAL 0015	Toroweap Fm, Brady Canyon Mbr	Cliff-forming limestone	BLM	Brachiopods, crinoids, bivalves, “woody” texture [stylolites], rugose corals, shell hash, echinoid spine, branching and fenestrate bryozoans
PARA PAL 0016	Kaibab Fm, Fossil Mtn Mbr	Limestone, shallow marine environment. Thick beds here!	BLM	Bivalve, brachiopods, fenestrate and branching bryozoans, tabulate corals (“woody” texture), crinoids, sponge
PARA PAL 0017	Toroweap Fm, Woods Ranch and a little bit of Brady Canyon Mbrs	Limestone	BLM	Petrified wood, tabulate corals, brachiopods, crinoids
PARA PAL 0018	Kaibab Fm, Harrisburg Mbr	Dissolution of gypsiferous beds in the Harrisburg limestone have created this house-size cave. Roof of cave is limestone with spherical chert nodules. No cave exterior pictures were taken for safety of cave resources.	BLM	Rabbit skull, amberat

Appendix Table D-1 (continued). Basic information for localities recorded during 2020 paleontological inventory.

Locality #	Stratigraphy	Lithology	Mgmt.	Fossils Observed
PARA PAL 0019	Kaibab Fm, Harrisburg Mbr	Gypsiferous limestone	BLM	Mummified carcasses of domestic origin, human bones
PARA PAL 0020	Kaibab Fm, Harrisburg Mbr	Thick gypsiferous limestone	BLM	Pack rat middens, amberat, unidentified rib, 2 unidentified femoral heads, unidentified nodule (pine cone), unidentified vertebral column
PARA PAL 0021	Tertiary basalt, Tertiary red dune sands, and an unmapped limestone	Basalt-rimmed maar with cross-bedded, fine-grained, well-rounded sandstones and sand; and several horizons with sandy limestone some containing possible stromatolites and many places where the limestone has basalt inclusions.	BLM	Stromatolites(?), burrows(?)
PARA PAL 0022	Chinle Fm, Petrified Forest Mbr	Faulted area—dipping beds, colorful red / purple siltstones and sandstones.	BLM	Burrows and petrified wood
PARA PAL 0023	Kayenta Fm	Red, fine-grained, well-sorted, ledge-forming sandstones. Gypsiferous fins, Moqui marbles in beds, orange siltstone with planar, ripple, and cross-stratification.	BLM	Burrows, possible trackways
PARA PAL 0024	Moenkopi Fm, lower red to upper red mbrs	Very thinly bedded, red, tan, green-tan, gray slope-forming, gypsiferous siltstones and mudstones. Also med- to thickly-bedded gray fossiliferous limestones.	BLM	Star crinoids, bivalves, corals, shell hash, burrows
PARA PAL 0025	Redwall Ls, Mooney Falls Mbr?	Limestone dissolution cave with all the cave ornaments that come with limestone caves.	BLM	Fox, goat, cat, rodent, bat, and other unidentifiable skeletal elements
PARA PAL 0026	Redwall Ls	Cliff-forming limestone, chert lenses present, dolomitized beds.	BLM	Crinoids, rugose corals, bryozoans, brachiopods
PARA PAL 0027	Supai Group, undifferentiated	Undifferentiated members of gray laminated limestone, fine-grained tan sandstone, and a lighter limestone with coquina.	BLM	Crinoids, clams, brachiopods, shell hash, bryozoans
PARA PAL 0028	Moenkopi Fm, upper red and Shnabkaib Mbrs?	–	BLM	Bivalve shells or brachs, branching bryozoans, burrows

Appendix Table D-1 (continued). Basic information for localities recorded during 2020 paleontological inventory.

Locality #	Stratigraphy	Lithology	Mgmt.	Fossils Observed
PARA PAL 0029	Gypsum facies of the Rocks of the Grand Wash Trough	Topography here is gentle small hills mostly talus and cryptobiotic soil covered. Outcrops of interest are where wash has made cuts in these hills. Abundant worthwhile outcrops are available. Lithology is thin to medium beds of light red and white siltstone, white and gray mottled gypsum, and fine-grained sandstones that form ledged and small cliffs. There are also few very thin beds of brown mudstone. Some beds are massive.	BLM	None
PARA PAL 0030	Rainbow Gardens Fm and Proterozoic-clast conglomerate facies of the Rocks of the Grand Wash Trough	Thick green-gray carbonate bed. Pink-gray nodular textured carbonate bed. Fine silty carbonate cemented sandstone beds. At least one true limestone bed. Some beds are stained red by an overlying red gravel and pebble conglomerate. At the top of the outcrop is a 20–30 m thick bed of pebble and boulder conglomerate of pegmatitic, granitic, other phaneritic igneous and metamorphic boulders some 1.5 m in diameter.	NPS	None
PARA PAL 0031	Kaibab Fm, Fossil Mtn Mbr	The Kaibab looks fairly different here than elsewhere. Similar to how the Redwall, when dolomitized, only shows preserved fossils in the chert lenses, Kaibab here has few fossils outside of the chert. The chert is very abundant. Gray carbonate (dolomite or limestone?) reacts well with acid. Chert is desert varnished, black with some orange. Fossils are thus mostly black. Crinoid discs seem to be the only fossil still well preserved in the gray material.	NPS	Brachiopods, fenestrate bryozoan, crinoids
PARA PAL 0032	Navajo Ss	Majority tan, mostly very-fine- to fine-grained, sub-rounded to rounded, mature, quartz sandstone. Red and pale red bands of silt and very-fine sand. Some thin, fine-grained material (interdunal pond deposits?). Most sandstone is cross-bedded. Where red is present, lamination is planar to undulating. Undulations are polygonal in plan view shape.	State lands	Packrat middens, bones in carnivore den (fairly modern I believe)
PARA PAL 0033	Kaibab Fm, Harrisburg Mbr	Sandy bed, some limestone. Pink cherty limestone, pink sandstone.	BLM	Only lobey brachiopods

Appendix Table D-1 (continued). Basic information for localities recorded during 2020 paleontological inventory.

