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Contents

- Possible Exhumed Fossil Caverns in the Madison Group (Mississippian) of the Northern
Rocky Mountains: A DiscussionNewell P. Campbell 43
- Archeology and Speleology: The Case for ConservationDavid G. Anderson 55

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Possible Exhumed Fossil Caverns in the Madison Group (Mississippian) of the Northern Rocky Mountains: A Discussion

Newell P. Campbell *

ABSTRACT

A fossil karst on the upper surface of the Mission Canyon formation of the (Mississippian) Madison group in Montana, northern Wyoming, and western South Dakota was infilled by late Mississippian or early Pennsylvanian sediments of the Amsden and Kibbey formations. The many caves in the Mission Canyon formation may represent exhumed fossil caverns that date back to Mississippian time. Evidence substantiating exhumed fossil caverns of Mississippian age is:

1. Closed, sediment-filled caves intersected by drill holes down to a depth of several hundred feet that have not yet been exhumed.
 2. Remnants of a fossil sediment fill (filled "blindleads") in caves open to the surface.
 3. Large caves with their passages oriented down dip in steeply dipping limestones but showing features common to phreatic caverns.
- Evidence not applicable for proving the existence of exhumed fossil caverns in the study area is:
1. Fossil breccia in sinkholes and small caves which appears to encounter large cave passages only at random.
 2. Microfossils (inconclusive, but recent fossil material was found only in the top few inches of the cave fill).
 3. Age dating by radiometric or paleomagnetic means (not useful for dating caves that may date back to Mississippian).

Introduction

The term, *fossil karst*, is usually defined as karst topography developed in the geologic past and preserved until the present. *Exhumed karst* can be fossil karst which has been uncovered by surface erosion of overlying beds or, pertaining to caves, fossil caverns that have been re-excavated and opened to the surface.

A number of authors have cited the presence of possible exhumed caverns in Mississippian carbonates located in the northern Rocky Mountain states (Schultz, 1969; Elliott, 1963; Deike and White, 1961; Keefer, 1963; and Deal, 1962). These authors relate the formation of the caves to sub-aerial erosion during Late Mississippian time, creating a karst surface on the limestone. This is followed by in-filling and burial of the caves by Pennsylvanian sediments. They remained buried until the Laramide and Cascade Revolutions uplifted the region. The overburden was then stripped off and the caves re-excavated.

The mechanics involved in creating an exhumed cave that dates back to the Paleozoic are complex. The problems in proving that a cave is exhumed are more difficult than usually realized. I will discuss fossil and exhumed karst in general and will examine the evidence for exhumed karst in Mississippian rocks of the northern Rocky Mountain states.

Nature of the Problem

Definitions and Examples

Fossil Karst. It is usually assumed that caves and other solution features are geologically young. Caves tend to be unstable and to collapse or be destroyed by erosion in a short period of geologic time. However, in certain cases, it is possible to preserve karst features for much longer periods of time, usually by infilling or burial, but sometimes by stable conditions over long periods. The term, *fossil karst*, (sometimes called paleokarst or buried karst), implies karst which has survived several geologic periods. However, some authors discuss fossil karst within the Quaternary. For example, Ford (1971, p. 595) calls Castleguard Cave, Canada, "a

fossil of the last interglacial or earlier."

In this paper, the words *fossil karst* will be used to describe solution features that have been preserved since mid-Tertiary or earlier time, in order to avoid the problem of where the time boundary between fossil and non-fossil karst actually lies (Fig. 1). Since many treatises on the origin of caves state that caves are "usually only a few million years old," any early Tertiary karst can clearly be called fossil.



Figure 1. Sinkhole filling in the Florida Keys. The breccia is Pleistocene in age. In this paper, the term *fossil karst* will be applied to karst that is older than mid-Tertiary. Compare this relatively recent breccia with those of the Mission Canyon formation, figures 5, 6, and 8.

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Examples. It is well known that a fossil karst exists in middle Mississippian limestones in Wyoming, Montana, and South Dakota. Roberts (1966, pp. 17-21), referring to numerous studies, documents the existence of a fossil karst on the Mission Canyon formation of the Madison group. Keefer (1963) discusses fossil karst formed in Mississippian rocks in the Tosi basin of the Gros Ventre Range, Wyoming. Deike and White (1961, p. 17) describe fossil sinks and cave fills in the Pahasapa limestone (Mississippian) in Wind Cave, South Dakota.

Fossil karsts are not limited to the northern Rocky Mountains. Halstead and Nicoll (1971) describe fossil caves containing Triassic sediments and vertebrates in southwest England. Jennings (1971, p. 4) mentions infilled caves in Devonian rocks in Tasmania, part of a cave filled with Permo-Triassic breccia in England, and fossil karst in Poland. Popov (1972, p. 361 and p. 369) discusses two fossil karst areas in the U.S.S.R.—one in upper Devonian rocks, the other in Cretaceous carbonates. Finally, Sweeting (1973, pp. 300-305) writes of fossil karst at a wide variety of locations in various geologic periods.

Exhumed Karst. As in the case of fossil karst, the term, *exhumed karst*, takes on a variety of meanings. Exhumed karst (also called resurrected karst) can be fossil karst that has been buried and later uncovered, exposing the old karst surface; it also can mean fossil karst which has had once-filled sinkholes and caves re-opened. Closely associated with exhumed karst is *relict karst*, in which the caves and sinks were never actually filled but have remained open since their origin. In this paper, exhumed karst will mean fossil karst which was once buried and filled but later re-excavated and is now air-filled.

Examples. Several writers claim the existence of exhumed karst in Mississippian limestones located in northern Rocky Mountains. Elliott (1963, p. 10) and Schultz (1969, p. 11) believe that caves in the Pryor Mountains of Montana and Wyoming are of Mississippian age, having been exhumed after uplift in the Tertiary. Keefer (1963, p. 130) describes an exhumed karst in the Tosi basin, Wyoming. At least part of the fossil karst in Wind Cave and Jewel Cave, South Dakota, has been exhumed (Deike and White, 1971, p. 25 and Deal, 1962, p. 57). Thrailkill (1960, p. 59) believes that a part of Fulford Cave, Colorado, is exhumed fossil karst dating back to the formation of the Leadville limestone.

Exhumed karst has been described in other limestone areas of the world, also. Avias (1972, p. 137) describes exhumed Cretaceous karst in the Paris Basin. At least one of the caves of the Mendip, described by Halstead and Nicoll (1971), is exhumed since it was formed in the Triassic. Popov (1972, p. 369), in speaking of a fossil karst in the U.S.S.R., states that karst formation began in Cretaceous but continued and was intensified in the Pleistocene. Sweeting (1973, pp. 301-303) discusses the exhumed karsts of Great Britain, some with several phases of karstification. It is important to note here that the majority of exhumed karsts described consist of re-excavated valleys, sinkholes, karren, and other surface features. Mention of exhumed caverns and deep sinkholes is rarely made. One exception appears to be the exhumed Mississippian karst of the northern Rocky Mountains.

Basic Evidence

When describing any exhumed karst, previous studies have discussed the following features: breccia association, sediment fill, passage orientation, fossils, and age-dating. One or all of these items have, in one paper or another, been used as evidence to suggest exhumed karst.

Breccia Association. Surface features in fossil karst areas are often filled with solution breccia. Sinks, karren, valleys, and sometimes caves contain angular blocks of limestone or other

sedimentary rocks cemented in a matrix of clay, siltstone, or calcite (Fig. 1). The breccia fragments are normally carbonate, unless the overburden that filled the karst is of a different composition—sandstone and conglomerate blocks may form part of the fill. The matrix is usually red, if the karst surface was formed under tropical or sub-tropical conditions or if the overburden consists of redbeds.

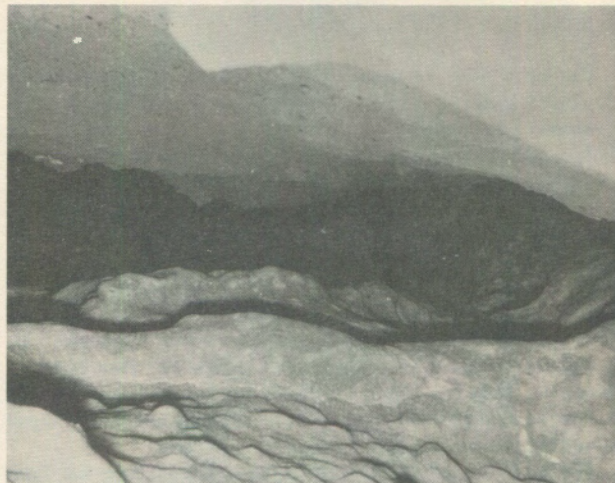
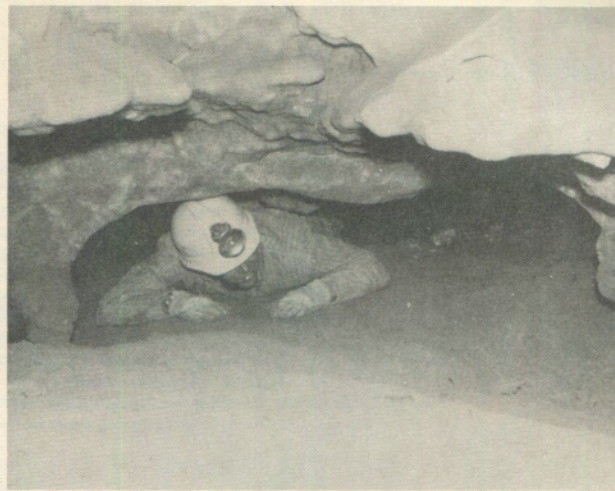


Figure 2. Clay fill in Red Clay Room, Little Ice Cave. The fill occupies nearly the entire room and may block off passage beyond.

In some places, the exposed fossil breccias become excavated, forming new karst in exactly the same place as the old karst. This may be caused because the breccia is more soluble or more easily penetrated by ground water than the surrounding rock. Once the breccias are removed, the surface is one of exhumed karst.

Sedimentary Fill. Clay and sometimes sand and gravel are often found filling fossil karst. The fill is loose and not tightly cemented, as in breccia, and the fragments are rounded by abrasion. The material was probably washed in shortly after karst formation. In some caverns, the fill has been re-excavated, leaving exhumed caverns (and sinkholes) behind (Fig. 2). It is necessary to show that the cavern filling was not recent in order for the karst to qualify as an exhumed karst as defined in this paper.

Passage Orientation. Studies by Davies (1960), Moore and Nicholas (1964), and Ford (1965) have shown that caves are often developed across steeply-dipping limestones. This is because passages are developed along the water table. There are some caves

(especially those associated with fill and breccia) that have their passages oriented down dip in steeply dipping limestones. These caves are thought to have been developed originally in flat-lying limestones and later were uplifted to their present position. The fill was then removed, and the cave became exhumed.

Fossils. Fossils that are found in caves and sinks can be used to date the age of the exhumed karst, provided that the fossils were not washed in *after* the cave was exhumed. Halstead and Nicoll (1971) found Triassic vertebrates in cave fills in southwest England. The fossils were apparently deposited along with the fill in Triassic time. Vertebrate fossils are most often used as age indicators, but microfossils may prove to have a wider application.

