# AN INVENTORY OF PALEONTOLOGICAL RESOURCES ASSOCIATED WITH CAVES IN GRAND CANYON NATIONAL PARK

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Strategies to better document occurrences of paleontological resources within units of the National Park Service were developed by the NPS Geologic Resources Division during the late 1990s in response to the Natural Resource Challenge. The primary objective for these inventories is to compile baseline paleontological resource data to enhance the scientific understanding and management of these nonrenewable resources.

The first inventory strategy is designed to survey all occurrences of fossils, including plants, invertebrates, vertebrates, and trace fossils, within each park. This comprehensive park-level strategy was piloted at Yellowstone National Park in 1996 (Santucci 1998). The Yellowstone survey, as well as subsequent comprehensive inventories, involved literature review, examination of museum collections, and extensive field inventories.

The second inventory strategy involves the development of thematic paleontological resource inventories throughout the NPS. Thematic inventories focus on one category of fossils and attempt to locate which units of the NPS preserve this type of resource. The first thematic resource inventory identified park units that contain fossil vertebrate tracks (Santucci et al. 1998). The Grand Canyon research summarized in this report was conducted as part of a thematic resource inventory identifying paleontological resources associated with caves in the NPS (Santucci et al. 2001). Cave and karst features are a significant resource in the NPS, with more than 3600 such features documented in at least 79 units, 35 of which preserve paleontological resources in caves (Santucci et al. 2001).

## METHODS

This inventory was initiated during the summer of 1998, and was completed during the summer of 2001. The first step was to contact Grand Canyon National Park via an electronic mail survey to obtain basic information as to the status of caves in the park and to determine if paleontological resource studies have been conducted in the past or were currently underway. Phone conversations with the park staff as well as a number of scientists outside of the NPS who have participated in paleontological research laid the groundwork for this study. An extensive literature review was also completed, as there are many publications regarding paleontological resources in Grand Canyon caves. Information gathered through these methods was assembled and summarized, and the summary was then sent to both Grand Canyon park staff and outside reviewers for comments and suggestions.

## RESULTS

As a result of this inventory, 28 caves, summarized below, in Grand Canyon National Park were identified as containing paleontological resources. These resources are extensive and vary from examples of marine forms found in the Cambrian Muav and Mississippian Redwall Limestones through packrat middens, *Oreamnos harringtoni* (Harrington's extinct mountain goat) and *Gymnogyps californianus* (California condor) remains, plant microfossils, and dung deposits. These resources are important tools for paleoecological reconstruction. Indeed, among the 10 caves known to contain sloth dung deposits in North and South America, two are located in the Grand Canyon: Rampart Cave and Muav Caves (P. Martin, written communication 1975).

## DISCUSSION

Grand Canyon National Park (GRCA) was established to preserve the world-famous Grand Canyon of the Colorado River. The park encompasses 446 km of the river, with adjacent uplands, from the southern terminus of Glen Canyon National Recreation Area to the eastern boundary of Lake Mead National Recreation Area. The canyon has been shaped by the forces of erosion and river-cutting to expose Precambrian and Paleozoic strata.

The extensive Muav and Redwall Limestones of the Grand Canyon contain thousands of caves and shelters. Significant paleontological and archaeological resources are associated with many of these caves. The earliest report of fossils from Grand Canyon caves dates back to 1936 when National Park Service employee Willis Evans located a rich cave deposit of late Pleistocene fossil bones and sloth dung in Rampart Cave (Martin et al. 1961).

The Cambrian Muav Limestone, part of the Tonto Group, represents an offshore marine unit. Deep channels were carved by streams or marine scour in the upper portion of the Muav (Harris et al. 1995). The Mississippian Redwall Limestone lies unconformably on top of the Muav where the Devonian Temple Butte Limestone is absent. The Redwall is a bluish gray limestone stained red by water dripping down from the overlying Supai and Hermit Shale redbeds. Marine fossils within the Redwall are common, including bryozoans, brachiopods, and other marine organisms. Chambered nautiloid fossils are a recent discovery in the Redwall Limestone of the Marble Canyon region (Harris et al. 1995).

GIS analysis can be used to extrapolate the total number of caves likely in the Grand Canyon. Most of the known caves in the Redwall Limestone are clustered around trail and river access routes, whereas helicopter transit through the canyon reveals the presence of abundant unknown, inaccessible caves. A survey of the frequency of obvious cave entrances in three well-known areas—Cottonwood Canyon, Hance Canyon, and the southern Nankoweap Basin—revealed 1.7, 1.3, and 1.5 caves per kilometer of Redwall perimeter (K. Cole, unpublished data). The total perimeter of Redwall Limestone outcropping on the eastern Grand Canyon geologic map (river mile 34 to 157) calculated from GIS geologic coverage is 1517 km. Applying the average value of 1.5 caves per km to this figure yields an estimate of 2215 Redwall Limestone caves with obvious openings in the eastern Grand Canyon alone.

Most of the caves studied thus far can be accessed without direct equipment support by climbers from the top or bottom of the Redwall cliff (although not easily). But the great majority of the total number of caves seem to be accessible only through fairly heroic rappelling efforts involving 100–200 m of vertical exposure and running ropes over knife-sharp limestone ledges. Many of the rappelling anchor points may not even be accessible without helicopter support. The amount of fossil organic remains from the last 20,000 years is undoubtedly highest in caves accessible by terrestrial fauna and people. But the possibility remains that some of the now inaccessible caves contain abundant debris from even earlier times when they may have been more accessible than at present.

In addition to the modern caves documented in the Grand Canyon, the Redwall Limestone also contains evidence of caves formed during the Mississippian that were subsequently filled with sediments. Fossils have been reported from cave-fill deposits within paleo-karst features formed within the Mississippian (Osagean and Meramecian) Redwall Limestone (Billingsley et al. 1999). These paleo-karst features were developed in the Mooney Falls and Horseshoe Mesa members of the Redwall Limestone. The caves are believed to have formed during the Mississippian based upon the age of the sedimentary cave fill and the associated fossils. The cave fill deposits have been mapped and identified as the Upper Mississippian (Chesterian) Surprise Canyon Formation (Billingsley et al. 1999). The Surprise Canyon Formation, originally described by Billingsley and Beus (1985), occurs within erosional depressions, stream valleys, sinkholes, and solution caves formed in the Redwall Limestone. The formation consists of a lower fluvial unit and middle and upper marine units. Fossil plant material, especially *Lepidodendron* logs, and vertebrate bone fragments are common in the fluvial facies. The marine component contains an abundance of marine invertebrates such as corals, bryozoans, molluscs, brachiopods, trilobites, echinoderms, and condonts (Beus 1999).