Locality #	Stratigraphy	Lithology	Mgmt.	Fossils Observed
PARA PAL 0034	Upper portion of lower Supai Group	Gray limestone with a lot of red chert lenses.	BLM Wilder-ness	Radiating colonial corals, burrows, crinoids, rugose corals, branching bryozoans
PARA PAL 0035	Esplanade Ss, Pakoon Ls, and upper portion of lower Supai Group	Esplanade is blocky, planar laminated sandstone. Promising outcrop for tracks or trace fossils, but none seen. LS seems to interfinger with SS of Esplanade. LS some beds are unfossiliferous, but most have some fossils. Gray limestone.	BLM Wilder-ness	Exceptional colonial corals both tabulate and rugose. Also brachiopods, branching and fenestrate bryos, burrows, echinoids, pecten shells, possible fish plate, solitary corals, crinoids
PARA PAL 0036	Upper portion of lower Supai Group	Gray limestones or dolostones with some beds containing chert lenses, and red and gray sandy limestones and lime cemented sandstones. Mostly planar laminated and some low angle cross bedding.	NPS	Crinoids, some fossil hash
PARA PAL 0037	Esplanade and Hermit Fms	Mostly fine- and very-fine grained sandstones with few beds of shaley mudstone. Mostly red with the more indurated layers sometimes being white. Esplanade and Hermit seem to interfinger here OR the Esplanade is very thin and the Hermit is very sandy. Top of unit has a thick (10 m) bed of very cliff forming medium-grained sandstone.	NPS	Burrows
PARA PAL 0038	Wescogame Fm(?)	Gray fossiliferous limestones, planar laminated sandy limestones, carbonate cemented fine-grained sandstones.	BLM	Large and small crinoids, brachiopods, trilobite trackways, scaphopods, branching bryos, burrows, laminated mounds

Fossils Identified from Localities

Identifications were first made in the field by the inventory crew, and appended to the photo index. Justin Tweet later reviewed the photos, amending some identifications and refining others to lower taxonomic levels. Robert Blodgett provided additional identifications of silicified specimens from PARA PAL 0002 that had been prepared from Kaibab Formation blocks with acid (LAKE 33378 and 33379).

Locality PARA PAL 0001, BLM

Kaibab Formation, Fossil Mountain Member
Taxa:
Actinocoelia maeandrina?
Undetermined horn coral
Coral undetermined
Fenestrate bryozoan
Composita sp.
Derbyia sp.
Productida undetermined
Brachiopoda undetermined
Crinoidea undetermined
Undetermined shells

Locality PARA PAL 0002, BLM

Kaibab Formation, Harrisburg Member
Taxa:
Bryozoa undetermined
Derbyia sp.
Brachiopoda undetermined
Nuculana-type bivalve
Pleurophorus sp.?
Bivalvia undetermined
Bellerophontida undetermined
Meekospira-type gastropod
Murchisonia-type gastropod
Naticopsis-type gastropod
Gastropoda undetermined
Scaphopoda undetermined
Mollusca undetermined
Undetermined echinoid-like fossil
Undetermined replaced fossil
Undetermined tubular fossil

Additional identifications from Robert Blodgett (prepared samples):
Brachiopoda undetermined (small)

Aviculopecten sp.
Murchisonia sp.
Naticopsis sp.
Warthia sp.
Undetermined bellerophonts
Undetermined subulitid gastropod
Undetermined gastropods
Undetermined mollusk debris
Echinoid plates
Undetermined fossil debris

Locality PARA PAL 0003, BLM
Chinle Formation, Petrified Forest Member
Taxa:
Petrified wood

Locality PARA PAL 0004, BLM
Chinle Formation, Petrified Forest Member
Taxa:
Petrified wood

Locality PARA PAL 0005, NPS
Esplanade Sandstone
Taxa:
Invertebrate burrows
Escape traces

Locality PARA PAL 0006, NPS
Redwall Limestone, Thunder Springs Member?
Taxa:
Vesiculophyllum sp.
Undetermined horn corals
Syringopora sp.?

Redwall Limestone, Horseshoe Mesa Member?
Brachiopoda undetermined
Bellerophontida undetermined?
Gastropoda undetermined
Scaphopoda undetermined?
Crinoidea undetermined

Locality PARA PAL 0007, NPS
Pakoon Limestone
Taxa:
Probable chaetetid-type sponge

Undetermined coral
Fenestrate bryozoan
Bryozoa undetermined
Meekella-type brachiopod
Productida undetermined
Brachiopoda undetermined
Gastropoda undetermined?
Crinoidea undetermined
Echinoidea undetermined
Undetermined invertebrate fossils

Locality PARA PAL 0008, State
Esplanade Sandstone
Taxa:
Invertebrate burrows

Locality PARA PAL 0009, NPS
Redwall Limestone, member uncertain
Taxa:
Vesiculophyllum sp.?
Undetermined horn corals
Rugosa undetermined
Syringopora sp.
Spiriferida undetermined
Brachiopoda undetermined
Crinoidea undetermined
Stromatolites

Locality PARA PAL 0010, BLM
Toroweap fossils in Quaternary deposits
Taxa:
Undetermined horn corals
Fenestrida undetermined
Stenolaemata undetermined
Bryozoa undetermined
Avonia or *Composita*
Derbyia sp.
Peniculauris sp.?
Peniculauris or *Rugatia*
Brachiopoda undetermined
Crinoidea undetermined