Age Dating. Dating of fill or speleothems within a cave can show that it was exhumed, provided that the history of the cave after infilling is well known. Ford and Goodchild (1968, p. 34) used Carbon-14 to date the re-excavation of part of Nakimu Caverns, British Columbia, at between 4,350 and 8,000 years B.P. However, in this paper, we are only concerned with fossil karst that is Mid-Tertiary or older; Carbon-14 dating cannot be used successfully for older rocks. It is difficult to date very old sediments using other radiometric methods. Paleomagnetic dating has only recently been used in cave dating and will be discussed later.

Mississippian Rocks and Associated Caverns in the Northern Rockies

Studies of the Mississippian fossil karst in the northern Rocky Mountain states have centered around describing the breccias and sedimentary fill. The remainder of this paper will discuss Mississippian fossil karst in the northern Rocky Mountains, citing the pros and cons of the five lines of evidence mentioned above.

Area Description

The study area includes Montana, northern Wyoming and western South Dakota. Mississippian rocks showing fossil karst crop out in the Rocky Mountains in western Montana and northeastern Wyoming, in the so-called "plains mountains" of central Montana and Wyoming, and in the Black Hills of South Dakota and Wyoming (Fig. 3). Specific mountain ranges where fossil karst has been reported include:

Montana—Flathead Range, Sawtooth Range, Helena Mountains, Big Belt Mountains, Little Belt Mountains, Castle Mountains, Horseshoe Hills, Bridger Range, Gallatin Range, Absaroka Range, Beartooth Range, Sweetgrass Hills, Little Rocky Mountains, Moccasin Mountains, Judith Mountains, Big Snowy Mountains, Pryor Mountains, and the Bighorn Mountains.

Wyoming—Beartooth Mountains, Bighorn Mountains, Sheep Mountain, Owl Creek Range, Wind River Range, Teton Range, Gros Ventre Range, Black Hills, Casper Mountains.

South Dakota—Black Hills.

In nearly every mountain range, Paleozoic rocks, exposed by uplift and erosion during the Tertiary, crop out on the flanks of the mountains. In many instances, the Mississippian carbonates have been stripped from the tops of the mountains and are exposed only around the edges. In others, such as the Pryor and Big Snowy Mountains, Mississippian rocks cover the entire mountain range.

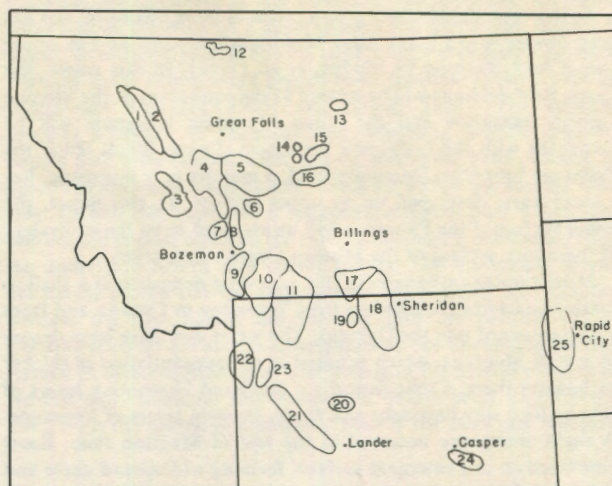


Figure 3. Index map of Montana, Wyoming, and South Dakota, showing mountains where fossil karst has been reported. 1-Flathead Range, 1-Sawtooth Range, 3-Helena Mountains, 4-Big Belt Mountains, 5-Little Belt Mountains, 6-Castle Mountains, 7-Horseshoe Hills, 8-Bridger Range, 9-Gallatin Range, 10-Absaroka Range, 11-Bear-tooth Range, 12-Sweetgrass Hills, 13-Little Rocky Mountains, 14-Moccasin Mountains, 15-Judith Mountains, 16-Big Snowy Mountains, 17-Pryor Mountains, 18-Big Horn Mountains, 19-Sheep Mountains, 20-Owl Creek Range, 21-Wind River Range, 22-Teton Range, 23-Gros Ventre Range, 24-Casper Mountains, 25-Black Hills.

Madison group. In central Montana and Wyoming, a fossil karst can be seen in exposures of the Mission Canyon formation of the Madison group. In the subsurface, as seen in well cores, the Madison group contains three formations: (upper) Charles, (middle) Mission Canyon, and (lower) Lodgepole. The Charles formation is largely evaporitic and is never exposed at the surface. Solution breccia visible at the top of the Mission Canyon formation may be the remains of the Charles formation and is discussed later. Thickness of the Madison varies from 1700 ft in central Montana to less than 200 ft in central Wyoming. The Madison group thins to the south and east (Table 1).

TABLE 1. Relative thicknesses of the Madison group (and related rocks) in Montana, Wyoming, and South Dakota.

Area	Mission Canyon thickness	Lodgepole thickness	Madison thickness	Source
Pryor Mountains	undivided	undivided	700+	Richards
Little Rockies	335	500	835	Sandberg
Little Belts	1,107	650	1,757	Klepper
Sawtooth Range	810	575	1,385*	Mudge
Flathead Range	undivided	undivided	1,000*+	Mudge
Big Snowy Range	1,025	640	1,665+	Sandberg
Horseshoe Hills	800 ±	600 ±	1,400 ±	Robinson
Absaroka Range	656	480	1,136	Roberts
Owl Creek Range	undivided	undivided	465	Sandberg
Southern Bighorn Mountains	325 ±	325 ±	650 ±	Andrichuk
Casper Mountains	undivided	undivided	240	Burk
Southern Wind River Range	175	350	525	Strickland
Gros Ventre Range	450 ±	350 ±	800 ±	Andrichuk
Teton Range	450 ±	550 ±	1,000 ±	Andrichuk
Black Hills	370 ±	230 ±	600 ±	Andrichuk

* probably equivalent of the Madison Group

To the west, the Madison group becomes more dolomitic and has been divided into a lower Allan Mountain limestone and an upper Castle Reef dolomite by Mudge, *et al.* (1962). In this paper, the Castle Reef dolomite will be treated as the equivalent of the Mission Canyon formation and the Allan Mountain limestone will be correlated with the Lodgepole formation. In the Black Hills, the Pahasapa formation (Mississippian), a massive grey limestone, has a fossil karst developed on its upper surface. In this paper, the upper surface of the Pahasapa will be assumed to be the equivalent of the upper surface of the Mission Canyon formation.

Mississippian carbonates in this area were deposited in a shallow marine embayment extending from Wyoming to Canada and from Idaho eastward into the Dakotas. The water may have been deeper in central Montana, which resulted in the accumulation of thicker carbonates there. Cyclic deposition produced alternating layers of thin-bedded silty limestone and thick, massive layers of limestone. A slight emergence occurred at the end of Madison time. Karst developed on this emergent surface, forming widespread caves and sinkholes. In late Mississippian and early Pennsylvanian times, the karst was infilled by the deposition of red clastics of the Amsden formation and Big Snowy group. The Madison remained buried until uplift and exposure in the Tertiary.

The Madison group is composed of light grey or brown, finely crystalline, fossiliferous limestones and dolomitic limestones. The dolomite content generally increases to the west. Insoluble material usually comprises between two and five percent of the rock, although it increases with the dolomite content (Roberts, 1966, p. 138). The insoluble material is concentrated as thin, silty layers between carbonate beds and is composed mostly of clay-sized material. The limestones are mainly biosparites, although intrasparites, pelsparites, and pelmicrites are common in some bedding layers. Reef-building is not common, except locally in the upper Mission Canyon formation. The remainder of the rocks are typical cyclic carbonates common to the Paleozoic of the western United States.

Amsden Formation and Big Snowy Group. Overlying the Madison group and filling the fossil karst developed on the Mission Canyon formation is either the Amsden formation or the Big Snowy group (Fig. 4). In central Montana, where the basin was apparently

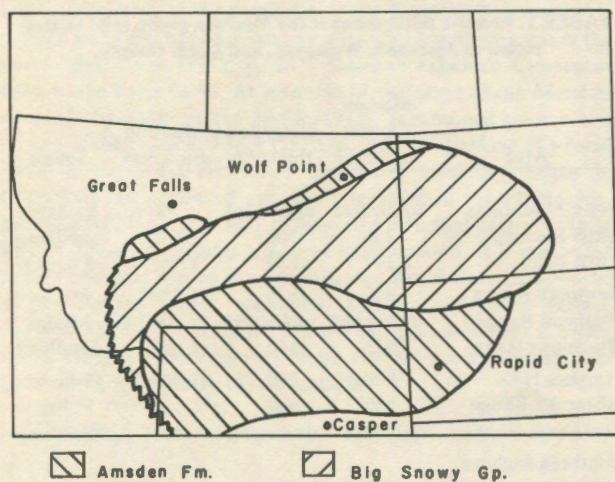


Figure 4. Areal extent of rocks overlying the Madison group.

deeper during Mississippian time, the Big Snowy group was deposited on top of the Madison. Elsewhere in the study area, the Amsden formation (Pennsylvanian) covered the Madison group.

Within the Big Snowy group, we are concerned only with the Kibbey formation, since it directly overlies the karst surface on the

Mission Canyon formation. The Kibbey formation varies in composition across central Montana, but often consists of red, silty sandstone or shale with mixed beds of white gypsum and sandstone. Some silty limestones crop out in a few localities. The Kibbey is considered to be a flood plain deposit laid down in an estuarine environment with local evaporite basins (Walton, 1946, p. 1297). The distinctive red color of the formation makes it easy to spot karst fillings, but it is difficult to distinguish a Kibbey-filled sinkhole from an Amsden-filled sinkhole.

In places where the Big Snowy group was not deposited, the Amsden formation usually is in direct contact with the Mission Canyon formation. The Amsden formation, late Mississippian to early Pennsylvanian in age, consists of red shales, siltstones, and iron-rich sandstones, with some marine limestone in the upper half. Debris from the Amsden formation fills fossil karst in southern Montana and Wyoming. In the Black Hills, the Minnelusa formation, a series of red shales and sandstones, are found filling the Mississippian fossil karst and will be considered equivalent to the Amsden in this report. The origin of the lower part of the Amsden formation is considered to be similar to that of the Kibbey. Suggestions have been made that the Amsden is partly made up of re-worked Madison carbonates.

Other rock units that lie directly on Madison Group rocks have been reported in the literature. The Brazer dolomite probably is equivalent to the Mission Canyon formation within the study area. The Sacajawea formation is probably equivalent to the Big Snowy group when it crops out in the Wind River Range. The (Jurassic) Ellis group lies directly on Madison rocks in north-central Montana, but little fossil karst has been reported this far north. Perhaps it was removed by Pre-Jurassic erosion which cut into Madison rocks.

Breccia Association

Solution breccia is widespread in the upper part of the Mission Canyon formation. Breccia can be found in or near almost every cave associated with Mississippian carbonates in the area (Fig. 5).



Figure 5. Breccia from Ramshorn Cave, Montana. Note the large amount of clay matrix between blocks. The breccia fills a sinkhole that was formed in Mississippian time (see p. 47.)