Research into the caves of Grand Canyon National Park has been extensive and multifaceted. These cave deposits have yielded approximately 200 animal taxa and more than 200 plant taxa (Spamer 1993). A Microsoft Access database, GCPALEO, created and maintained by E. Spamer of the Academy of Natural Sciences of Philadelphia, provides an index to every fossil that has been cited in the Grand Canyon library. This database includes all fossils found in the park, not just those in caves. Of the more than 17,000 records in the database, nearly 2400 are from cave localities (Spamer 1993, GCPALEO records). The arid conditions present in the Grand Canyon create ideal conditions for spectacular fossil preservation in the caves; for example, the soft parts of *Oreamnos harringtoni* such as hair, muscle, and ligament, as well as the keratinous horn sheaths and large quantities of dung, are unique to Grand Canyon caves (Mead et al. 1986a). In addition, the aridity aids in the preservation of pollen from the caves (O'Rourke and Mead 1985). The general inaccessibility of most of the caves in the Grand Canyon to all those except experienced rock climbers (or sure-footed rodents, artiodactyls, and birds) enhances their preservation.

Considerable research has been directed toward packrat middens in Grand Canyon caves (Phillips 1977; Cole 1981, 1990; Dryer 1994; Coats 1997). Today, there are four known species of *Neotoma* in the Grand Canyon, all of which collect seeds, leaves, flowers, twigs, bones, and other small objects to incorporate into dens or nests. The packrats periodically clean their dens, producing piles, or middens, of discarded material. Repeated trampling and urination serves to compact the midden into a hard, sometimes well-cemented accumulation of waste. The middens are quite durable when deposited in a dry place, especially in the arid Grand Canyon, where they date back more than 40,000 years. This longevity provides an excellent resource for paleoecological reconstruction of the cave and the region around the cave. The oldest middens have sometimes been found near the mouth of the cave. This relative placement of packrat middens inside caves has been suggested for use as a proxy to determine rates of cliff retreat (Cole and Mayer 1982), although this has not yet been comprehensively investigated.

### Muav Limestone Caves

Vulture Cave is a small limestone cave in the Spencer Canyon Member of the Muav Limestone located in the far western portion of the Grand Canyon. Vulture Cave consists of three major conduits that come together to form a large room. Fifteen packrat middens and a *Bassariscus astutus* (ringtail cat) refuse area were collected and examined from within Vulture Cave. Forty-seven plant taxa were identified from the middens, with twigs and seeds of *Juniperus* sp. (juniper) being the most abundant identifiable plant fragment (Mead and Phillips 1981; Phillips 1977). The plant contents of the middens depict an arid juniper woodland during the late Pleistocene, dominated by *Juniperous osteosperma* (Utah juniper) and *Coleogyne ramosissima* (blackbrush), very different from the hyperarid desert scrub present today. Bones and teeth of 37 vertebrate taxa were also identified, consisting of one tortoise, eight species of lizards, ten snake species, three bird species (also one unidentified shell fragment and one member of the Fringillidae), one shrew species, nine rodent species, four artiodactyl species, and one carnivore species (Mead and Phillips 1981). The remains of *Lampropeltis pyromelana* (Arizona mountain kingsnake) represent the first Pleistocene find of the snake in the Grand Canyon. The remains of *Trimorphodon biscutatus* (lyre snake) found in Vulture Cave represent the first record of the snake in the Grand Canyon. Likewise, the Vulture Cave remains of *Microtus* (vole) are the only known remains of that taxa in the Grand Canyon. The single shrew found in Vulture Cave, *Notiosorex*, represents the first late Pleistocene occurrence within Grand Canyon. The tooth of *Camelops* (camel) represents the largest mammal recovered from Vulture Cave. Insects were also recovered, but specific identification is not yet available (Mead and Phillips 1981). Radiocarbon dates in Vulture Cave reveal a history dating back more than 30,000 years. The oldest date obtained from Vulture Cave is from a *Juniperus* twig recovered from a packrat midden, which yielded a date of 33,600 years BP (Mead and Phillips 1981).

The species *Bassariscus astutus* produces accumulations known as ringtail refuse deposits, similar to packrat middens. One such deposit, encompassing approximately 1 sq m, was discovered and studied in Vulture Cave (Mead and Van Devender 1981). The deposit consisted mostly of small animal bones and scat. In total, 540 elements representing 22 taxa were recovered from the ringtail refuse deposit (Mead and Van Devender 1981). The vertebrate taxa represented consisted of seven lizard species, six snake species, three bird species, and six mammalian species. The most common of the vertebrate remains were that of *Neotoma*, with a minimum number of individuals (MNI) calculated to be 40 or more. Lizards (1–4 MNI) were more common than snakes and birds, both with an MNI of one (Mead and Van Devender 1981). Arthropods, mostly members of the Diplopoda, were also recovered from the ringtail refuse deposit; radiocarbon dates yield an approximate age of 1930 years BP. The Late Holocene remains in the refuse deposit were interpreted as being dietary remnants.

Skeletal remains of *Oreamnos harringtoni* (Harrington's extinct mountain goat), which is found in many GRCA caves, have also been reported from Vulture Cave (Mead et al. 1986a). Mead and Phillips (1981) and Emslie (1987) also reported the remains of *Gymnogyps californianus* (California condor) in Vulture Cave.

Rampart Cave, located near the base of the Muav Limestone, was one of the first caves to be studied in Grand Canyon National Park. NPS employee Willis Evans first entered Rampart Cave in 1936, when he discovered the extensive Shasta ground sloth dung deposit and a number of scattered bones (Figure 1; Martin et al. 1961). Initial excavations by Civilian Conservation Corps (CCC) crews in the late 1930s uncovered some paleontological resources. The cave was then more comprehensively excavated in 1942 by Remington Kellogg, working for the Smithsonian Institution. Many vertebrate remains were collected, which are still part of the Smithsonian collection. Mary Carpenter of Northern Arizona University is currently studying many of these unpublished collections.