Undesignated near Locality PARA PAL 0010, BLM
Hermit Formation

Taxa:
Invertebrate burrows

Toroweap Formation
Taxa:
Undetermined fenestrate bryozoans
Invertebrate burrows

Locality PARA PAL 0011, NPS
Kaibab Formation, Fossil Mountain Member
Taxa:
Porifera undetermined?
Undetermined horn coral
Fenestrida undetermined
Stenolaemata undetermined
Productida undetermined
Brachiopoda undetermined
Scaphopoda undetermined?
Echinoidea undetermined
Undetermined punctate fossils

Kaibab Formation, Harrisburg Member?
Taxa:
Bivalve or brachiopod

Locality PARA PAL 0012, BLM
Toroweap Formation, Brady Canyon Member
Taxa:
Fenestrida undetermined
Stenolaemata undetermined
Derbyia-type brachiopod
Meekella-type brachiopod
Peniculauris sp.
Productida undetermined
Productida undetermined?
Brachiopoda undetermined
Acanthopecten sp.
Annuliconcha sp.?
Bivalve or brachiopod
Crinoidea undetermined
Echinoidea undetermined
Invertebrate burrows

Locality PARA PAL 0013, BLM
Kaibab Formation, Fossil Mountain Member?
Taxa:
Porifera undetermined
Undetermined horn coral
Fenestrida undetermined
Stenolaemata undetermined
Bryozoa undetermined
Brachiopoda undetermined
Bivalvia undetermined
Straparollus sp.
Murchisonia-type gastropod
Gastropoda undetermined
Scaphopoda undetermined?
Crinoidea undetermined
Echinoidea undetermined
Undetermined shell

Locality PARA PAL 0014, BLM
Kaibab Formation, Fossil Mountain Member
Taxa:
Porifera undetermined
Fenestrida undetermined
Stenolaemata undetermined
Bryozoa undetermined
Derbyia sp.
Meekella sp.?
Meekella-type brachiopod
Productida undetermined
Brachiopoda undetermined
Acanthopecten sp.?
cf. *Pseudomonotis hawni*
Pectinida undetermined
Crinoidea undetermined

Locality PARA PAL 0015, BLM
Toroweap Formation, Brady Canyon Member
Taxa:
Stenolaemata undetermined
Crinoidea undetermined
Echinoidea undetermined

Locality PARA PAL 0016, BLM
Kaibab Formation, Fossil Mountain Member

Taxa:
Porifera undetermined
Rugosa undetermined
Fenestrida undetermined
Stenolaemata undetermined
Bryozoa undetermined?
Derbyia sp.?
Meekella sp.
Meekella or *Pugnoides*
Peniculauris sp.?
Productida undetermined
Strongly ribbed brachiopod
Acanthopecten sp.
Aviculopecten sp.
Crinoidea undetermined

Locality PARA PAL 0017, BLM
Toroweap Formation, Woods Ranch Member
Taxa:
Petrified wood (perhaps eroded from somewhere else?)

Toroweap Formation, Brady Canyon Member
Taxa:
Derbyia sp.?
Acanthopecten sp.
Aviculopecten or *Deltopecten*

Locality PARA PAL 0018, BLM
Taxa:
Neotoma sp. droppings and middens
Lepus sp.
Canis latrans

Also modern elements of rabbits and rodents

Locality PARA PAL 0019, BLM
Taxa:
Neotoma sp. droppings and middens
Mammalia undetermined

Locality PARA PAL 0020, BLM
Taxa:
Pine cone?
Neotoma sp. droppings and middens

Locality PARA PAL 0021, BLM
Cenozoic deposits
Taxa:
Oncoids or inorganically coated grains
Stromatolites?
Possible microbial laminations
Invertebrate burrows

Locality PARA PAL 0022, BLM
Chinle Formation, Petrified Forest Member
Taxa:
Invertebrate burrows

Locality PARA PAL 0023, BLM
Undivided Moenave/Kayenta Formation
Taxa:
Petrified wood
Invertebrate burrows

Locality PARA PAL 0024, BLM
Moenkopi Formation, float?
Taxa:
Holocrinus sp.

Moenkopi Formation, lower red member
Taxa:
Bakevellia or *Unionites* in float
Leptochondria sp. in float
Holocrinus sp. in breccia
Undetermined shells in float
Invertebrate burrows
Possible microbially induced sedimentary structures

Moenkopi Formation, Virgin Limestone Member
Taxa:
Eumorphotis sp.?
Bivalvia undetermined, non-Pectinida
Bivalvia undetermined
Holocrinus sp.
Crinoidea undetermined
Miocidaris sp.?
Bivalve or brachiopod
Undetermined diminutive shells
Undetermined fossils

Invertebrate burrows

Locality PARA PAL 0025, BLM

Taxa:
Gastropoda undetermined
Rodentia undetermined
Chiroptera undetermined
Chiroptera undetermined?
Canidae undetermined
Felidae undetermined
Bovidae undetermined?
Mammalia undetermined

Locality PARA PAL 0026, BLM

Redwall Limestone
Taxa:
Undetermined horn coral
Rugosa undetermined
Syringopora sp.
Bryozoa undetermined?
Brachiopoda undetermined
Crinoidea undetermined
Undetermined fossils

Locality PARA PAL 0027, BLM

Supai Group, undivided
Undetermined horn coral
Rugosa undetermined
Bryozoa undetermined?
Productida undetermined
Crinoidea undetermined
Echinoidea undetermined
Undetermined flared fossil
Undetermined replaced fossils
Undetermined fossils
Invertebrate burrows
Possible microbially induced sedimentary structures

Locality PARA PAL 0028, BLM

Moenkopi Formation, upper red member?
Taxa:
Invertebrate burrows

Moenkopi Formation, Shnabkaib Member?