When considering whether modern caves are, indeed, exhumed and Paleozoic in age, breccia association must be examined closely. There are many references in the literature to filled sinkholes and other buried karst phenomena (Roberts, 1966), but reports of underground breccia associated with large caverns are uncommon. Deike and White (1961) describe solution breccia within Wind Cave, South Dakota, and Campbell (1973) describes solution

breccia associated with several of Montana's larger caves. Keefer (1963) discusses small caves formed in breccia in the Madison Group.

Breccia Varieties. Several distinct varieties of solution debris, commonly called "solution breccia", occur in the upper part of the Mission Canyon formation. Sando (1967, p. 537-540) and Roberts (1966, p. 17-21) attempt to sub-divide the various breccia types. In order to avoid confusion in this paper, the terms "intraformational breccia," "collapse breccia," and "sinkhole deposits" will be used to distinguish the three main types.

Intraformational breccia will be used to describe breccia that resulted from the leaching of evaporites from the upper part of the Madison group. In the subsurface, the uppermost unit is known as the Charles formation and consists almost entirely of evaporitic material. This formation is missing in surface outcrops, but in its place are solution breccias and conglomerates that are placed at the top of the Mission Canyon formation. Removal of the evaporites by sub-aerial weathering during the Mississippian or late Tertiary has left behind widespread intraformational breccias. The leaching of the evaporite beds is at least in part pre-Pennsylvanian, since it can be recognized in the subsurface in many places. However, unleached Charles formation can also be recognized in deep well cores.

The breccia is characterized by angular or sub-angular (sometimes sub-rounded) blocks of limestone, dolomite, and chert, cemented with yellowish-brown or reddish-brown clay or siltstone. The fragments tend to become larger toward the top of the breccia zone (Sando, 1967, p. 538). Some of the clay and silt matrix probably represents insoluble residue from the carbonate itself, but much of the material appears to be washed in from the overlying Amsden or Kibbey formations. Roberts (1966, p. 321) identifies the principle clay mineral as kaolinite, whereas illite is found in other types of breccia. An important feature of the intraformational breccia is that the clay matrix forms a small percentage of the total volume of the breccia (Fig. 6). The breccia follows the bedding planes of the Mission Canyon formation and often is of uniform thickness over short distances (several miles, in the case of the Bighorn and Pryor mountains).



Figure 6. Intraformational breccia in the Mission Canyon formation, Big Snowy Mountains, Montana. Note the angular blocks and relatively small amount of clay matrix compared to that found in sinkhole fills (metal notebook for scale).

Collapse breccias are breccias that resulted from the collapse of underground caverns formed during the Mississippian. Although Deal (1962, p. 129) makes a case for relict (open) caverns in the Black Hills, it is likely that the weight of the overburden collapsed any cavern not infilled prior to the Pennsylvanian. When one

considers the thickness of late Paleozoic and Mesozoic sediments deposited on the Mission Canyon Formation (3000' minimum), it would be difficult to conceive of large relict caves surviving until Tertiary uplift (some small crystal-lined solution pockets may be relicts—see Richards, 1955; and Elliott, 1963). The collapse breccias observed in Montana and Wyoming contain angular blocks that were shifted from nearby limestone beds. Blocks of limestone are rotated less as one moves up within the breccia zone (Fig. 7). This is as expected, if collapse is initiated from above. The overburden presses down on the cavern roof, which collapses, filling the underlying cavern with ceiling blocks. The uppermost blocks are hardly moved but the lower pieces are jumbled and chaotic, because the first blocks fall together into the passage below. Collapse breccias are always associated with the underlying caverns formed in Mississippian time. The matrix of the breccia consists of reddish clay, siltstone, and sometimes quartz sand that filtered down from the overlying sediments. Illite is the chief clay mineral.

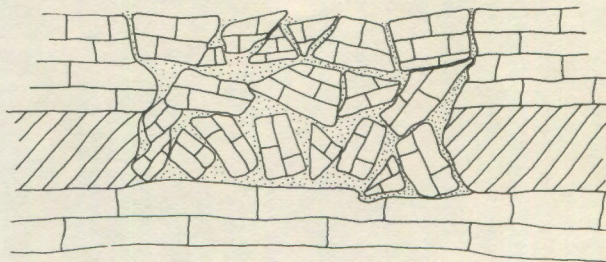


Figure 7. Collapse breccia, from the collapse of caverns. The rotation of blocks becomes less severe toward the top.

Sinkhole deposits refers to sinkholes, karren, or other open solution features that are filled with breccia. Unlike collapse breccia, which results from cavern collapse after burial, sinkhole deposits fill solution features that were open to the surface during the Mississippian. After the sinkhole was formed, debris fell or was washed into the opening, filling it and preserving the features as fossil karst. Sinkhole deposits have extremely jumbled blocks of limestone, dolomite, and chert. All sizes and shapes exist, although angular fragments prevail. The matrix occupies a large percentage of the total volume of fill (figs. 1 and 5). A chamber open to the surface allows more fine-grained sediment to be carried underground. The matrix is composed of red or reddish-brown clay and siltstone. Illite is the main clay mineral. It should be understood that all three types of breccia deposits are closely related and often difficult to tell apart. This has resulted in some authors calling intraformational breccia fossil karst when, in fact, at least part of it was due solely to evaporite leaching.

Relationship to Modern Caverns. The question of whether present caves in the Mission Canyon originated in Mississippian time relates in part to understanding breccia formation. There is no doubt that some sinkholes and small-scale solution features date back to Paleozoic time, but whether breccia can be entirely re-excavated from large fossil caves is questionable. Most breccia can be considered less soluble than the surrounding limestone, because the clay matrix itself is less soluble and because the fragments are often composed of less soluble dolomite and chert. The breccia may also be silicified (such as those found by Witkind [1969, p. 27]), which further reduces the solubility. The Mission Canyon formation contains numerous joints. The breccia, on the other hand, is very massive and usually contains no joints or fractures of any kind. Meteoric water may flow around rather than penetrate the breccia (especially the sinkhole fillings). In certain areas, the breccia acts as an insoluble cap rock and actually limits cavern development.

It may be that ground water can work downward along the contact between the fossil breccia and the unaltered limestone, creating a modern cavern *under* the old karst. This has been observed by the author in many Montana caves, for example Ramshorn Cave, The Slot, Snowy Ice Cave, Crater Ice Cave, Bighorn Caverns, and Lick Creek Cave (Campbell, 1973). In these caverns, cave passage has been formed underneath the breccia, perhaps in more soluble carbonate. The ceilings of the newer caves have partially collapsed, leaving blocks of breccia lying on the cave floor and covering the non-brecciated limestone below. An observer traveling through the cave sees breccia in the ceiling and breccia breakdown on the floor and erroneously concludes that the cave was exhumed from fossil karst.

In the larger Montana and Wyoming caves such as Ramshorn, Bighorn, and Lick Creek caves, breccia is found only in isolated rooms. In these caves, modern cavern formation has randomly

intersected fossil breccia zones, but the majority of each cave is not developed in breccia. Deike and White (1961, p. 17), in studying Wind Cave, South Dakota, state that "old sinkholes and perhaps cave fills dating to Pennsylvanian time are exposed in many parts of the cave" but conclude that it is not known if the present cave follows the same structural trends as the old caves and sinks (p. 25). Once again, random encounter with fossil karst is indicated.

However, the strong association of fossil karst with modern caverns cannot be completely ignored. Some smaller caves appear to be entirely excavated from fossil breccia. Keefer (1963, p. 3130) found entire caverns exhumed from fossil karst in the Tosi Creek basin. An entrance to an exhumed sinkhole can be seen on the east face of Sawtooth Mountain, near Augusta, Montana (Fig. 8). Recent landsliding of the cliff face exposed the sinkhole and breccia can be seen filling another old sinkhole. The breccia "drained" out of the upper part of the sink, creating a cave. Many larger caverns, while not exhumed fossil karst, may owe their location and development to the position of fossil caves and sinkholes, although the exact relationship is not yet understood.

Sedimentary Fill

Nearly all limestone caves contain some fill. This fill is either sediment washed into the cave from the surface or insoluble residue left behind in the cave. Caves in the Mission Canyon formation often contain large amounts of clay fill, sometimes completely blocking major passages. It has been suggested that these caves may have at one time been completely filled with clastic material and only recently re-excavated. The caves were formed during the Mississippian, filled by Pennsylvanian sediment and remained buried until recently. The fill supported the cavern roofs and prevented collapse during deep burial.

In order to fully examine this possibility, two caves were studied—Little Ice Cave in the Pryor Mountains and Lillyguard Cave in the Little Belt Mountains. These caves were chosen because both contain deep fill and because they have been suggested as possible exhumed fossil caves (Elliott, 1963; and Campbell, 1973). In addition, sedimentary fill from several other caves was examined for comparison. Little Ice Cave (Fig. 9) contains fill in moderate amounts in both the lower and upper levels, but one room (Red Clay Room) was chosen because its position makes it unlikely that the fill could have been recently washed in through the present entrance. Little Ice Cave is formed in flatlying Mission Canyon limestone.

Lillyguard Cave (Fig. 10) is developed in steeply dipping limestone and has little sedimentary fill near the entrance. The lower part of the cave is choked with fill and the cave appears to continue beyond the clay plug.

Lithology. Both caverns display fill that is very fine-grained. Several random samples were collected from each cave and screened. Less than three percent of the fill was retained on a 40 mesh screen and more than eighty percent of the fill passed through a 250 mesh screen. There was no appreciable difference in sediment size from samples taken near the top and near the bottom of the fill.

The solubility of the fill was measured by dissolving a weighed sample in hydrochloric acid. Fill from Little Ice Cave contained only two percent soluble material, while fill from Lillyguard Cave averaged 22% carbonates (the average of four other caves ran 24%). The remaining insoluble material was almost entirely composed of clay-sized fragments that passed through a 250 mesh screen.

The material retained on a 250 mesh screen was composed of mostly quartz and some hematite and limonite. Lillyguard Cave contained more biotite and iron minerals, probably because of a nearby iron deposit. The fill in Little Ice Cave was light reddish-brown in color and showed no laminations, cross-bedding,



Figure 8. Sawtooth Mountain Cave, Montana. The cave is part of an old fossil sinkhole, exposed by sliding along the front of the cliff. Part of the breccia "drained" out of the upper part of the sink, leaving a cave (arrow points to man).