Rampart Cave, like the nearby Muav Caves, was originally within the boundaries of Lake Mead National Recreation Area, but was incorporated into Grand Canyon National Park in January of 1975 (K. Rohde, personal communication 2001; Hansen 1978). Rampart Cave contains rich organic layers, which are uncommon in the frequently dry caves of the arid Southwest (Mead 1981). Until 1976, when a fire destroyed much of the deposit, Rampart Cave contained the thickest and least disturbed deposit of stratified *Nothrotheriops shastensis* (Shasta ground sloth) dung known from any locality (Figure 2; Long and Martin 1974; Hansen 1978). Martin and others (1961) reported radiocarbon age dating of three sloth dung samples to >35,500, 12,050, and 10,050 years BP. Later radiocarbon dating of 16 dung boluses and two trampled dung mats of *N. shastensis* yielded dates discontinuously ranging from greater than 40,000

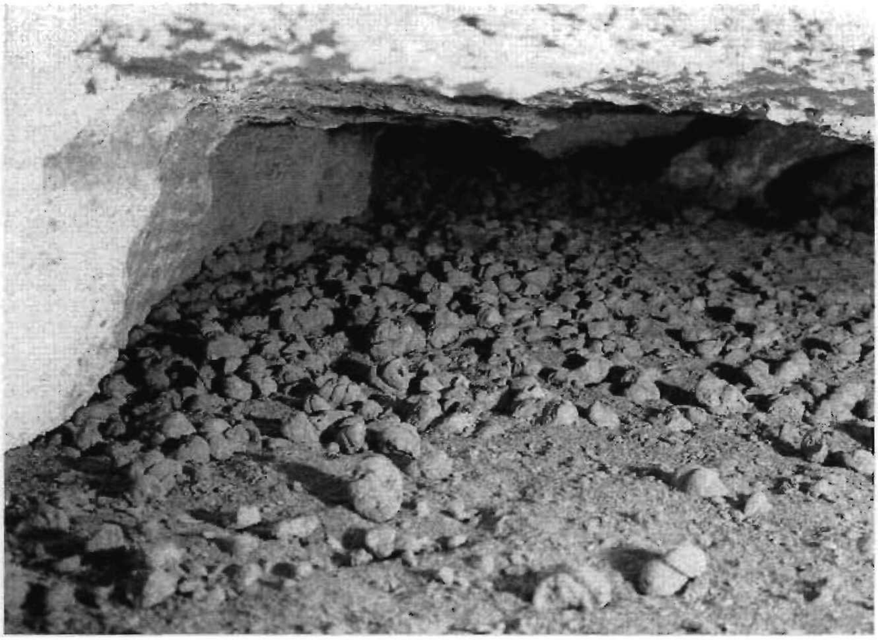

Figure 1. The original surface of the sloth dung deposit in Rampart Cave. Individual untrampled sloth dung balls on top of the deposit, deposited by the last surviving sloths, date to around 11,200 yr BP. (Photo: CCC)

years BP to approximately 11,000 years BP, similar to the dates reported by Martin and others (1961; Mead and Agenbroad 1992). Additional radiocarbon dating has been performed by Long and Martin (1974), yielding a similar range of dates from more than 40,000 years BP to approximately 10,035 years BP. Recent research by Mary Carpenter has generated additional radiocarbon dates from the cave, which will be reported in her thesis. Within the dung, 72 genera of plants were found, enabling paleoecological reconstruction over that extensive time span (Martin et al. 1961; Hansen 1978). Pollen from these plants revealed seasonal variation in the sloth's diet (Mead 1981). No direct skeletal association of the ground sloth and the dung has been reported, although more than 200 bones of *Nothrotheriops shastensis* have been found in Rampart Cave (Figures 3 and 4; Hansen 1978).

Although the sloth remains and dung deposit are among the most well studied aspects of Rampart Cave, other paleontological resources are also present, such as packrat deposits. One such deposit is a 33 cm unindurated "seam" that separates the two major dung layers in the cave. The seam is made up of plant material such as twigs and other macrofossils that are "perfectly preserved" (Phillips 1977; Phillips and Van Devender 1974). Deposited by packrats between 24,000 and 14,000 years BP, the seam may constitute the largest Pleistocene packrat deposit ever found (Phillips and Van Devender 1974). Thirty additional indurated middens have been found both in and around Rampart Cave (Phillips 1977). Sixty types of plants have been identified from within these middens, aiding in paleoecological reconstruction of the Rampart Cave area. Additional plant material from packrat middens yielded dates ranging from 18,890 (*Fraxinus anomala* twigs) to 9520 years BP (*Agave utahensis*; Van Devender et al. 1977). These middens were also a rich source of small mammal and reptile remains, including one tortoise species, three lizard