Taxa:
Brachiopoda undetermined?
Leptochondria sp.?
Bivalvia undetermined
Undetermined shells
Invertebrate burrows and trails

Locality PARA PAL 0029, BLM
Gypsum and gypsiferous siltstone facies of Grand Wash Trough rocks
Taxa:
None reported or observed in photos

Locality PARA PAL 0030, NPS
Rainbow Gardens Formation and Proterozoic-clast conglomerate facies of Grand Wash Trough rocks
Taxa:
None reported or observed in photos

Locality PARA PAL 0031, NPS
Kaibab Formation, Fossil Mountain Member
Taxa:
Actinocoelia maeandrina?
Fenestrate bryozoans
Productida undetermined
Brachiopoda undetermined
Crinoidea undetermined
Echinoidea undetermined
Undetermined punctate fossil
Stromatolites?

Locality PARA PAL 0032, State
Taxa:
Neotoma sp. droppings and middens
Vertebrata undetermined

Locality PARA PAL 0033, BLM
Kaibab Formation, Harrisburg Member
Productida undetermined

Locality PARA PAL 0034, BLM
Upper part of lower Supai Group
Colonial Rugosa
Rugosa undetermined
Undetermined corals
Stenolaemata undetermined
Brachiopoda undetermined

Straparollus-type gastropod
Crinoidea undetermined
Echinoidea undetermined
Invertebrate burrows

Locality PARA PAL 0035, BLM
Pakoon Limestone
Taxa:
Michelinia sp.
Undetermined horn coral
Favosites sp.
Undetermined colonial coral
Fenestrate bryozoan
Stenolaemata undetermined
Bryozoa undetermined
Derbyia-type brachiopods?
Small ribbed brachiopod
Productida undetermined
Brachiopoda undetermined
Gastropoda undetermined
Scaphopoda undetermined?
Crinoidea undetermined
Echinoidea undetermined
Undetermined shells
Undetermined triradiate fragments
Undetermined fossils
Invertebrate burrows
Fusulinida undetermined

Locality PARA PAL 0036, NPS
Upper part of lower Supai Group
Taxa:
Gastropoda undetermined?
Crinoidea undetermined

Locality PARA PAL 0037, NPS
Esplanade Sandstone and Hermit Formation
Taxa:
Plantae undetermined?
Invertebrate burrows

Locality PARA PAL 0038, BLM
Upper lower Supai Group (Wescogame Formation?)
Taxa:

Psammichnites isp.

Pakoon Limestone
Taxa:
Stenolaemata undetermined
Brachiopoda undetermined
Crinoidea undetermined
Echinoidea undetermined
Undetermined wormy fossil
Stromatolite?

Appendix E: Glossary

Aetosaur: a quadrupedal herbivorous armored reptile related to the crocodiles, known from the Late Triassic.

Alluvial (adjective), **alluvium** (noun): a general term for unconsolidated terrestrial sediment moved by water and not attributed to a more specific process (i.e., not fluvial, glacial, or lacustrine).

Amberat: crystallized urine of the rodent *Neotoma* (packrats, woodrats, trade rats); may also sometimes be used in a general sense for undefined *Neotoma* midden contents.

Ammonoid: an extinct shelled cephalopod. Most but not all ammonoids had planispiral, tightly coiled shells. Ammonoids are also sometimes called "ammonites", although that term more strictly applies to a subgroup of ammonoids.

ARPA: Archaeological Resources Protection Act.

Arthropod: any of a diverse group of invertebrates with exoskeletons, segmented bodies, and jointed appendages. Insects, arachnids, and crustaceans are modern examples.

Articulate brachiopod: a brachiopod with a shell hinge featuring hard "teeth" and "sockets."

Asteroid: an echinoderm familiar for its five radiating arms; also known as a "sea star" or "starfish".

Ball-and-pillow structure: a sedimentary structure produced when layered but consolidated sediment is subjected to a physical shock such as an earthquake, causing "balls" or "pillows" of sediment to founder from an overlying layer into a lower layer.

Basin (geological): a geologic downwarp formed by folding and faulting; geologic basins can often be identified by rock strata dipping to a central point, a bull's-eye pattern of rocks in a geologic map with the youngest rocks at the center, or an anomalous area of young rocks at the same elevation as older rocks in the vicinity. An eroded geologic basin does not necessarily form a physical depression.

Bellerophont: an extinct mollusk with a planispiral shell and a flaring aperture. Bellerophonts are usually classified with snails but at least some may be monoplacophorans.

Bennettitale or **cycadeoid**: a plant known from the Permian to the Cretaceous, noted for combining cycad-like foliage with flower-like reproductive organs.

Bioclast: a clast of biological origin; biological remains functioning as sedimentary particles. Any fossil can technically be considered a bioclast, but the term is most often used for skeletal fragments of marine organisms.

Biostratigraphy: using fossils to identify the relative positions and relative ages of rocks.

Bioturbation: disturbance of sediment by organisms to the extent that sedimentary features such as bedding and stratification are destroyed.

Bivalve: a mollusk with two shells; bivalves are also sometimes known as pelecypods, to reduce confusion (the term "bivalve" in a general sense also applies to other groups, such as brachiopods and some arthropods). Examples include clams, oysters, mussels, and scallops.

Blastoid: an extinct stalked echinoderm resembling a crinoid but with a nut-shaped body bearing numerous small filtering appendages, rather than a cup-shaped body with a smaller number of large appendages. Blastoids are sometimes identified informally as "sea buds".

Blattoid: an extinct relative of modern cockroaches.