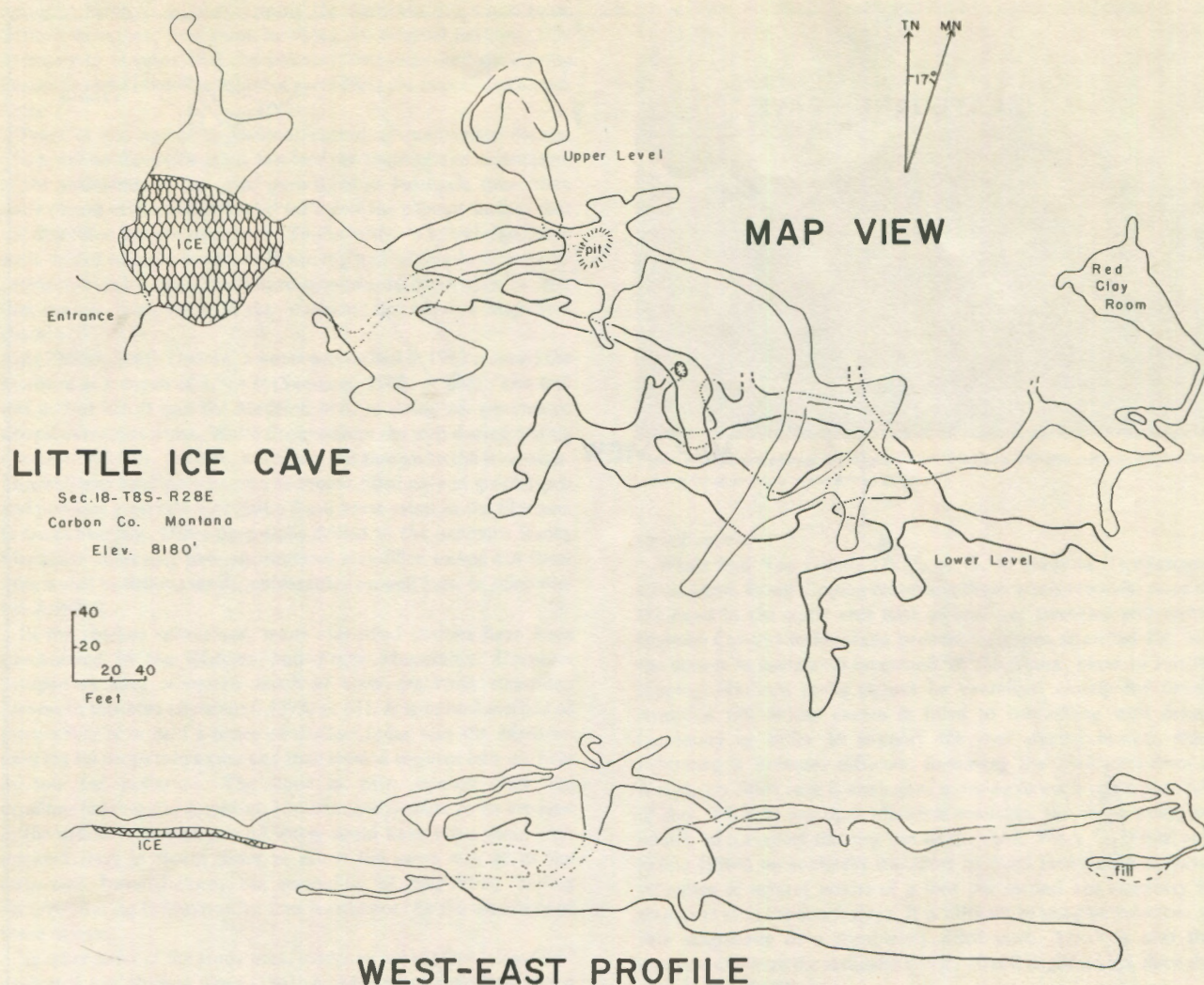


Figure 9.

or cut and fill structures. Lillyguard Cave contained a mixture of two clays—a light yellowish-brown clay and a dark-grey, silty clay. The clays were randomly intermixed from top to bottom of the fill. Again, there was no stratification of the fill.

Some random samples from other caves (Bighorn Caverns, Dry Wolf Cave, Lick Creek Cave, and French Creek Cave) were generally of the same composition. French Creek Cave is formed in Devonian rocks but has been suggested to be exhumed karst (Meyers, 1952). Except for crushed quartz and sulfides, the clay in this cave was quite similar to the fill in the Mississippian caves. The color of the fill in all of the caves is controlled by the amount and variety of iron minerals; fill containing limonite is yellowish-brown, while fill with hematite is dark red in color.

The fill could have come entirely from insoluble residue left behind in the cave. Madison group carbonates commonly contain more than 98% carbonate material (Roberts, 1961; 1966, p. 139). On the chance that the caves were formed in more insoluble layers, samples were collected along the walls of several caves. The Red Clay Room in Little Ice Cave (Fig. 9) was chosen for analysis, because it is far from the entrance in an isolated part of the cave. Limestones collected from this room and along the upper level averaged 99.5% soluble carbonates (other caverns showed similar results).

The volume of this room was calculated at 4,400 cf, with the clay occupying over 3,200 cf of the room (Fig. 2). Even if all the residue

from the entire upper level (estimated volume of 120,000 cf) was concentrated in Red Clay Room, the volume of the residue would still be less than one-third the volume of the fill. In addition, the insoluble residue from the rock contained almost no quartz or iron minerals, while the fill contained quartz and iron oxides (also see Deal, 1962, p. 53).

It is obvious that the majority of the fill is derived from outside the cave. The fill is fine-grained enough to have been carried in by slowly moving phreatic water during formation of the cave, although the small amount of coarser material mixed with the clay would have to be explained. The sediment was probably carried in by surface water, either from an entrance that is now blocked or through small joints and fissures connecting with the surface. The sediment is fine enough to pass through very small openings and could easily have been carried from the overlying Amsden formation by vadose water.

Other caverns probably were filled in much the same way. Lillyguard Cave could have received its sediment directly from the present entrance, but the lack of stratification and abundant coarse material suggests otherwise.

Relationship to Modern Caves. From the above discussion, it appears that at least some Madison caves could have been infilled by Pennsylvanian sediment and preserved until recently. The

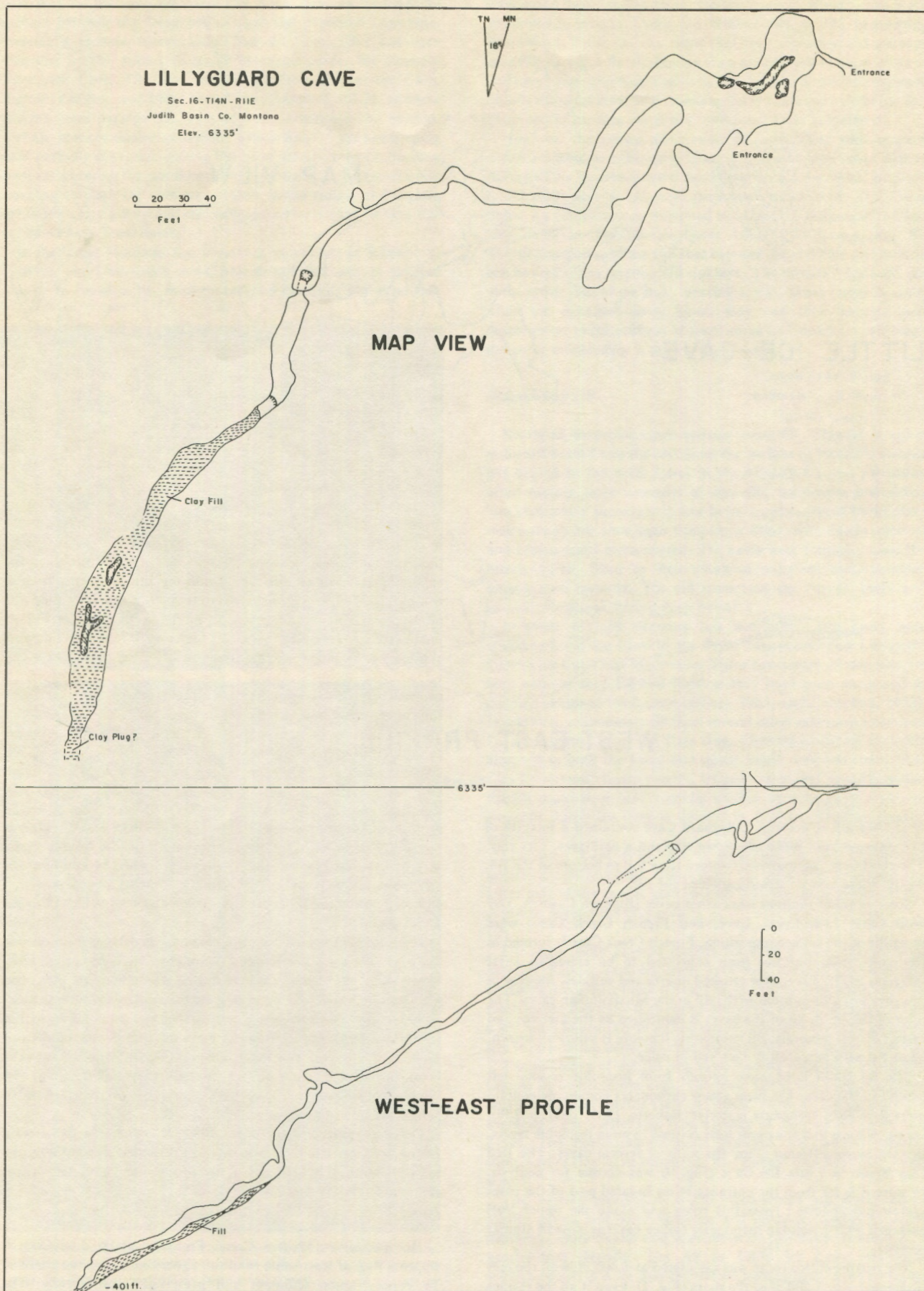


Figure 10.

problems involved in re-excavating the sediment are much more difficult to explain than those involving the original infilling. It is necessary to 1) prove that the sediment was deposited during the Paleozoic and 2) show a method of excavating the material at a later date.

Proof of the age of deposition, excluding radioactive dating, which will be discussed later, involves the position and orientation of the sediments. If the caves were filled in Paleozoic time, then there should exist caverns buried far below the present surface that are clay-filled but not excavated. To the author's knowledge, deep wells drilled into the basins of Wyoming and Montana have never penetrated such a cave. Wells have encountered small open cavities that contain fresh water in the Madison, but never a clay-filled chamber.

At Phillip, South Dakota, a water well drilled in 1962 reached the Madison at a depth of 3,784 ft (Swenson, 1968, p. 203). The well was drilled 226 ft into the Madison and, in doing so, penetrated several cavernous zones. Water flushed from the well during testing contained cobbles, pebbles, sand, and silt foreign to the limestone. This well may have penetrated a sediment-filled cave at great depth and provides good evidence that a fossil karst exists in the Madison in the subsurface. Other deep wells drilled in the northern Rocky Mountain states may have encountered clay-filled rooms but these were sealed by drilling muds, unidentified on well logs, or otherwise not detected.

In the shallow subsurface, many clay-filled cavities have been encountered in the Bighorn and Pryor Mountains. Uranium prospectors have recovered much of their ore from clay-filled caverns in this area (Egemeier, 1973, p. 61). A standard method of prospecting is to drill a series of shallow holes into the Madison until the bit drops into a cave and then lower a counter into the hole to test for radiation. The cave is then opened and the uranium-bearing clay removed. Unfortunately, these caves are now in the vadose zone and ground water could have filled them with Amsden clays in recent times in much the same way as in the Paleozoic. Never-the-less, the possibility of clay-filling having occurred during Pennsylvanian time is enhanced by the discovery of these caverns.