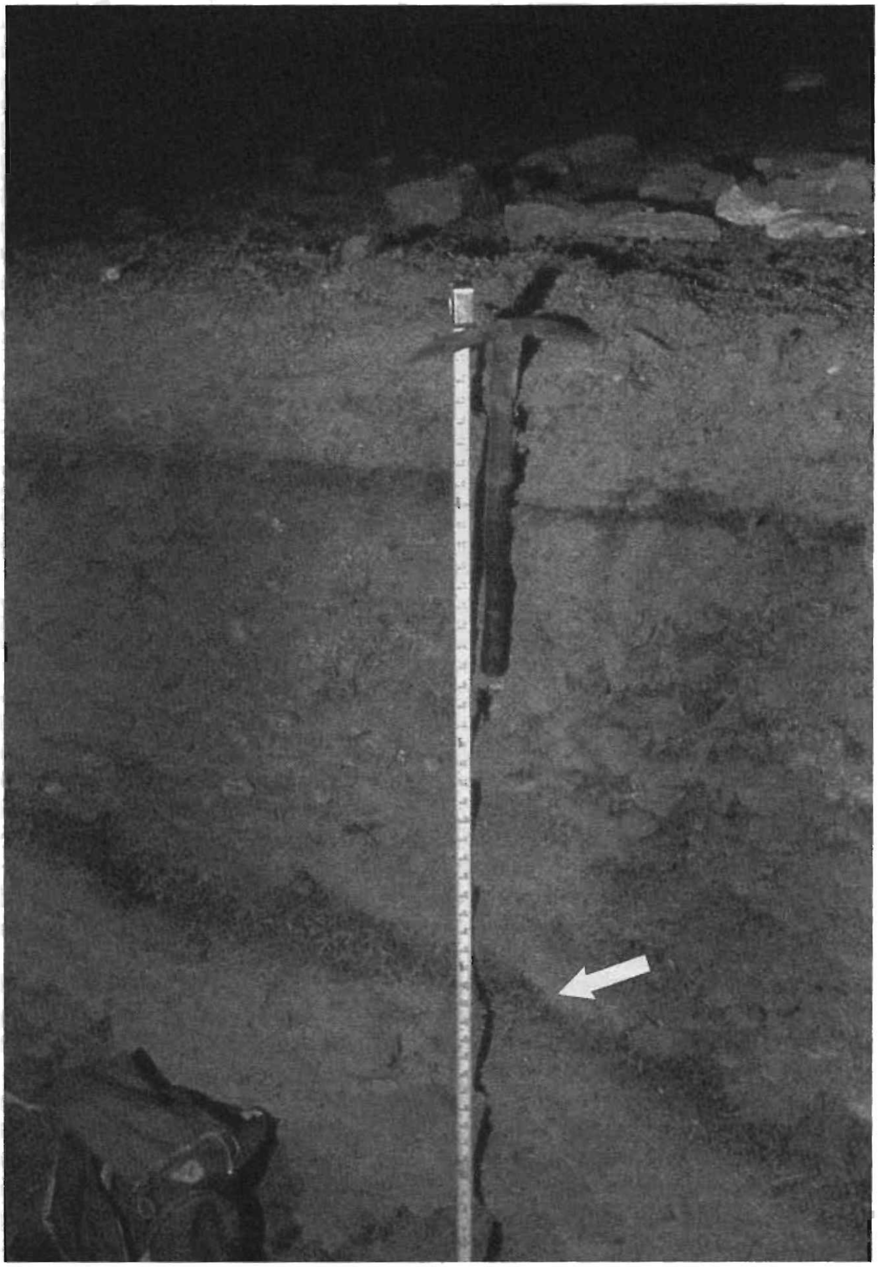

Figure 2. Section through the stratified sloth dung deposit in Rampart Cave. The arrow points to the packrat seam. This section was preserved from the 1976 fire by the 1942 trench in which the photographer is standing. (Photo: James King, 1969)

Figure 3. Excavation of *Nothrotheriops shastensis* bones in Rampart Cave by workers from the Smithsonian. (Photo: Smithsonian Institution, 1942, courtesy of Mary Carpenter)

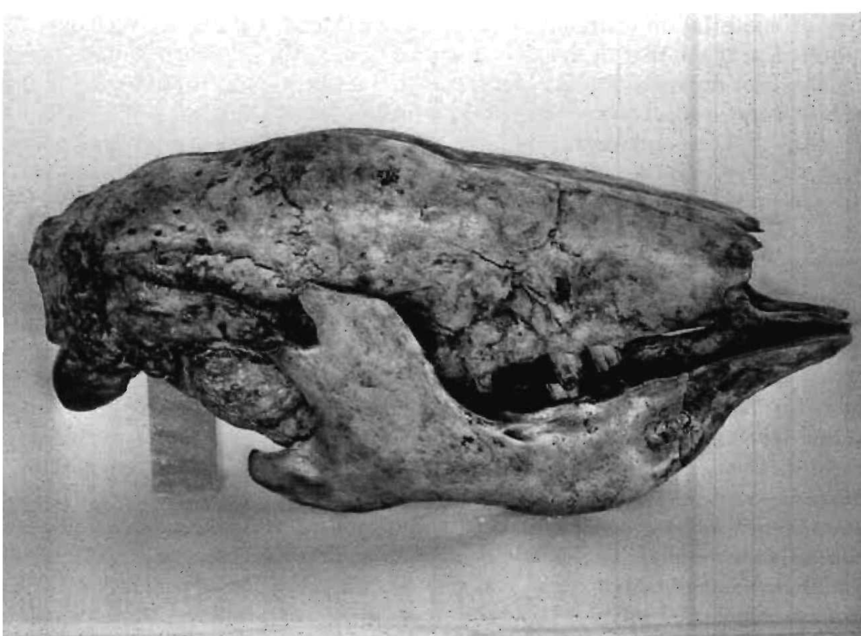

Figure 4. Lateral view of skull and lower jaw of *Nothrotheriops shastensis* collected in Rampart Cave, 1936. (Photo: NPS)

species, three snake species, the vampire bat *Desmodus stocki*, four *Neotoma* species, and one species of deer mouse (*Peromyscus* sp.). The remains of *Erethizon dorsatum* (porcupine) and *Marmota flaviventris* (yellow-bellied marmot) were also recovered from Rampart Cave (Van Devender et al. 1977).

Rampart Cave also contains skeletal remains and dung pellets of *Oreamnos harringtoni* (Mead et al. 1986a). Dung pellets of *O. harringtoni* were dated to approximately 18,430 years BP (Mead and Agenbroad 1992). Eight keratinous horn sheaths were also dated from Rampart Cave. These sheaths yielded ages ranging from 10,140 to 28,700 years BP (Mead et al. 1986b). The age of 28,700 years BP represents the oldest documented age of an *O. harringtoni* horn sheath (Mead et al. 1986a). *Equus* (horse) remains were found in the cave as well; however, they are interpreted as having been brought into the site by *Felis concolor* (mountain lion; Figure 5) due to the steep slope and cliff face below the cave (Hansen 1978). A number of skeletal remains of *Gymnogyps californianus* have also been reported from Rampart Cave (Emslie 1987). Deposits of material interpreted as bat guano located near the rear of the cave are among the oldest deposits in the cave; the guano has been radiocarbon dated to >35,500 years BP (Long and Martin 1974).

The Muav Caves consist of three small caves in the Muav Limestone located upstream from Rampart Cave. Like Rampart, Muav Caves were formerly located within Lake Mead National Recreation Area until the boundaries of Grand Canyon National Park were expanded in January of 1975 (K. Rohde, personal communication 2001; Hansen 1978). Formal and comprehensive excavations have not yet been undertaken in Muav Caves (Mead and Agenbroad 1992), but they contain abundant unsampled packrat middens. Two mid-Holocene *Bassariscus* middens were recently found on ledges outside the cave, suggesting that more may be found inside. Skeletal remains of *Oreamnos harringtoni* are known from Muav Caves (Mead et al. 1986a), and Harrington (1936) and Long and Martin (1974) have reported the presence of a *Nothrotheriops shastensis* dung deposits. Radiocarbon dating of the deposit yielded dates of 11,140 and 11,290 years BP (Long and Martin 1974). Several additional *N. shastensis* dung boluses recovered from the caves radiocarbon dated to 11,810–10,650 years BP (Mead and Agenbroad 1992); this is approximately the time range when *O. harringtoni* and 31 other large mammal genera became extinct at the end of the Pleistocene. This extinction is concurrent with the arrival of the Clovis hunters in North America (Hansen 1978; Mead et al. 1986b).