BLM: Bureau of Land Management.

Brachidium: a mineralized structure supporting a brachiopod's lophophore.

Brachiopod: a marine filter-feeding animal with two shells, resembling bivalve mollusks but more closely related to bryozoans. Brachiopods are sometimes known as "lamp shells" because some of them resemble ancient oil lamps.

Bradoriid: an extinct small bivalved arthropod resembling modern ostracodes.

Bryozoan: a filter-feeding aquatic colonial animal. Bryozoans are sometimes called "moss animals" because they often encrust objects.

Caecilian: a type of limbless amphibian.

Calcite: a mineral made of calcium carbonate; found in limestone and some fossils.

Calcium carbonate: $CaCO_3$, a mineral-forming compound. Calcite is a common form.

Cambrian: the first geologic period of the Paleozoic Era, noted for the abrupt diversification of life ("Cambrian explosion"); approximately 539 to 487 Ma.

Carbonate: in geology, a general term for minerals containing carbonate ions (CO_3^{-2}), such as calcite, and rocks containing these minerals, such as dolomite and limestone.

Cenozoic: a geologic era, dated approximately 66 Ma to the present, noted for the diversification of mammals; the term means "new life".

Cephalopod: a mollusk with a prominent head fringed by tentacles. Examples include squids, octopuses, *Nautilus*, and many extinct forms, especially ammonoids.

Chert: a rock made of silica lacking obvious macroscopic crystals. Flint is a variety of chert found in chalk and marly limestone.

Clast: a rock fragment of any size. A rock made up of clasts, such as sandstone or shale, is called clastic.

Columnal: individual segments of an echinoderm's stalk, particularly crinoids. They resemble doughnuts, sprockets, or gears.

Conchostracan: a bivalved crustacean, also known as "clam shrimp".

Conifer: a general term for non-flowering plants that produce seeds and pollen from cones.

Conodont: an extinct eel-like chordate, known primarily from jaw elements.

Contact: in geology, the horizon or plane where two formations meet.

Conulariid: extinct distant relatives of corals that formed conical structures from mineralized rods.

Coprolite: fossil feces.

Coquina: a bed consisting primarily of shells and/or other invertebrate body fragments. "Coquinoid" may also be used.

Corallite: the dwelling cell of an individual coral animal.

Cretaceous: the third and last geologic period of the Mesozoic Era, noted for the rise of flowering plants and the extinction of many groups at the end of the period; approximately 143 to 66 Ma.

Crinoid: an echinoderm, also known as a sea lily, featuring a cup-like body with feathery tentacular arms, usually but not always attached to a surface with a stalk.

Cystoid: an extinct echinoderm similar to a crinoid but with an ovoid body, instead of cup-like.

Devonian: the fourth geologic period of the Paleozoic Era; approximately 419 to 359 Ma.

Dicynodont: a type of non-mammalian therapsid, or "mammal-like reptile", noted for having two tusks. Dicynodonts lived from the Permian to the Triassic.

DOI: Department of the Interior.

Dolomite: a mineral made of calcium-magnesium carbonate, and a rock (alternatively **dolostone**) composed primarily of this mineral. Most dolomite is formed by the replacement of some of the calcium ions in calcium carbonate by magnesium, a process called dolomitization.

Dolomitization: the conversion of calcium carbonate to dolomite by the replacement of calcium ions with magnesium. This process involves recrystallization and is destructive to fossils made of calcium carbonate, although not all such fossils are affected the same way: mollusk shells are more vulnerable than brachiopod and bryozoan specimens, which in turn are more vulnerable than echinoderm columnals and plates.

Drepanosaurid: an enigmatic reptile resembling a chameleon with a bird-like head, known from the Late Triassic. Some drepanosaurs have been interpreted as tree-dwelling, digging, or aquatic.

Echinoderm: any of a group of invertebrates noted for their five-fold symmetry. Sea stars (asteroids) and sea urchins (echinoids) are familiar echinoderms.

Echinoid: an echinoderm, also known as a sea urchin, commonly having a globose body covered in spines.

Eocrinoid: an extinct stalked echinoderm of the early Paleozoic, somewhat similar to crinoids but not closely related.

Eolian: wind-blown transport or an environment where wind transport dominates.

Erg: a sand-covered desert at least 125 km^2 (48 mi^2) in area; may also be called a dune sea if dunes are abundant.

Eurypterid: an extinct aquatic arthropod also known as a sea scorpion.

Extrusive: in igneous rocks, "extrusive" refers to rocks erupted at the surface of the Earth.

Facies: a body of rock that is distinct from the surrounding rock, due to specific aspects of deposition and setting; facies are generally invoked when there are differences within a formation or member that are not suitable for mapping (i.e., not laterally persistent).

Float: in geology, eroded material resting on the surface, not attached to an outcrop.

Fluvial: a river as depositional environment or mode of transport.

Foraminifera: a "shelled amoeba"; "foraminifera" is often used for both singular and plural, although some authorities prefer "foraminiferan" for singular and "foraminiferans" or "foraminifers" for plural, and others use the more informal "foram" and "forams." Foraminifera, which still exist today, are well-known as microfossils from their tests, which are usually composed of calcium carbonate or tiny sediment grains (agglutinated).

Formation: a group of rocks that share some characteristics and can be depicted on a geological map; the basic unit of stratigraphy.

Fossiliferous: a rock or deposit that yields fossils.

Fucoid: in paleontology, a term often used in the 19th and early 20th centuries for fossils thought to be seaweed impressions (after Fucales, the brown algae), but now known to be invertebrate burrows and other trace fossils.