In other parts of the study area, evidence for shallow, clay-filled cavities is less obvious. Dyer (1961, p. 147) reports drilling into a clay-filled cavern beneath Jewel Cave, South Dakota. Campbell (1973) has reported clay-filled rooms in caves in various parts of Montana.

Another method of proving prior infilling is to search the present caves for filled "blind leads". If the cave were once completely filled with sediment, blind leads high on the walls of the cave should be sediment-filled. Some of these pockets may retain their sediment when the cave is re-excavated. If the clay fill is entirely recent in origin, then one should not expect to find filled blind leads high above the present sediment level. Such fillings are difficult to locate, but several have been found in Lillyguard Cave (Fig. 11). One of these is fifteen feet above the present cave floor and is nearly filled with sediment. It was probably filled when the cave was still horizontal, before Tertiary uplift. After the Madison was tilted into its present position, the fill below this pocket was removed, but the fill trapped in the blind lead remained behind. Alternate methods of emplacing this fill would be difficult to explain. Other caves in Montana and Wyoming contain less spectacular filled blind leads that are rare and hard to recognize. If the pocket is completely filled with sediment, it takes on the same configuration as the cave wall and can be easily overlooked.

Finding tilted, stratified fill might suggest early infilling of the cave. Some caves, such as Lillyguard, may have developed in flat-lying limestones and were later tilted by uplift. If the cave were filled when the limestone was still horizontal, stratified sediment should parallel the bedding planes. After uplift, the sediment layers should dip at the same angle as the dip of the bedding. Sediment deposited *after* uplift and tilting should have horizontal



Figure 11. Elliptical passage in Lillyguard Cave, Montana. This phreatic tube is now tilted down-dip at an angle of more than 30°.

stratification.

White and Van Gundy (1974, p. 7), in studying Timpanogos Cave, Utah, found dipping sediments there. Unfortunately, none of the caves in the study area have yielded any stratified sediments. Bighorn Caverns in Montana probably contains stratified fill, but the cave is in horizontal limestone. In the future, caves in steeply dipping Madison rocks should be examined closely for tilted, stratified fill. If the cavern is filled to the ceiling with debris (necessary in order to support the roof during burial), then exhuming it becomes difficult. Removing the sediments from a completely filled cave is analogous to trying to wash out a pipe full of clay. Without any open channels available, the water would be unable to transport the clay out of the cave. Work by White and White (1968) on sediment transport in caves indicates that water velocities of several tenths of a foot per second are necessary to transport even the finest clays. It is difficult to imagine velocities of this magnitude in a completely filled cave. There is also the question of where the sediment can go after it is picked up, since the cave is already filled.

There are at least three possible explanations. First, all of the caves now found in Madison rocks are at high elevations. The resulting steep gradient may have allowed high enough water velocities to remove the sediment. Also, once the water table fell below the cave, vadose water moving down through the cave might pick up the very fine sediment and carry it away (see discussion by Deal, 1962, p. 57).

A second explanation involves the solubility of the fill. It was noted earlier that the sediments averaged 24% soluble material. Slowly moving ground water could dissolve some of the carbonates in the fill. Once the cave was partially opened, currents could occur strong enough to remove particles physically.

A third possibility is that part of the present day caves were dissolved from rock directly above the old fill. Once passages had been opened by solution, ground water could remove the fill from the underlying fossil caves. Thraillkill (1960, p. 59) suggests that Fulford Cave, Colorado, was formed in this way.

The data above suggest that some of the caves studied may be exhumed fossils dating back to Paleozoic. Conclusive evidence, such as that presented by Ford (1968) in his study of the re-excavation of Nakimu Caverns in the Pleistocene, is lacking, but indirect evidence does exist.

Passage Orientation

Many Mississippian caves are formed in steeply-dipping limestones. This is to be expected, since uplift has steeply tilted the Paleozoic sedimentary rocks in the surrounding foothills of many

mountain ranges. A significant number of these caverns are oriented so that their main passages plunge down dip at the same angle as the dip of the bedding. Larger caves, such as Azure Cave, Lewis and Clark Caverns, Lick Creek Cave, Ramshorn Cave, Castle Mountain Cave, and Lillyguard Cave, all in Montana, have a majority of their passages oriented down dip. In some cases, these passages follow a single layer of limestone for long distances (Lillyguard Cave, Lick Creek Cave). In others, the passage jumps from one soluble bed to another via short, slanted, and enlarged joints (Ramshorn Cave, Azure Cave). Furthermore, the passage cross-section often forms an ellipse, a shape normally attributed to phreatic development (Fig. 11). Some caves also include maze-type passages, typical of phreatic formation.

In the past, writers have shown that caves developed in steeply dipping limestones are usually oriented across the bedding, along the water table. Davies (1960) found this relationship in caves in folded limestones in West Virginia. Ford (1965) shows several levels of caves cutting across tilted limestones in the Mendip Hills, England, all related to changes in the water table. From these and other, similar, studies, one would expect to find dominantly horizontal passages in the tilted limestones of Montana and Wyoming, but such is not the case. The orientation is distinctly down dip, as characterized by Lillyguard Cave (Fig. 10). For the entire length of this cave, the dip of the bedding and the inclination of the passage are 34°. Elliptical passages can be seen in several places in the lower part of the cave, where not masked by fill and breakdown.

The configuration of the passages in Lillyguard Cave and other, similar, caverns suggests that they may have been formed along the water table while the limestone was still horizontal, during late Mississippian time. The caves were then tilted along with the rocks, during Tertiary uplift.

It should be emphasized that not all evidence points to such an origin. Recent work by Palmer (1972) shows that elliptical passages, mazes, and blind tubes can be formed *above* the water table in caves with a high hydraulic gradient. Palmer also indicates that the passages are oriented down dip along single bedding planes. This suggests that the Mississippian caves in question could be entirely vadose and, therefore, geologically young.

Caves can often be associated with stream terraces. Davies (1960) has correlated passage levels with nearby stream terraces. Most Montana caves cannot be correlated with terrace levels. One possible exception is Bighorn Caverns in Montana and Wyoming, which has many phreatic features and may be low enough in elevation to be correlated with the Flaxville Terrace, along the Bighorn River, which is late Miocene or Pliocene in age (Richards, 1955, p. 81). Bighorn Caverns is one of the largest caverns in the northwestern United States, with over ten miles of passage, and has a dip of 3° toward the present Bighorn River.

In the nearby Pryor Mountains, caves may be related to Pleistocene terraces. Hoppin and Jennings (1971, p. 44) note patches of Oligocene and Miocene gravel at elevations about 7,000 ft, placed there by uplift in Pliocene. Hart (1958, p. 524) states that "the highest parts of Big Pryor and East Pryor Mountains are thought to have stood only slightly above the highest level of the aggraded fill deposited during early Tertiary time". (However, Hart postulates two stages of cavern development: in Mississippian time, and in the Pliocene.) Bighorn Caverns, as well as two of the larger caves in the Pryor Mountains, shows no passage orientation with regard to the Bighorn River. Several other large caves, closer to the Bighorn River but on Crow tribal lands (trespassing prohibited), should be examined for a possible terrace correlation.

Caves developed as far back in time as the Paleozoic should be completely unrelated to present topography. Most Montana and Wyoming caves are too small to show any definite relationship one way or the other. Bighorn Caverns, the one exception, seems to be associated with a terrace along the modern Bighorn River.

Fossil caves should also show a relationship with solution breccia

and karst infilling. Deike and White (1961), in their study of Wind Cave, South Dakota, were not able to uncover any clear evidence that the fossil sink fillings and the passage orientation were related. This is an important consideration and should be studied closely in the future.

Fossils

The use of fossils to date either breccia or sedimentary fill is an important consideration when examining any exhumed karst. Fossils will give a minimum, rather than a maximum, age of cavern formation. Few studies have been made on fossils in very old cave deposits.

Vertebrate Fossils. Vertebrate fossils can provide conclusive evidence for the age of cave deposits, providing that certain criteria are met. Halstead and Nicoll (1971) have determined the age of some cave sediments in Mendip, England to be Triassic, using vertebrate fossils as the prime evidence.

Vertebrate fossils in Montana, Wyoming, and South Dakota caves of Mississippian age have received little attention. The few studies that have been made were concerned with removing fossil material from the entrance rooms of caves. Not surprisingly, the fauna was limited almost entirely to Pleistocene remains. The latest study in Natural Trap, Wyoming recovered bones as old as late Pliocene (Rushin, 1973). Fills deep within caves have so far been ignored.

In order to prove a Paleozoic age for cave deposits in the Madison group, vertebrate fossils of Late Mississippian or Early Pennsylvanian age must be found. Such fossils are rare in surface rocks and have never been located in any cave deposits to date. Of the solution breccias, only old sinkhole deposits are likely to yield vertebrate remains. The best chance of recovery is in the clay fills of the larger caves. To the author's knowledge, no systematic search has been made.

Invertebrate Fossils. Smaller and more easily transported invertebrates are a more attractive means of dating caves. However, the faunas of the Madison group and the overlying Big Snowy and Amsden groups are quite similar. Only conodonts are considered to be distinctive enough to provide good evidence for fossil infilling. Ehlers (1943) and Koucky, *et al.* (1961) provide lists of conodonts found in the region. An attempt was made to recover conodonts from several caves. In Little Ice Cave and in Lillyguard Cave, samples were taken at six inch intervals to the bottom of the fill. Surface samples were also collected from Dry Wolf Cave, Bighorn Caverns, Lick Creek Cave, and French Creek Cave. The samples were prepared using a method outlined by Gary Webster (1973, personal communication) and then searched for conodonts and other fossils.

It was reasoned that if mixtures of Pleistocene fauna (*e.g.* bat bones) and Mississippian conodonts extended all the way to the bottom of the fill, then the age of the fill would be relatively recent. If two distinct faunas were found, the lower one containing only Paleozoic and the upper one only Pleistocene material, then a Paleozoic age would be indicated. Any sort of layering, with each layer containing a different species of conodont, would also favor a Paleozoic age for the fill.

Only one conodont was found, in a surface sample from Dry Wolf Cave. There was no apparent stratification of any fossils or sediments. Bat bones and other modern material were limited to the upper few inches of sediment in every cave. Crinoid fragments, brachiopods, and sponge spicules, the only other fossils found, were intermixed from top to bottom in the fill. One of the problems was that the clay fill was so fine-grained that little sediment was retained on the 200 mesh screen. A second run was made using larger samples. Again no conodonts were recovered.

A lack of bat bones below the upper six inches of fill shows that the fill has not been re-worked recently and suggests that the fill beneath has been there for some time. The apparent lack of

conodonts has not been explained.

An attempt was also made to use pollen to date the cave fill. Four samples, two from Lillyguard Cave and two from Little Ice Cave, were processed by the Washington State University Anthropology Department for possible pollen content. No pollen was recovered. Since most of the fill was derived from red beds, oxidation may have destroyed any fossil material before it was washed into the caves.