### Redwall Limestone Caves

Stanton's Cave is a large solution cavern that developed within the Redwall Limestone. The cave is an important archaeological site, with a number of split-twig figurines having been recovered there (Euler 1984; Mead and Agenbroad 1992; Emslie et al. 1987). Several groups of large *Oreamnos harringtoni* dung pellets from Stanton's Cave were radiocarbon dated to 17,300–10,870 years BP (Mead and Agenbroad 1992); skeletal remains of *O. harringtoni* are also known from Stanton's Cave (Mead et al. 1986a). Well over 70 bones of *Gymnogyps californianus* have been found in Stanton's Cave, representing at least five individuals (Emslie 1987). Radiocarbon dating of these condor remains provided an approximate age of 14,260 years BP (Emslie 1987). Radiometric dating of dung pellets of a large artiodactyl, perhaps *Ovis canadensis*, from Stanton's Cave yielded a date of less than 11,000 years BP, an early Holocene date (Mead and Agenbroad 1992). Overall, Stanton's Cave deposits have yielded 23 species of mammals and 70 species of birds (Emslie 1988). Extensive studies of pollen recovered from Stanton's Cave were undertaken independently by Martin in 1984 and also Robbins, Martin, and Long in 1984 (O'Rourke and Mead 1985). Packrat middens from Stanton's Cave were analyzed and reported in Dryer (1994).

Bida Cave is a limestone grotto in the Redwall Limestone. Inside the rather large (approximately 46 x 91 m, Figure 6) lower entrance room were numerous surface skele-

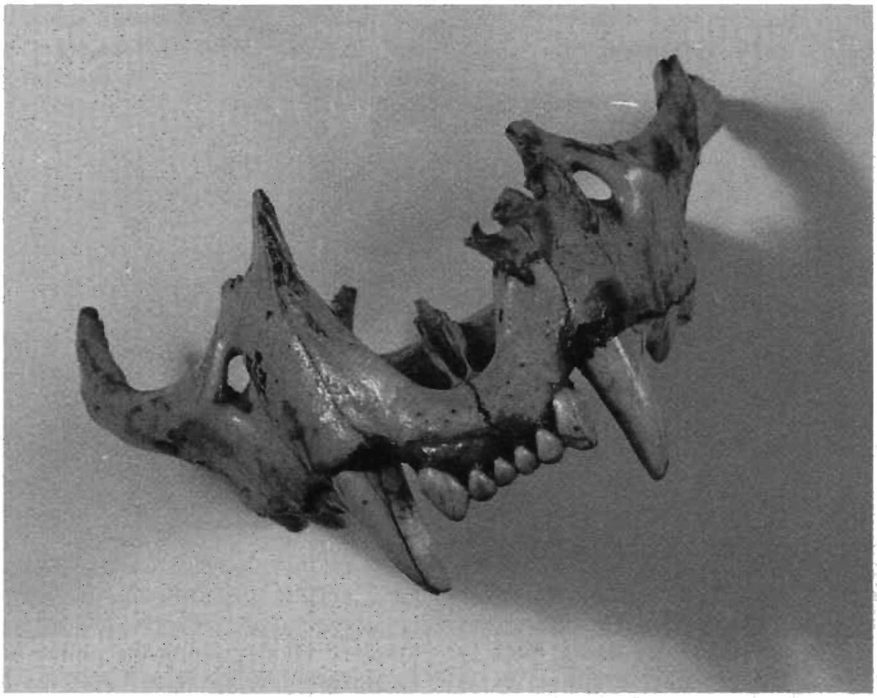

Figure 5. Partial *Felis concolor* skull collected in Rampart Cave, 1936. (Photo: NPS)

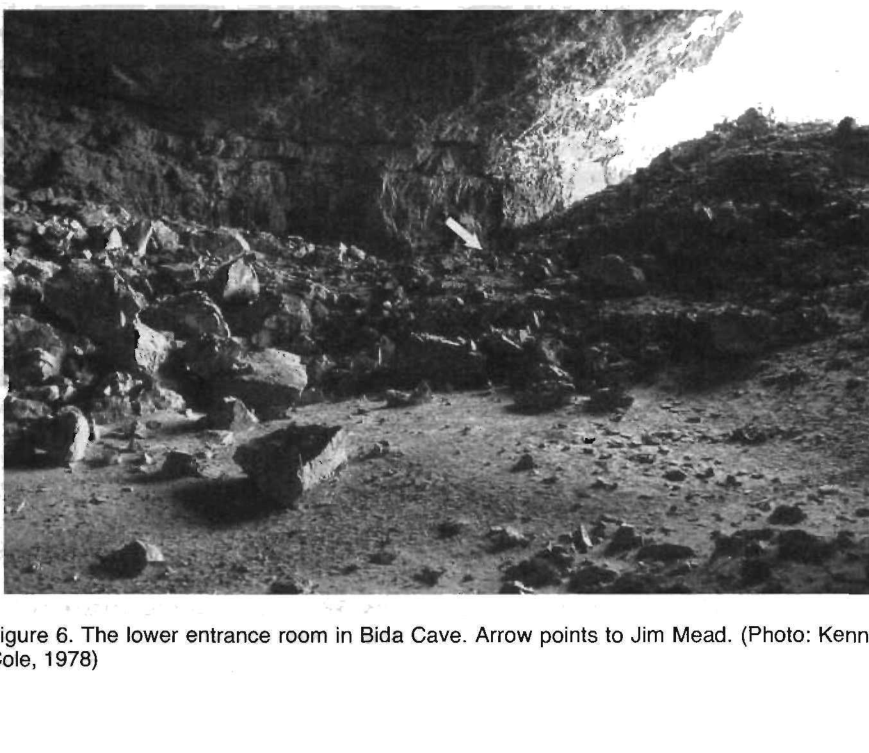

Figure 6. The lower entrance room in Bida Cave. Arrow points to Jim Mead. (Photo: Kenneth Cole, 1978)

tal remains of *Oreamnos harringtoni* (Mead 1986b; Mead and Agenbroad 1992). Four groups of *O. harringtoni* dung pellets returned radiocarbon dates ranging from 24,190 to 11,850 years BP (Mead et al. 1986b; Mead and Agenbroad 1992). A skull with horn sheath was also found in the cave; it dated to approximately 12,930 years BP (Mead et al. 1986b; Mead and Agenbroad 1992). Many such Pleistocene bones and plant parts are still present either directly on the cave's surface or buried under only a thin covering of dust (Figure 7). Extensive pollen samples were also extracted from the dung of *O. harringtoni* and *Ovis canadensis* in Bida Cave (Mead et al. 1986a).