Fusulinid: a variety of extinct foraminifera noted for their chambered, relatively enormous tests (as much as several cm long). In the field, they may resemble rice or other similar grains, and can be abundant in rocks of Pennsylvanian or Permian age.

GIP: Geoscientists-in-the-Park program; replaced by Scientists in Parks after 2020.

GRCA: Grand Canyon National Park.

GRD: Geologic Resources Division of the National Park Service.

GRI: Geologic Resources Inventory.

Holocene: the second and most recent epoch of the Quaternary Period, following the Pleistocene and the last glacial maximum; approximately 11,700 years ago to the present.

Holothurian: an echinoderm, also known as a sea cucumber, with a sack-like body generally supported by an internal skeletal framework of microscopic mineralized elements known as ossicles or sclerites.

Holotype: a name-bearing specimen for an organism. Some species are based on multiple specimens, which are called cotypes (outdated; sometimes "co-types") or syntypes.

Horn coral: a solitary rugose coral. The name refers to the animal-horn-like hard structure.

Hyolith: an extinct animal with an elongate triangular shell, apparently close to the ancestry of brachiopods, mollusks, or both.

Ichnofossil: fossilized remains of biological activity of an organism, including traces of footprints, tracks, burrows, trails, and other biogenically produced features.

Ichnogenus, ichnospecies, ichnotaxon: a scientific name used for a trace fossil, existing in parallel to the names used for body fossils.

In situ: when describing fossils, this means found in place at an outcrop.

Inarticulate brachiopod: a brachiopod with a shell hinge lacking hard structures to keep it closed, instead relying on muscles.

Intrusive: in igneous rocks, "intrusive" refers to rocks that cooled from a molten state below the surface of the Earth.

Jurassic: the second geologic period of the Mesozoic Era; approximately 201 to 143 Ma.

Lacustrine: a lake as depositional environment or mode of transport.

Lagerpetid: a small bipedal pterosaur or dinosaur relative.

LAKE: Lake Mead National Recreation Area

Lepidosaur: a member of Lepidosauria, the group including lizards, snakes, and sphenodontians.

Lithology: the variety or varieties of rock in a formation, member, bed, or other division.

Load cast: a sedimentary structure formed in unconsolidated layered sediment, in which blobs of denser overlying sediment sink into less dense underlying sediment due to a physical shock such as an earthquake. Ball-and-pillow structures (see above) are an extreme example.

Lophophore: the tentacle-bearing feeding organ of brachiopods, bryozoans, and some other groups.

Ma: an abbreviation for “mega-annum,” but more easily understood as “million years ago.”

Maar: a crater formed when groundwater comes in contact with magma or lava and causes an explosion.

Marl: calcium carbonate mud or mudstone that commonly forms in lakes.

Massive: in geology, this describes rocks without visible stratification or other bedding features.

Meganeurid: an extinct relative of modern dragonflies.

Member: a subdivision of a formation.

Mesozoic: a geologic era, dated approximately 252 to 66 Ma, noted for the dominance of dinosaurs on land and the appearance of birds, mammals, and flowering plants; the term means “middle life”.

Microbially induced sedimentary structure: sedimentary features formed by the interaction of microbes with sediment. They are at the intersection of trace fossils and sedimentary structures.

Microconchid: one of a group of enigmatic extinct invertebrates known from small spiral-coiled shells resembling certain fossil “worm” tubes, found encrusting other fossils.

Microfossil: a fossil, typically a millimeter or less in size, that must be studied with a microscope.

Miocene: the first epoch of the Neogene Period; approximately 23 to 5.33 Ma.

Mississippian: in North America, the de facto fifth geologic period of the Paleozoic Era (internationally a subperiod of the Carboniferous Period); approximately 359 to 323 Ma.

MOJN: Mojave Desert Inventory & Monitoring Network.

Mollusk: any of a diverse group of invertebrates noted for their combination of a muscular foot, a shell, and a mantle that covers the innards and secretes the shell. Examples include bivalves, cephalopods, and gastropods (snails).

Monoplacophoran: a type of mollusk; most monoplacophorans have a cap-like or limpet-like shell, but some extinct forms had planispiral shells.

NAGPRA: Native American Graves Protection and Repatriation Act.

Neogene: the second geologic period of the Cenozoic Era; approximately 23 to 2.58 Ma.

NPS: National Park Service.

Oncoid: a concentrically laminated structure formed by microbes; rocks made of oncoids are oncolites.

Ordovician: the second geologic period of the Paleozoic Era, following the Cambrian; approximately 487 to 443 Ma.

Organic: made of organic compounds (i.e., molecules of carbon, hydrogen, nitrogen, and oxygen); pollen, spores, and cysts, all of which can be fossilized, have organic walls.

Ornithischian: a "bird-hipped" dinosaur, which despite the name was not closely related to birds. Ornithischians included the armored dinosaurs, bone-headed dinosaurs, horned dinosaurs, and ornithopods. All had a bony beak at the tip of the lower jaw.

Ornithopod: a beaked herbivorous dinosaur, bipedal at small body weights but progressing toward quadrupedality when large. Hadrosaurs, or "duck-billed dinosaurs", are the best-known ornithopods.

Ostracode: also spelled "**ostracod**;" a shelled crustacean, generally microscopic. Ostracodes are known informally as "seed shrimp."

Paleozoic: a geologic era, dated approximately 539 to 252 Ma, noted for the diversification of invertebrates and the appearance of vertebrates and land plants; the term means "early life".

Palynomorph: an organic-walled microfossil. Pollen and spores are common examples; other types include tests of some microorganisms and jaw elements of worms.

PARA: Grand Canyon-Parashant National Monument, sometimes given as Parashant National Monument.

PARA-BLM: the portion of Grand Canyon-Parashant National Monument under management of the Bureau of Land Management.