Age Dating

Ford (1971) has used Carbon-14 to date exhumed passages in Nakimu Caverns, Canada to the last inter-glacial period or earlier. Since Carbon-14 cannot be used to date material as old as Paleozoic, it is of little use in dating caves of Mississippian age, with one possible exception. If suitable material at the base of the clay fill can be dated as Pleistocene or younger, then that cave is not likely to be Paleozoic in age. No dating of this sort has ever been attempted and, judging from test pits dug in some of the caves, finding suitable material would be very difficult.

Dating of clay fill by Potassium-Argon, Uranium-Lead and other methods normally used to date rocks as old as Paleozoic is usually not of any value, because one is dating the age of the clay particles, not the age of the clay deposit. The only material observed in the cave fill that could be dated is biotite. Dates obtained from the biotite might be in error because of leakage of argon from the mica.

One possible exception is the caves of the Pryor and Bighorn mountains. As stated earlier, some of these caves contain uranium mixed within the clays. The ore, primarily Tyuyamunite, might be dated to determine a minimum age for the fill and the caves. Elliott (1963, p. 5) suggests a Pleistocene age for the uranium. Egemeier (1973, p. 61-66) has found uranium being deposited in Kane Caves, Wyoming and suggests that the age of the uranium in the Pryor-Bighorn caves might be quite recent. Jarrard (1957, p. 37) documents the discovery of small, unidentified, rodent-like mammals embedded in the ore material at depths of a foot or more. The bones are probably only a few years old.

It appears from the above information that the clays are much older than the ore, but more work is needed to confirm the age relationship of clay and ore emplacement.

It is also possible to date speleothems by radioactive means (Thompson, 1970). However, all speleothems are thought to be relatively young and probably post date the fill. No tilted or deeply buried stalactites or stalagmites have been found.

Paleomagnetic Dating. Clays found in caves within the study area are very fine-grained, contain magnetite and hematite, and should be ideal for dating. However, the magneto-stratigraphy has only been worked out in detail for the Late Tertiary. If the cave sediments are Pliocene or younger, they could be dated, but if they are Mississippian in age, then dating the sediment by paleomagnetic means would be extremely difficult. No cave sediment dating has ever been attempted in the northern Rocky Mountains, but the

method has been used successfully in caves in at least one other area (Kopper and Creer, 1973).

Summary

The following information is considered important when considering whether Mississippian caves in the northern Rocky Mountains are truly exhumed fossil caverns:

1. The excavation of fossil breccia to form caverns appears to have occurred in sinkholes and small caves. Passages in larger caves encounter fossil breccia only at random. The breccia is usually too tightly cemented and impermeable to allow large caves to form entirely in the breccia. Some caverns may be formed just beneath the fossil breccia.
2. Several of the larger caverns contain sediments that may represent the remnants of a fossil fill. While clay-filled caves have not yet been found in the deep subsurface, they have been intersected by drill holes up to a depth of several hundred feet. "Blind leads" filled with sediment in some caves suggest a re-excavated cavern. Sediment removal may have occurred by first dissolving the carbonate from the fill and, once the chamber was partially open, removing the clay by fast moving vadose water.
3. Several caves, in steeply-dipping limestones, have passages oriented down dip. These caves exhibit elliptical passages, blind pockets, mazes, and other features common to phreatic caverns. The caverns may have been formed when the limestone was still horizontal, during the Mississippian. The caves were later tilted, during uplift in the Tertiary.
4. The use of fossils to date the age of the caverns was inconclusive. No Pennsylvanian vertebrates have been found in any of the caves and an attempt to use conodonts and pollen to date the clay fill was unsuccessful. Recent fossil material was found only in the top few inches of the fill.
5. Age dating by radioactive means is not practical for dating cave sediments, due to lack of suitable material in the fill and breccia. One exception may be the uranium found in clay-filled caverns of the Pryor and Bighorn mountains. The uranium is thought to be Pleistocene or younger, but could have been deposited much later than the clay. Paleomagnetic dating may prove to be the best method for determining the age of the caves, but has not yet been attempted.

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Archeology and Speleology: The Case for Conservation

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ABSTRACT

Caves and rock shelters have proven significant sources of information for archeologists. The recovery of archeological remains in undisturbed context from such sites is vital to the interpretation of past human behavior. Similarities in research interests, the nature of their respective resource bases, and a history of cooperation link archeology and the speleological community. Cooperation between archeologists and speleologists in the fields of conservation and resource management is needed and can prove of mutual benefit. Mechanisms for cooperative interaction include increased research opportunities, effective utilization of federal legislation, and programs of public education and involvement. Archeological remains discovered in the course of speleological investigation should be left alone, and the proper authorities contacted.

Introduction

Caves and rock shelters around the world have long proven rich sources of archeological data. In the investigation of these resources, archeologists have often been assisted by specialists in other fields of speleological research. Through this interaction, it is apparent that archeologists, in dealing with their resource base, face many of the same problems and challenges which are before the speleological community in general. It is argued that archeologists and speleologists can greatly assist each other's interests, both in the area of research and in the development of resource conservation strategies. Public education, public opinion, and relevant federal legislation are seen as highly effective mechanisms capable of being channeled toward the resolution of common problems.

Historical Perspective

Archeologists have long been aware of the value of caves as sources of information relevant to the interpretation of past human behavior (figs. 1, 2). The archeological literature is filled with reports of significant discoveries from cave sites. Furthermore, it is apparent that the history of archeological and speleological research has been long intertwined. Thomas Jefferson, the author

of the first detailed report on excavations at a prehistoric American Indian site, has also been called the first American speleologist (Schmidt, 1965, p. 82). Jefferson's excavations introduced the concept of stratigraphy to American archeology; as a technical achievement, the work was a century ahead of its time (Ceram, 1971; Willey and Sabloff, 1973). His speleological investigations include commentary on blowing caves (Schmidt, 1965, p. 82) and a description of prehistoric sloth remains found in Organ Cave, West Virginia (Davies, 1955, p. 133).

In Europe, speleology and archeology were associated at an early date. Scientific acceptance of the antiquity of man, an event crucial to the development of modern archeology, occurred in the middle of the nineteenth century. Speleological investigations, notably in England and France, contributed significantly to this achievement.

Early in the nineteenth century, William Buckland, a pioneer in British cave science and the first professor of Geology at Oxford, investigated and reported on associations of extinct animal remains with human artifacts at a number of cave sites in England (Boylan, 1967). Buckland repeatedly denied that direct association existed, however, and discouraged further investigations. His reluctance stemmed partially from a strict adherence to the climate of scientific opinion of the period, which did not favor acceptance of a great age for man (Gruber, 1965, p. 379).

Evidence suggesting the association of human remains with extinct fauna continued to accumulate during the first half of the nineteenth century, however, particularly from a number of cave sites in England and on the Continent (Gruber, 1965). The field of geology was itself changing at this time, as the concepts of Hutton and Lyell regarding the age of the earth and the nature of geologic change became increasingly accepted.

The critical turning point came in May of 1859, when Joseph Prestwich reported to the Royal Society on his visit, with Sir John Evans, to the Sommes gravel pits in France. There, in deposits near Abbeville and Saint-Acheul, Bocher de Perthes had for years been recovering flint handaxes and other tools in association with extinct fauna. This evidence, like that from excavated cave sites, had previously been largely ignored or discredited. Prestwich's paper, entitled "On the Occurrence of Flint Implements Associated with the Remains of Animals of Extinct Species in Beds of Late Geological Period at Amiens and Abbeville and in England at Hoxne" marked the beginnings of the formal acceptance, by the scientific community, of a great antiquity for man (Daniel, 1967).

In September of 1859, William Pengelly, a Devonshire geologist, reported on what appeared to be indisputable associations of human remains with extinct fauna at Brixham cave (Davies, 1964). The findings, complementing the report of Prestwich and Evans, created a great deal of excitement in the British scientific community, and within a few years were widely accepted (Gruber, 1965). Pengelly continued to contribute to the field of archeology; his excavations at Kent's Cavern further confirmed and elaborated



Fig. 2 Pictographs from the walls of an Ozark bluff shelter. Highly visible archeological remains such as these are easily subject to defacing and vandalism by ignorant or malicious visitors. (Courtesy, University of Arkansas Museum)

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Fig. 1. Archeological excavations at the Breckenridge rock shelter (3CR2), a prehistoric habitation site in the Arkansas Ozarks. Controlled excavations at sites such as this can greatly add to our knowledge of past human behavior. (Courtesy, University of Arkansas Museum)

the relationship between human populations and extinct fauna during the late nineteenth century.

Throughout the 19th and 20th centuries, the interests of archeologists, geologists, and a number of other specialists have increasingly intersected at cave sites. A wide range of techniques from the physical and natural sciences have been recognized as applicable to the resolution of archeological problems (Brothwell and Higgs, 1970). The application of these techniques often requires direct interaction with specialists in other disciplines. For example, concern with stratigraphy and the age and manner of deposition of archeological remains has led to increased coöperation between geologists and archeologists. When archeological investigations occur in cave or rock shelter sites, this interdisciplinary approach brings archeologists into close contact with specialists in areas of speleological research.

The Nature of Archeological Data

Archeological interest in caves and rock shelters is generated by a number of factors, some of which may be better understood in their relation to the goals and methods of the discipline. Archeology has as its goals the tracing of the origin and history of culture, the reconstruction of past lifeways, and the interpretation of cultural change and adaptation over time (Binford, 1968). Instrumental to the success of these goals is the careful investigation of archeological data *in context*. Context refers to the environment in which archeological remains are found (Hole and Heizer, 1969, p. 99), and includes the locational relationships between artifacts in addition to the nature of the matrix they are found on or in. The disturbance or removal of archeological remains from their original context without record greatly reduces their capability to inform on past human behavior.

For large areas of the globe, archeology provides virtually the only means for understanding past human behavior and for reconstructing any kind of history of human events. Historical documents and the records of modern observers provide data from only a tiny fraction of the period man has existed on earth. The destruction of archeological materials, or the loss of the full interpretive value of archeological remains through their improper removal from context, is, in effect, a piece of human history lost forever. Even in areas where historical records are available, archeology has come to be recognized as a valuable adjunct to historical and anthropological research. The tremendous growth in classical archeology in the last century (Ceram, 1949), and the recent rise of the discipline of historical archeology in North America (Noel Hume, 1969; South, 1976) bear witness to this phenomenon.

A major area of modern archeological research involves the investigation of spatial distributions and interrelationships among artifacts. Artifacts, as remains of past systems of behavior, can often, by their manner of deposition, inform on those past systems. The vertical positioning of artifacts within a site, for example, is often used to establish temporal sequences. This follows from the principle of superposition, where the lowest remains are assumed to be the earliest, those above them later, and those on top the most recent. Through the study of artifacts associated horizontally, on occupational levels or living floors, event reconstruction may be possible. Important to both forms of investigation is the assumption that disturbance of the remains, accidental or otherwise, has been minimal. By investigating how artifacts pass from living cultural systems into the archeological record (Schiffer, 1975), and through an awareness of the post-depositional changes that might occur to that record (Butzer, 1971; Schiffer and Rathje, 1973), archeologists hope to achieve an understanding of cultural history, cultural reconstruction, and cultural process.