The eolian fill of Bida Cave had a thin layer of Holocene sediment that contained pollen of *Juniperus osteosperma* (Utah juniper) and *Ephedra viridis* (mountain joint-fir), both of which are prevalent in the area today (O'Rourke and Mead 1985). The underlying late Pleistocene sediments, dating back to 24,000 years BP, revealed abundant *Pinus* (pine) during the interstadial, and abundant *Artemisia* (sagebrush) and *Picea* (spruce) during the full glacial Wisconsinan.

Abundant packrat middens have been studied from throughout Bida Cave, ranging in age from 14,500 to 5725 years BP (Cole 1981, 1990, and unpublished). Their plant contents demonstrate that a mixed conifer forest consisting primarily of *Pseudotsuga menziesii* (Douglas fir), *Abies concolor* (white fir), and *Pinus flexilis* (limber pine) grew near the cave during the late Wisconsinan. This forest gave way to the modern pinyon-juniper woodland of *Pinus edulis* (Colorado pinyon pine) and *Juniperus osteosperma* by 10,650 years BP. This is the earliest dated macrofossil of *Pinus edulis* in the eastern Grand Canyon.

*Neotoma* remains are common within four middens; they have been dated to 13,780–6800 years BP (Cole and Mead 1981). Remains of *Peromyscus* have also been identified in a Bida Cave midden. One of the middens containing *Peromyscus* remains yielded a date of 8470 years BP (Cole and Mead 1981). Additional remains reported from the middens of Bida Cave include *Thomomys* sp., a *Sceloporus* sp. scale, cf. *Sonorella* (land snail) shell fragment, *Microtus*, and *Coleonyx variegatus* (banded gecko; Cole and Mead 1981).

Kaetan Cave, in the Redwall Limestone, was first excavated by archaeologists who discovered split-twig figurines. Subsequent paleontological excavations have recovered *Oreamnos harringtoni* dung pellets, some contained in matted dung layers, that yielded radiocarbon dates ranging from 30,600 to 14,220 years BP (Mead and Agenbroad 1992). Skeletal remains of *O. harringtoni* have also been found in this cave (Mead et al. 1986a). Pollen from both Kaetan and Bida Caves has been described in detail by O'Rourke and Mead (1985). The pollen record in Bida Cave contained both Holocene and Pleistocene deposits, whereas the pollen from Kaetan Cave records only the late Pleistocene flora of the area. Another important difference between the two caves is that the cave fill containing the pollen in Bida Cave was primarily eolian in nature whereas the pollen from Kaetan Cave was recovered from dung pellets and matted dung. This is an important difference because pollen is easily separable from eolian fill, whereas the dung pellets containing pollen are rarely separable from the cave fill and matted dung layers. Thus, the pollen record from Kaetan Cave should be interpreted as a dietary component (O'Rourke and Mead 1985). Similar pollen types were found in both caves, but there were significant differences in diversity and composition, most likely due to the dietary nature of the Kaetan Cave deposit. *Artemisia* was found in much lower quantities in Kaetan Cave, whereas *Juniperus* was more abundant than in Bida Cave (O'Rourke and Mead 1985). *Pinus* represented the vast majority (91%) of the pollen recovered in the lower layers of Kaetan Cave (O'Rourke and Mead 1985). Extensive plant macrofossils are also found in Kaetan. Radiocarbon dates of this macrofossil material have provided approximate dates of 30,600, 24,000, 17,500, and 14,000 years BP for the various layers in Kaetan Cave (O'Rourke and Mead 1985). A *Gymnogyps californianus* ulna was found within

Figure 7. Fossil skull of *Oreamnos harringtoni* partially buried in Bida Cave prior to excavation. Many Pleistocene fossils like this remain directly on the cave floor or are buried by only a thin layer of dust. (Photo: Kenneth Cole, 1977)

Kaetan Cave that dated to approximately 16,290 years BP (Emslie 1987).

Packrat middens that date to 20,630–510 years BP have been studied from Crystal Forest Cave, Cave of the Domes, and several adjacent caves (Cole 1981, 1990, and unpublished). These middens show the transition of this now arid site from the late Pleistocene to the present. During the late Pleistocene the area was on the ecotone between the lower fringes of the mixed conifer forest and the upper limits of an arid juniper scrubland of *Juniperus osteosperma, Atriplex confertifolia* (shadscale), and *Artemisia tridentata* (sagebrush). Today, the area is on the ecotone at the lower limit of the pinyon-juniper woodland and the upper limit of the desert scrub dominated by *Coleogyne ramosissima* and *Ephedra viridis* (green ephedra).

Luka Cave contained several split-twig figurines as well as packrat middens dating to 14,050 and 15,840 years BP (Cole 1981, 1990; Figure 8). Fossils from this higher elevation cave, along with those from other unnamed caves, demonstrate the dominance of *Pinus flexilis* in the central portion of the mixed conifer forest during the late Pleistocene between the elevations of 1600 and 1800 m. *Pinus flexilis* is no longer present within Grand Canyon National Park. *Gymnogyps californianus* skeletal remains have also been reported from Luka Cave (Emslie 1987).

The highest elevation caves in the Redwall Limestone occur around 2000 m in the Nankoweap and Kwagant drainages where this unit is elevated on the northwest side of the Kaibab monocline and Butte Fault. Several unnamed high-elevation caves were found by Cole (1981, 1990) to contain abundant Pleistocene packrat middens, which were dominated by needles of *Picea pungens* (blue spruce) and *Juniperus communis* (common juniper), along with the mixed coniferous forest species.