PARA-NPS: the portion of Grand Canyon-Parashant National Monument under management of the National Park Service.

PARA-STATE: State of Arizona land within Grand Canyon-Parashant National Monument.

Pedicle: in brachiopod anatomy, a stalk used to attach them to objects.

Pelmatozoan: a general term for any echinoderm with a "stalk" or "stem," made up of columnals; the majority are crinoids, but several other groups of pelmatozoans existed during the Paleozoic.

Pennsylvanian: in North America, the de facto sixth geologic period of the Paleozoic Era (internationally a subperiod of the Carboniferous Period); approximately 323 to 299 Ma.

Permian: the seventh and last geologic period of the Paleozoic Era, ended by the largest mass extinction event in Earth's history; approximately 299 to 252 Ma.

Phosphate: in geology, a general term for minerals containing phosphate (PO_4^{-3}), such as apatite, found in bones and some shells (the phosphatic shells of some inarticulate brachiopods, for example).

Phytosaur: a crocodile-like semi-aquatic carnivorous reptile known from the Triassic.

Planispiral: a shell coiled in a flat plane, like a *Nautilus* shell.

Playa: a dry lake bed.

Pleistocene: the older of two epochs in the Quaternary, noted for ice ages; approximately 2.58 Ma to 11,700 years ago.

Pliocene: the second and final epoch of the Neogene Period; approximately 5.33 to 2.58 Ma.

Precambrian: time before the Cambrian, before approximately 539 Ma.

Procolophonid: a stocky lizard-like herbivorous or insectivorous reptile with a large head, known from the Permian into the Triassic.

PRPA: Paleontological Resources Preservation Act (2009).

Pseudofossil: an object or feature that resembles a fossil but is actually not of organic origin.

Pterosaur: an extinct flying reptile, known from the Triassic to the end of the Cretaceous.

Quaternary: the most recent geologic period, third and last in the Cenozoic Era, noted for multiple ice ages; approximately 2.58 Ma to the present.

Radiocarbon years: uncalibrated radiocarbon dates are presented as radiocarbon years before present (defined as 1950).

(Marine) Regression (noun), **regressive** (adjective): a marine retreat, exposing land.

Reworked: a fossil that has been eroded from an older rock unit and redeposited in a younger unit.

Rostroconch: an extinct mollusk noted for a “taco”-like single folded shell, resembling a bivalve.

Rugose coral: an extinct type of coral, with the name in reference to the wrinkled surfaces of their fossils. Rugose corals included both colonial and solitary forms, with the solitary forms known as horn corals.

Sabkha: a salt flat above the level of tides.

Sauropod: a quadrupedal herbivorous dinosaur with a proportionally long neck and tail and small head. Most known sauropods were at least 9 m (30 ft) long and weighed several tons.

Sauropodomorph: a member of the group of dinosaurs including the sauropods and their close relatives, sometimes known informally as prosauropods. The earliest sauropodomorphs differed from the sauropods by being small and bipedal.

Scaphopod: a mollusk with an elongate conical shell; also known as a tusk shell.

Septum: in corals, a septum (plural: septa) is a vertical plate in a corallite; in shelled cephalopods, the wall between chambers.

Sessile: an organism that cannot move on its own, usually permanently attached to something.

Silesaurid: a quadrupedal dinosaur relative, known from the Triassic.

Silica: the compound SiO_2, the building block of the common mineral quartz.

Silicate mineral: a mineral with a framework of silica. Quartz and felspar minerals are common silicates.

Silicification: the replacement of a non-silicate mineral with a silicate mineral.

Silurian: the third geologic period of the Paleozoic, following the Ordovician; approximately 443 to 419 Ma.

Siphuncle: the internal passage between chambers in a cephalopod shell.

Sphenodontian: a lizard-like reptile, part of a group including the modern tuatara of New Zealand and extinct relatives

Spicule: a structural element of many types of organisms. Many sponges have spicular skeletons; the spicules can be simple and toothpick-like or have multiple points, and the form of the tips also varies.

Steinkern: a cast of the interior of a hollow organic structure, such as a snail shell, formed when sediments entered the structure and became rock, followed by dissolution of the outer structure.

Stratigraphy: the study of rock layers.

Stromatolite: a layered microbial mat, typically columnar or domal.

Stromatoporoid: a coral-like sponge; seemingly extinct although some modern sponges are similar.

Strophomenid: a type of extinct articulate brachiopod known from wide D-shaped scallop-like shells. They lacked pedicles and lived directly on the sea floor.

Structure: in geology, structures are various three-dimensional features such as folds and faults.

Stylolite: surfaces that form within rocks, especially carbonate rocks, due to mineral dissolution, usually marked by thin accumulations of insoluble minerals; they generally form parallel to bedding, but at a small scale are extremely irregular. Fragments of stylolites may have a woody appearance, and can be mistaken for petrified wood.

Synapsid: a member of the group including mammals and all animals more closely related to mammals than to other vertebrates, sometimes known informally as “mammal-like reptiles”.

Tabula: in corals, a tabula (plural: tabulae) is a horizontal plate within a corallite.

Tabulate coral: a type of extinct colonial coral, commonly encrusting other fossils; fossils may resemble honeycombs.

Talus: broken rock shed from cliffs through rock falls; also known as scree.

Tanystropheid: a long-necked piscivorous reptile known from the Triassic.

Tectonics: the movements and interactions of Earth's plates.

Test: the formal name for the shells of foraminifera, echinoids, and some other marine organisms.

Tetrapod: an animal belonging to Tetrapoda, meaning "four feet", although some members have lost some or all four limbs (e.g., snakes). Tetrapods include amphibians, reptiles, birds, and mammals.