The Archeological Significance of Cave Deposits

In caves and rock shelters, depositional conditions favorable to archeological investigation often occur. Caves have long been recognized as providing both temporary shelter and a place of habitation for early man. Artifacts found within them may therefore be at or near their original place of use or discard in the past cultural system under investigation. In addition to the possibility of containing artifacts in a highly desirable context, the factor of unusual preservation may also obtain. The presence of a rock overhang or ceiling reduces the amount of direct weathering that the archeological remains and deposits might normally undergo.

While individual cave environments are highly variable, a number of common factors influence preservation (Butzer, 1971, p. 205). The greater the distance from the entrance within a cave, the lower the probability of direct weathering and the consequent reduction of archeological remains through mechanical and chemical action. In limestone caves, the calcareous, alkaline environment favors the preservation of bone materials (Butzer 1971, p. 212). The near-uniform temperature and humidity common to the interiors of many caves reduce weathering activity and favor preservation. In caves where extremely low humidity characterizes the interior, preservation through desiccation may occur. The exceptionally well-preserved, mummified human remains found in Kentucky caves (Meloy, 1971; Watson, 1974), and the excellent preservation of basketry and other woven artifacts from caves and rock shelters in the Ozarks (Scholtz, 1975; Raab, 1976) (Fig. 3) and the Southwestern United States (Jennings, 1957; Haury, 1950) are examples of this form of preservation.

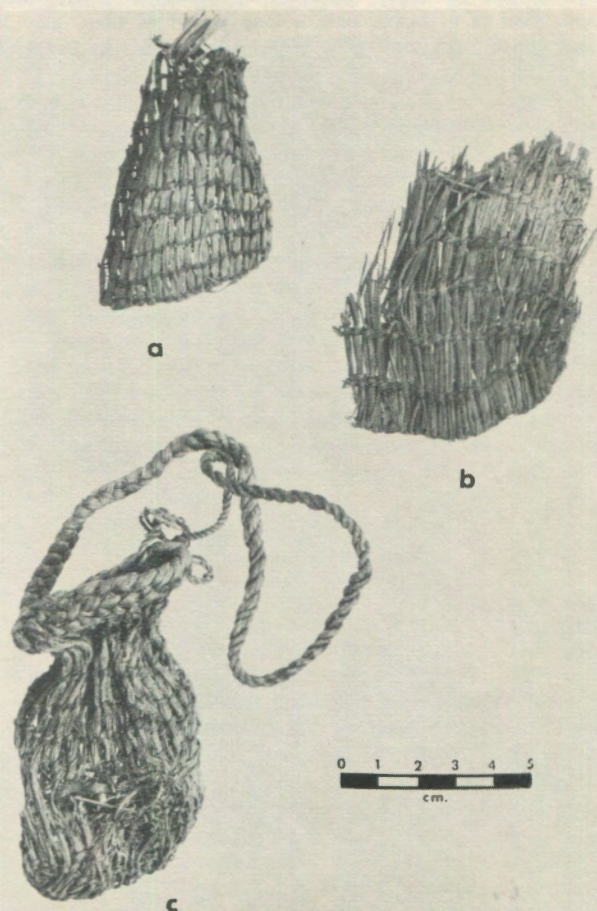


Fig. 3. Twined fabric bags recovered from Ozark bluff shelters; a-b fragments, c, complete (Scholtz, 1975, p. 117). Courtesy, University of Arkansas Museum

Natural sedimentation processes within caves are also of interest to archeologists. Through thermoclastic weathering—the effect of the alternate freezing and thawing of moisture on and within pores and crevices—rock shelters may form and be enlarged (Bordes, 1972), and archeological deposits may be covered over with rock spalls of varying sizes (Rosenfeld, 1964; Butzer, 1971). This erosional process is greatest near the entrances to caves, in the same area where human occupation is most likely to have occurred. The ensuing debris (éboulis) effectively cover or cap the archeological deposits. This seals and protects the remains, and separates earlier deposits from those of later occupations. Massive ceiling collapse may occasionally trap occupants, providing for the preservation of skeletal material in situations where such preservation may otherwise be rare—for example, where cremation was practiced or where disposal of the dead normally occurred in the open, away from cave sites. At least some of the Neanderthal remains from Shanidar Cave, Iraq were preserved in this manner (Solecki, 1963). As Kleindienst has recently indicated (1975, personal communication), much of the controversy over Early Pleistocene hominid evolution and tool use might be reduced or resolved by new discoveries of occupation areas or skeletal remains; cave or rock shelter sites could well prove excellent sources of such information.

The protection caves provided against the weather resulted in their widespread and repeated use by human populations. The extensive use of caves as habitation sites, both prehistorically and by historic and modern human populations, has been well documented (e.g., Bauer, 1971). Many cave sites were repeatedly utilized over time and contain long records of human occupation. At Niah Cave, in Borneo, for example, a 100,000-year span is represented, from the present day to the middle Paleolithic (Harrison, 1964). From these well-preserved sequences, the human occupation of a region, over a long period of time, may be investigated. Such a temporal perspective is often invaluable to studies of human adaptation and cultural change.

Extremely long occupational sequences have been found in caves from widely differing parts of the world. At the Combe-Grenal rock shelter in southwestern France, for example, a sequence exists that covers most of the period of and between the last two major Pleistocene glaciations (Bordes, 1972). In North America, cave sites have yielded some of the best continuous records of human occupation. Russell Cave in Alabama, discovered by amateur cave explorers (Pinney, 1962, p. 21), has provided a cultural sequence ranging over the past 10,000 years (Griffin, 1974). Recent excavations at the Meadowcroft rock shelter (Adovasio, *et al.*, 1975) in western Pennsylvania have produced evidence for the earliest known aboriginal occupation in Eastern North America dating to 14,000-15,000 years ago. An extensive series of radiocarbon determinations indicate more or less continuous occupations throughout the prehistoric period.

Interdisciplinary Research

The archeological investigation of cave sites can generate information that is both useful and relevant to research in a wide range of disciplines. The information gathered to help interpret the past human occupation of a given area may often be of great interest to biologists, zoologists, hydrologists, and climatologists, as well as a number of other specialists. Palynological investigations can yield information about the nature of prehistoric plant communities and help resolve questions about processes of domestication and succession (e.g., Mangelsdorf, 1974). Faunal remains encountered within archeological deposits may be of value to zoologists concerned with changes in animal communities over time. Both palynological and faunal analysis, for example, have proven important in the reconstruction of Pleistocene plant and animal communities (Butzer, 1971; Bordes, 1972). Geomorpholog-

ical environments, whose understanding is often crucial to the proper interpretation of archeological deposits, may also receive detailed investigation.

When archeologists investigate cave sites, they may enlist the aid of specialists in other disciplines. At the excavations of the Combe-Grenal rock shelter, mentioned earlier, geologists, paleontologists, pedologists, physical anthropologists, palynologists, sedimentologists, physicists, and chemists all participated, in addition to a number of archeologists (Bordes, 1972, pp 1-2). A similar interdisciplinary effort, including members of the Cave Research Foundation, has characterized recent archeological investigations in and near cave sites in the Mammoth Cave National Park, Kentucky (Watson, *et al.*, 1969; Watson, 1974). In these and other instances, archeologists have increasingly called upon specialists in other, speleologically-concerned disciplines.

The Nature of the Resource Base

In addition to common research interests, archeologists share a number of similar problems and concerns with the speleological community. The term "speleological community," as used here, includes all those concerned with the discovery, exploration, conservation, and preservation of caves. Cave scientists from a score of professions, as well as serious avocational cave investigators, are included in this rubric. The focal point for common concern centers on the nature of the resource base each community deals with.

Archeological resources may be regarded as nonrenewable cultural resources—once destroyed, their information content is gone forever. Speleological resources may be thought of as largely nonrenewable geological, cultural, and biological resources. While the geological and biological resources within a cave system may be regenerated, given enough time, from the perspective of a human lifetime they may be viewed as largely nonrenewable. Cultural resources (*i.e.*, archeological remains) within caves, or entire species of cave-dwelling organisms, are irreplaceable—once they are destroyed or become extinct, they are gone forever.

Site Protection and the Problems of Publication

Given the common fragility of their resource bases, it is perhaps hardly surprising that a strong conservation/preservation ethic pervades both communities. The position of the National Speleological Society on conservation has been widely stated and stressed within the speleological community (e.g., Schmidt, 1965, p 88; Folsom, 1962, pp. 245-246; Pinney, 1962, pp. 237-244; Mohr and Sloan, 1955). The motto of that organization: "Take Nothing But Pictures, Leave Nothing But Footprints, Kill Nothing But Time" is one that archeologists hope would become popular with members of the public who discover archeological remains. In fact, most archeologists can do without even footprints—which may indicated disturbance of the archeological deposits.

A major area of concern to professional archeologists is the problem of site protection. Both archeology and speleology have extensive avocational followings, and the record of responsible interaction between professionals and serious avocational members of each community is often excellent. Unfortunately, however, both communities face a grave problem from uninformed, unconcerned, or occasionally malicious members of the general public. The deliberate plundering of archeological sites for collector's pieces or salable antiquities has reached enormous proportions, both in the United States and around the world (Davis, 1972; Meyer, 1973; Morse, 1973). The speleological community faces a similar problem in many areas—caves may be plundered for their speleothems by mineral collectors or distributors (Schmidt, 1965), or subjected to vandalism by ignorant or malicious members of the public. Both

caves and archeological sites also suffer from the unintentional, often well-meaning acts of destruction by the uninformed, who often fail to recognize the significance of their actions.

The problem of intentional destruction of archeological or speleological resources is further aggravated by the amount of unintentional destruction resulting from construction; caves and archeological sites are both affected by urban sprawl and burgeoning economic and population growth. Recent passage of the Archeological Conservation Act of 1974 (Public Law 93-291) has greatly increased the funding available to archeologists for the recovery of information from endangered sites. Under the provisions of this bill, federal agencies initiating construction projects that endanger archeological resources are authorized to expend project monies to provide for the effective mitigation of the damage. The impact of this bill is producing profound changes in the archeological profession in the United States, and creating increasing opportunities for interdisciplinary research.

Another area of common concern to both archeologists and speleologists focuses on the publication of site locations. Recently, the National Speleological Society has been beset with an internal controversy concerning the publication of cave site locations (Medville, 1974; Rhodes, 1974; Stitt, 1974, p. 160). The argument centers on the possible use such information might be put to by various elements of the public. The NSS Board of Directors has recently gone on record as opposing the publication "of specific wild cave locations in publications intended for the general public except where such publication serves the better interest of the Society" (Rea, 1974, p. 204). While accurate information on the effect of publication on cave resources is currently not available, some evidence exists for an increase in vandalism and cave accidents (Wilson, 1974; Medville, 1974, p. 10; Schmidt, 1965,

p. 86).