Stevens Cave, a rather extensive cave, also formed within the Redwall Limestone. Cave sediments have been dated by Urani-

Figure 8. Split-twig figurine on the floor of Luka Cave. (Photo: Kenneth Cole, 1977)

um/Thorium to 700,000 years BP (Emslie 1988). Unlike many of the other Grand Canyon caves, Stevens was accessible to mammalian carnivores. This fact is supported by the presence of two associated humeri from either *Canis dirus* (dire wolf) or *C. lupus* (gray wolf). Radiocarbon dated to approximately 10,530 years BP, these remains represent the first record of wolf in the Grand Canyon (Emslie 1988). Another exceptional find within Stevens Cave is a nearly complete *Gymnogyps californianus* skull (Figure 9). The skull's beak was still intact and connective tissue was also present, dating to 12,540 years BP (Emslie 1987, 1988). The most common remains from Stevens Cave are those of *Oreamnos harringtoni;* dung, hair, and a number of bones representing at least four individuals have been found (Emslie 1988). The contents of packrat middens from Stevens Cave have been reported by Larry Coats (1997).

Sandblast Cave is made up of a series of three caverns that merge to form a small complex of caves. The caverns may represent a nest or roost for raptors, including *Gymnogyps californianus,* as evidenced by the extensive remains (Emslie 1988). Literally thousands of bones of fish, lizards, snakes, birds, and rodents are scattered on the floor of the cave (Emslie 1988). Sixty-four *G. californianus* bones found in the cave, representing at least five individuals, were radiocarbon dated to 13,110–9580 years BP (Emslie 1986, 1987, 1988). An unconsolidated packrat midden in the cave has also yielded a wealth of paleontological resources. Within the midden were fragments of large mammal limb bones (*Equus, Bison, Camelops,* and *Mammuthus*), as well as skeletal remains of *Oreamnos harringtoni* (Emslie 1988). These large mammal bones, together with the small bones littering the floor, probably represent the condor's diet. Dung pellets of *O. harringtoni* were also recovered and radiocarbon dated to >33,100 years BP (Mead and Agenbroad 1992). Driftwood in the cave yielded dates beyond the 40,000-year limit of radiocarbon dating (Emslie 1988). Additional avian remains recovered

Figure 9. Exceptionally well preserved *Gymnogyps californianus* skull collected in Stevens Cave. (Photo: Steve Emslie)

from the midden are *Podilymbus podiceps* (pied-billed grebe), *Aechmophorus occidentalis* (western grebe), *Cathartes aura* (turkey vulture), three species of *Anas* (ducks), *Aythya* (duck), *Buteo* (hawk), three species of *Falco* (falcons), *Fulica americana* (American coot), cf. *Porzana carolina* (sora), *Zenaida macroura* (mourning dove), *Aeronautes saxatalis* (white-throated swift), and *Corvus* sp. (crow or raven; Emslie 1988).

The Redwall Limestone's Shrine Cave is an important archaeological site. The large alcove is the site of more than 33 rock cairns and two split-twig figurines (Emslie et al. 1987). Associated with the archaeological resources are much older paleontological resources, which may indicate that the ancient people in the canyon used the paleontological resources as their own cultural artifacts; for example, many of the cairns include packrat middens. Some of the split-twig figurines have dung pellets, which may be from *Ovis canadensis*, wrapped inside of them (Emslie et al. 1987). Other middens in the cave contain bone, a skull, horn sheaths, teeth, and dung of either *Oreamnos harringtoni* or *Ovis canadensis*. The middens probably date back to the late Pleistocene, whereas the archaeological resources date back only to approximately 3500–3900 years BP (Emslie et al. 1987). Some skeletal remains of *Gymnogyps californianus* are also reported from Shrine Cave (Emslie 1987). The contents of a packrat midden from Shrine Cave are reported by Coats (1997).

Skull Cave is another cave developed in the Redwall Limestone. It has one large opening that leads to three separate passages. The floor of the cave is littered with the bones of small animals and *Neotoma* and *Peromyscus* feces. Anhydrite from a test pit excavated in the rear of the cave yielded a Uranium series date of approximately 16,000 years BP (Emslie 1988). Extensive mammalian and avian taxa have also been recovered from the cave. Mammalian taxa identified from the cave deposits include *Pipistrellus herperus* (western pipistrelle), *Sylvilagus*, *Lepus* sp., *Neotoma*, *Peromyscus*, *Spilogale* *gracilis, Oreamnos harringtoni, Ovis canadensis,* and a number of unidentified large mammal bones (Emslie 1988). The presence of *Spilogale putoris* represents a rare occurrence of this mammalian carnivore. The avian taxa include *Gymnogyps californianus* (Emslie 1987), *Chen caerulescens* (snow goose), four species of *Anas, Aythya* sp., cf. *Colinus virginianus* (bobwhite quail), *Phalaropus lobatus* (red-necked phalarope), *Colaptes auratus* (northern flicker), cf. *Junco* sp., and *Agelaius phoeniceus* (red-winged blackbird; Emslie 1988). Some of the *G. californianus* skeletal remains were radiocarbon dated to approximately 12,210 years BP (Emslie 1987).

Skylight Cave is located near Sandblast Cave in the Redwall Limestone. Two openings converge into one passage that continues for nearly 40 m into the Redwall (Emslie 1988). A number of avian taxa are represented in Skylight Cave: *Podilymbus podiceps*, cf. *Podiceps nigricollis* (eared grebe), *Gymnogyps californianus* (Emslie 1987), two species of *Anas, Falco spaverius* (American kestrel), *Recurvirostra americana* (American avocet), a member of the Picidae, and an unidentified Passeriformid (Emslie 1988). Tissue from a *Gymnogyps californianus* specimen was radiocarbon dated to approximately 11,345 years BP (Emslie 1987).

Hummingbird Cave is also located near Sandblast Cave. One large passageway of 30 m leads back to a crawl space. Hundreds of bones from small animals, such as birds and rodents, along with rodent feces (most likely *Peromyscus*) litter the floor (Emslie 1988). It is interesting that evidence of packrat activity was not observed in Hummingbird Cave. Several bird species, *Anas crecca* (green-winged teal), *Aythya affinis* (lesser scaup), *Circus cyaneus* (northern harrier), two species of *Falco, Larus* sp. (gull), and an unidentified Passeriformid have been identified from the remains (Emslie 1988). In addition, a mummified *Corvus corax* (raven) and a headless *Sphyrapicus varius* (yellow-bellied sapsucker) skeleton have been reported from Hummingbird Cave (Emslie 1988).