Theropod: a bipedal dinosaur, usually with a large head and three long functional toes per hind foot, generally carnivorous but sometimes omnivorous or herbivorous. Theropod dinosaurs include birds.

Trace fossil: fossils of biological activity, such as root casts; burrows, tracks, and eggshells; also known as ichnofossils.

(**Marine) Transgression** (noun), **transgressive** (adjective): a marine encroachment, submerging land.

Travertine: a carbonate rock formed by the precipitation of carbonate minerals from groundwater or surface water, or at hot springs.

Triassic: the first geologic period of the Mesozoic Era; approximately 252 to 201 Ma.

Trilobite: an extinct marine arthropod with a roughly oval body featuring an axial lobe and two lateral lobes (the three lobes of the name), also divided into three sections (cephalon for the head, thorax, and pygidium for the tail); trilobites vaguely resembled woodlice (roly-poly bug or pillbug).

Trilophosaurid: a herbivorous reptile that resembled a large lizard, known from the Late Triassic.

Tritylodont: a type of diminutive synapsid ("mammal-like reptile"), almost exclusively herbivorous, known from the Triassic into the Cretaceous.

Tuff: a rock which contains more than 75% volcanic ash. Rock with significant but lesser ash content (25% to 75%) is called tuffaceous.

TUSK: Tule Springs Fossil Beds National Monument.

Unconformity: a general term for any erosional or non-depositional surface between two rock units.

USGS: United States Geological Survey.

Valve: a shell; usually applied to mollusks but sometimes to brachiopods as well. Snails and monoplacophorans are univalved (one shell) and bivalves and brachiopods are bivalved (two shells).

Appendix F: 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. A 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 prospecting**—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 (2006; 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. 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 prospecting, 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.

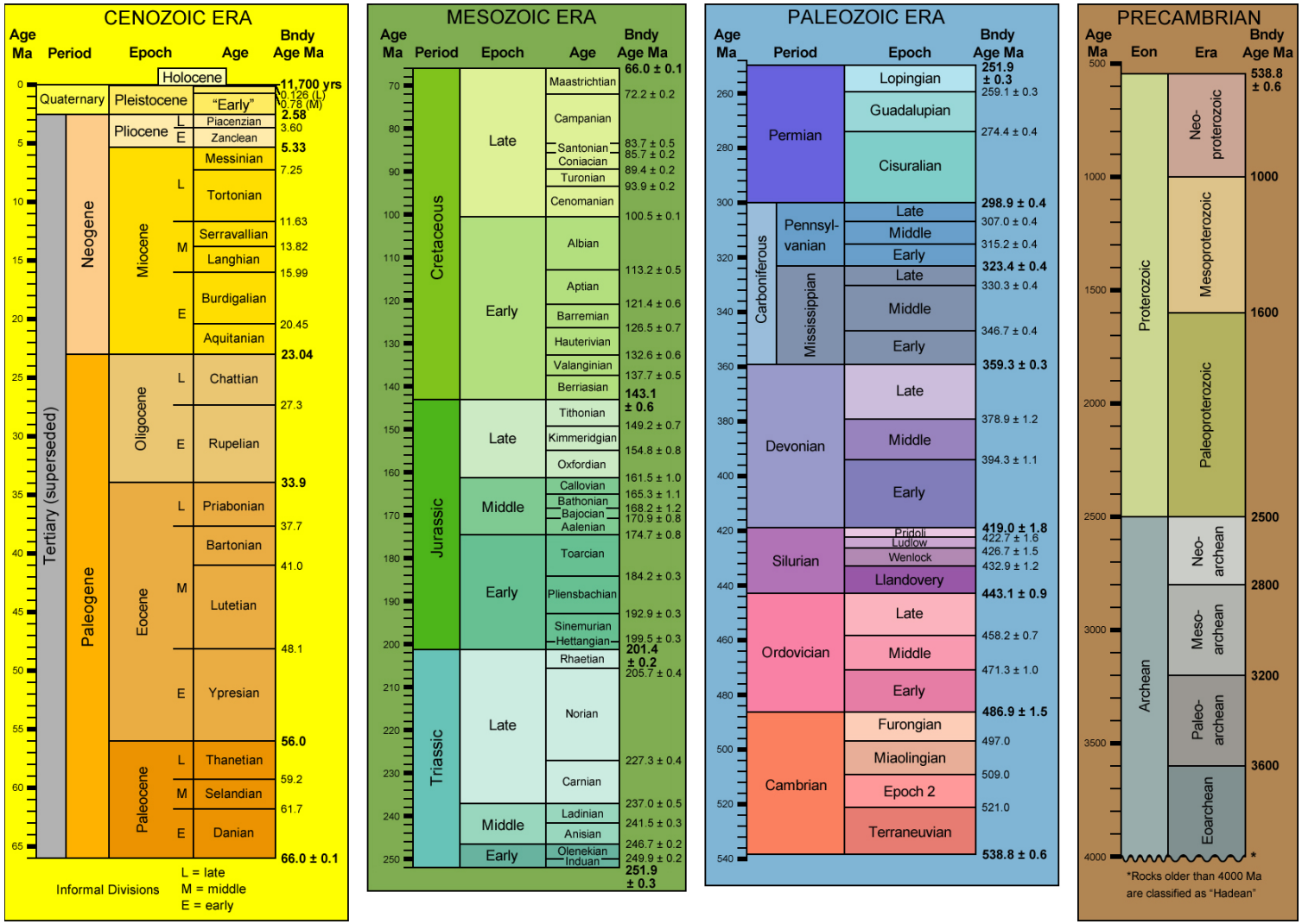
Condition Assessment and Cyclic Prospecting

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 G: Geologic Time Scale



Ma=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

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.

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525