Archeologists face a similar problem in reporting the results of their research. The inclusion of exact site locations in reports that reach a broad audience virtually ensures subsequent vandalism in many parts of the country. Archeology's problem in this regard differs in magnitude from that before the speleological community for two reasons. First, while there are probably no more than four or five thousand avocational cavers in the United States (based on NSS membership), there are approximately 25,000 avocational members in archeological societies (Hester Davis, personal communication). These figures do not include the great numbers of occasional cavers or casual relic collectors who may never join an avocational organization. These 'casual collectors are archeology's personal dilemma: while it is probable that few people can resist picking up an arrowhead they might find, only someone with special equipment and a certain bent of mind is likely to venture into a cave. No formal publication policy exists within the archeological community, although statements urging caution and discretion in reporting site locations have been made (McGimsey, 1972, p. 12).

In recent years, archeologists have become increasingly concerned with the preservation of their resource base. Much of this concern is directly related to the amount of archeological site destruction that has occurred in modern times. Excavation is increasingly becoming a "last-resort" mechanism, to be undertaken when all other preservation efforts have been exhausted (Lipe, 1974; Canouts, 1975) (Fig. 4). Where destruction is not imminent, portions of a site may be deliberately left unexcavated, so that future generations of archeologists, armed with better techniques and methods, might profitably investigate the deposits. At the Combe-Grenal rock shelter mentioned earlier, for example, this



Fig. 4 The Edgemont shelter (3BR6), a prehistoric occupation site in the Arkansas Ozarks. While archeologists rarely completely excavate such sites, their extreme visibility often attracts vandals who may churn through deposits looking for mantlepiece specimens. (Courtesy, University of Arkansas Museum)

policy has been pursued (Bordes, 1972).

Archeologists and speleologists can and should cooperate in the protection of their mutual resource base. The vandalism of archeological remains in cave sites is a problem that can be faced by both communities. Pleas for responsible action regarding archeological remains found in caves have been made by a number of archeologists in recent years (Brothwell, 1965; Vinnicombe, 1966; Grady, 1972, 1975). Recognition of the significance of historic and prehistoric archeological remains in cave sites appears to be growing among serious avocational cavers (Schmidt, 1965; Strong, 1975, p. 146). The destruction of archeological remains in cave sites is nevertheless a problem, and not one restricted to the United States. Examples of deliberate vandalism have been reported from France (Bordes, 1972), South Africa (Vinnicombe, 1966), and Venezuela (Cruzent, 1944), to give but a few examples.

Federal Legislation Relevant to the Protection of Archeological Cave Sites

In the United States, an impressive amount of federal legislation is in existence that directly pertains to archeological resources. Properly applied, this legislation can benefit both archeology and speleology. Specific federal legislation that can be relevant to both speleologists and archeologists include the Antiquities Act of 1906 (PL 59-209), the Historic Sites Act of 1935 (PL 74-292), the Historic Preservation Act of 1966 (PL 89-665), the National Environmental Policy Act of 1969 (PL 91-190), Executive Order 11593 "Protection and Enhancement of the Cultural Environment," and the Archeological Conservation Act of 1974 (PL 93-291). Grady (1975) has briefly noted the significance of some of these measures to the preservation and protection of cave-based archeological resources and has observed that they might be advantageously utilized to further general conservation goals. The present paper will explicitly detail some of the mechanisms within these laws that can be applied to the conservation and preservation of archeological and speleological resources in the United States.

The Antiquities Act of 1906

The Antiquities Act of 1906 provides for criminal sanctions—a fine of up to \$500.00 and a jail sentence of up to 90 days—for "any person who shall appropriate, excavate, injure, or destroy any historic or prehistoric ruin or monument, or any object of antiquity, situated on lands owned or controlled by the Government of the United States" (Sec. 1). In addition to affording a measure of protection to archeological resources found in caves on federal lands, this section has also come to apply to paleontological remains (McGimsey, 1972, p. 111). Thus caves containing fossilized animal remains (e.g., Hawksley, *et al.*, 1973; Ray, 1967), if located on federally owned or controlled property, would be subject to this measure of protection.

The Historic Sites Act of 1935

The Historic Sites Act of 1935 established as a national policy the preservation, for the public benefit, of historic and archeological sites, buildings, and objects of national significance. Under the provisions of this bill, a register of sites of national significance was established, and the National Historic Landmarks system established. Both served to indicate sites worthy of preservation.

The Historic Preservation Act of 1966 and Executive Order 11593

The Historic Preservation Act of 1966 established a greatly expanded National Register of Historic Places, including provisions

for the inclusion of sites significant to state, local, regional or national history, architecture, archeology, or culture. Placement of a site on the National Register affords it some measure of protection. Should any federally-funded project endanger that site, a formal review process must be undertaken, in which alternative policies must be considered. The Advisory Council on Historic Preservation reviews the situation, and makes recommendations for the resolution of the construction impact. While the Advisory Council's recommendations are merely advisory, without the authority of law, they have considerable weight.

Part of the measure of authority reinforcing the Advisory Council's recommendations stems from a recent Executive Order. Under Executive Order 11593, federal agencies are directly charged with the preservation of cultural properties both under their control and on nonfederally owned lands which their projects affect. A federal executive order carries virtually the weight of law with federal agencies; to disagree with an Advisory Council ruling would therefore go against both the spirit of the Historic Preservation Act and the Executive Order.

A great many cave sites in the United States contain archeological or historical remains of such significance as to warrant inclusion on the National Register. In addition to caves with prehistoric archeological sites in them, caves with saltpetre mining remains (Jackson, 1949; Faust, 1955) or unusual historical inscriptions, such as the records of Civil War soldiers found on cave walls in Virginia (Davies, 1955, pp. 136-137) or Alabama (Torode, 1973), may also be eligible for inclusion on the Register. Once on the Register, these sites are afforded a measure of protection, at least from federally-funded destruction. Furthermore, the Historic Preservation Act provides for a program of matching funds for the preservation, for the public benefit, of sites on the National Register.

Information on implementation procedures for the nomination of sites to the National Register may be obtained from any of the members of the Committee on Public Archeology (Appendix I) or from the State Historic Preservation Officer for each state. Guidelines for the nomination of sites to the National Register, and a detailed description of the formal review procedure for endangered sites, are to be found in the Federal Register for 25 January 1974 (Garvey, 1974).

The National Environmental Policy Act of 1969

Under the National Environmental Policy Act of 1969, any federal agency contemplating a project that may significantly affect the environment must prepare, prior to initiating construction, an Environmental Impact Statement describing the impact of the project on the environment, alternatives to this project, irreversible effects, short-term versus long-term effects, and recommendations for the mitigation of these effects. Both archeological and speleological resources must be considered under this legislation. Recent recognition of this fact has been publicized by the speleological community (Stitt, 1974, p. 160). Guidelines, delimiting what must legally be contained in an Environmental Impact Statement, are to be found in the Federal Register for 1 August 1973 (Train, 1973).

The Archeological and Historic Conservation Act of 1974

With the passage of the Archeological and Historic Conservation Act of 1974 (PL 93-291), archeologists find themselves faced with research opportunities undreamed of only a few years earlier. The increased level of funding the act provides will enable the profession to carry out a wide range of interdisciplinary research projects in the years ahead. Increased contact with specialists in other disciplines,

including those in speleologically-related disciplines, will result. Opportunities for interaction will increase, and members of several disciplines will almost certainly find it advantageous to promote mutual research and conservation goals. Archeologists are prepared to join forces with other groups towards the advancement of conservation measures (e.g., Lipe, 1974), and they have an effective battery of legislative support to enlist in this activity.

Public Education and Involvement

While legislation can provide a partial solution to the problems before both archeology and speleology, it can only provide a partial solution. Archeology and speleology have large publics: relatively small coteries of professionals and serious avocational members, and a much larger body of interested but largely uninformed citizens. It is primarily through programs of public education that effective measures of protection and conservation can be achieved. The public needs to be aware of the concept of "nonrenewable resources" as it applies to archeological remains, speleothems, endangered species, and so on. The value of these items, both as sources of scientific information and as parts of a unique and rapidly vanishing cultural and natural heritage needs to be stressed. Within archeology, the Committee on Public Archeology serves as a primary liaison body for dealing with the public (Appendix I).

One of the best ways to ensure public acceptance for the preservation of archeological and speleological remains is to stress their value intelligently and intelligibly. Abstruse theoretical appeals, or overly detailed compendiums of jargon and trivia, serve more to enervate than to educate. Appeals directed to the public must be in a language the public understands (MacLeod, 1975). A discussion of the value of archeological resources directed towards geologists or speleologists will be somewhat different from an appeal to a group of Boy Scouts or high school students.

Avocational groups can be channeled towards the protection of resources—citizens in British Columbia monitor archeological sites and report incidents of vandalism to responsible authorities (Russell, 1975). A similar program is being developed in Arkansas—the concept of "archeological site stewards" (Schambach, 1975). Avocational members can serve as environmental "gadflies" (Lipe, 1974), lobbying for relevant federal legislation, media coverage, or by becoming involved in the political maneuvering associated with major construction projects to advance environmental concerns. Finally, through effective training avocational members can be valuable sources of assistance in both speleological and archeological research.

The Discovery of Archeological Deposits in Caves: Procedures for Effective Investigation

In the course of any form of speleological activity, if archeological or paleontological remains are encountered, a number of steps should be followed. The most important is to leave the remains exactly as they are, and to try not to disturb the surrounding environment (Fig. 5). Carbon samples can be easily contaminated, throwing off a C-14 determination. A breath of fresh air in the wrong spot can cover an ancient object with modern pollen. A responsible archeologist should be contacted, particularly if the possibility of vandalism is likely. If contact with a member of the Committee on Public Archeology (Appendix I) is difficult or impossible, responsible archeologists may usually be found on



Fig. 5. Hafted deer mandible sickle, *in situ*, Putman bluff shelter (3WA4), Arkansas. An example of extremely rare and informative preservation; such remains are often quite fragile. (Courtesy, University of Arkansas Museum)

university or college faculties. Failing in this, government officials of the National Park Service or the Forest Service should be contacted. If the site is located on federal grounds both government and professional personnel should be contacted.

An additional procedure to follow is to be discrete in discussing the discovery, particularly if it is or appears important. Publication of an archeological find, without contacting a responsible authority, may only ensure the destruction of the remains. If for some reason archeological investigation is not immediately forthcoming, the information can be filed with archeological or governmental authorities, and with the NSS. The NSS cave files include a provision for the filing of "sensitive" data (Medville and Medville, 1974, p. 65). Data so labelled will not be released except with the permission of the contributor.

Archeologists are overworked in many areas of the country now, partially as a result of recent legislation. Furthermore, in many areas the nearest archeologist may be a hundred miles away or more. Unless the remains are directly and immediately threatened with destruction, however, do not attempt to remove them or enlist the aid of "amateur" archeologists to "salvage" the data. A few days or months additional waiting is likely to matter little if the remains have been there for centuries. The Cave Research Foundation in the United States operated for a number of years in the Mammoth Cave National Park without disturbing the archeological remains they encountered within a number of cave sites. Archeological investigations that were ultimately undertaken in these caves directly benefitted from this conservation attitude (Watson, 1974).

This paper has attempted to explore some of the similarities that exist between archeology and speleological research in general. Through cooperation in research and by advocating strong and effective conservation policies, the goals of both communities may be advanced. The increased education—of members inside as well as outside of the speleological and archeological communities—can facilitate these ends.

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