Crescendo Cave is a large opening in the Redwall that contains at least 11 rock cairns. The remains of *Lepus* sp., *Corvus* sp., and *Gymnogyps californianus* have been found. Dung layers, probably representing *Oreamnos harringtoni*, were radiocarbon dated to approximately 10,950 years BP (Emslie et al. 1995). The contents of packrat middens from Crescendo Cave were reported by Coats (1997).

Rebound Cave is located south of Crescendo Cave. A layer of *Ovis canadensis* or *Oreamnos harringtoni* dung was found and radiocarbon dated to approximately 16,640 years BP (Emslie et al. 1995). A partial artiodactyl humerus was also recovered. The contents of packrat middens from Rebound Cave are reported by Coats (1997).

Left Eye Cave is located south of both Rebound and Crescendo Caves. Within this cave is a layer of *Ovis canadensis* or *Oreamnos harringtoni* dung. A packrat midden was also observed (Emslie et al. 1995).

Right Eye Cave, west of Left Eye, is a small cave also containing several *Ovis canadensis* and *Oreamnos harringtoni* bone fragments. No dung was found in the cave, but a packrat midden was reported (Emslie et al. 1995).

Five Windows Cave, on the same ledge as Left and Right Eye, has five openings within 10 m of each other. Extensive faunal remains have been found in Five Windows. A "loose" in situ packrat midden was observed in this cave, along with a mat of *Oreamnos* or *Ovis* dung. Several *Gymnogyps californianus* bones were found near one of the middens. Numerous other avian taxa are represented by bones in Five Windows, consisting of *Zenaida macroura, Falco sparverius, Catoptrophorus semipalmatus* (willet), *Anas* sp., and an unidentified passerine. The skull of a lizard and femur of a squirrel were recovered from the cave. The presence of a partial feather from *G. californianus* may indicate that Five Windows was a late Pleistocene nesting site for the condor (Emslie et al. 1995). Coats (1997) has reported the contents of packrat middens from Five Windows Cave.

A number of other caves in the Redwall Limestone have been the subject of more limited research. Skeletal remains of *Gymnogyps californianus* have been recovered from Bridge Cave, yielding radiocarbon dates of approximately 11,140 years BP (Emslie 1987). Additional skeletal remains of *G. californianus* found in Midden Cave were radiocarbon dated to approximately 22,180 years BP (Emslie 1987). Skeletal remains of *Gymnogyps californianus* have also been reported from Three Springs Cave and Tooth Cave (Emslie 1987). *Oreamnos* or *Ovis* dung was found at White Cave (Emslie et al. 1995). Radiocarbon dating of *Oreamnos harringtoni* dung pellets and an amalgamated dung layer in Chuar Cave yielded dates of approximately 29,380 years BP (Mead and Agenbroad 1992). Disappearing Cave, a small limestone shelter near the Marble Canyon region, contains a small, stratified section of sediments, plant remains, and *O. harringtoni* dung pellets. The dung pellets from Disappearing Cave were radiocarbon dated to approximately 27,360 years BP (Mead and Agenbroad 1992). Coconino Cavern contains remains of *Nothrotheriops* (Lindsay and Tessman 1974). A mummified canid, which appears to have wandered into the cave and subsequently died, was found in an unidentified Grand Canyon cave (Carpenter and Mead 2000). Mats of late Pleistocene *O. harringtoni* dung and masses of late Pleistocene to Holocene packrat middens were also found in the cave with the mummified canid (Carpenter and Mead 2000).

## PROTECTION OF PALEONTOLOGICAL RESOURCES IN NPS CAVES

The remarkable paleontological resources found in Grand Canyon National Park's caves offer a glimpse into the wide variety of fossils found in caves throughout NPS service areas. Caves are extraordinarily unique resources with a number of traits that make them significant paleontological localities. Caves provide windows into rock units where internal structure can be viewed as well as exposures of marine invertebrates commonly entombed in Paleozoic limestones. Few paleontological localities offer a more constant environment than caves. This relatively constant environment often allows for exceptional preservation, even of soft tissues and dung which are not often found outside of caves. Caves are obviously important localities for fossils of cave-dwelling organisms, especially bats, whose fossils are very rare outside of caves. In addition, trace fossils such as claw and scratch marks can be preserved in cave sediments. Packrats, ubiquitous Grand Canyon cave denizens, present a unique taphonomy by gathering micro and macro fossils for use in their middens, which become time capsules for paleoecological reconstruction. Finally, some cave deposits are stratified, allowing the opportunity to view successional relationships and ecological change through time.

Caves are very important localities; however, the fragile nature of cave deposits necessitates cautious planning and management decisions. Locality information and other data related to paleontological and cave or karst resources are considered sensitive and are thus not provided in this report. A number of federal laws and NPS regulations and policies support restricted access to sensitive natural and cultural localities. The 1998 National Park Service Omnibus Management Act legislated a Freedom of Information Act (FOIA) exemption for such localities.

Unfortunately there are a number of documented incidents where paleontological resources within NPS caves have been stolen or vandalized. Perhaps the best-known example of paleontological resource loss in an NPS cave occurred at Rampart Cave in Grand Canyon National Park. In 1976, these extensive sloth dung deposits, the largest such deposits known, were almost entirely destroyed by a human-caused fire fueled by the flammable dung with oxygen supplied from fossil nitrates in the deposit (Figure 10). Recent work by Northern Arizona University's Mary Carpenter, however, reveals that some bone material survived the devastating fire and that the Smithsonian's 1942 excavation trench acted as a firebreak that preserved a small portion of the original stratigraphic section.

In response to such incidents, we believe that a strong resource protection message should accompany this report. Our goal is to help promote responsible stewardship of

Figure 10. Firefighters responding to fire in Rampart Cave, 1976. (Photo: Tom Van Devender)

nonrenewable cave fossils. The first step in understanding paleontological resources in caves is to compile baseline inventory data. These data are summarized here for Grand Canyon National Park, and for other NPS units in Santucci and others (2001). These data can allow for more informed managerial decision making. In addition, the current permitting policy distributes collection and research permits to institutions well equipped to carry out the collection and research of paleontological resources in national parks. These cooperative endeavors between the NPS and outside institutions, such as the extensive work in the Grand Canyon conducted by a number of Northern Arizona University scientists and students and USGS researchers, foster an increase in knowledge and interest of paleontology in all arenas: scientific, public, and managerial. Continued in situ paleontological resource management coupled with strategic sampling plans will allow the continuation of the excellent paleontological research in the caves of Grand Canyon National Park and throughout National Park Service properties, thus ensuring their longevity for generations to come.

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