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Contents

OCTOBER 1966

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Terrestrial Pseudokarst and the Lunar Topography

By William R. Halliday

ABSTRACT

Correlation of certain types of lunar craters or sinks with terrestrial karstic phenomena is inappropriate. Pahoehoe lava appears to be widespread on the moon, though its parameters and those of any lava tube caverns contained therein probably differ significantly from those of earth. To date, collapse features characteristic of lava tube areas have not been identified, but the potential importance of lunar lava tubes warrants considerable study. Terrestrial fissure caves in volcanic rocks may be correlable with lunar rills or postulated subsurface lunar "crevasses."

In an otherwise hostile environment, lunar caverns could offer astronauts shelter (fig. 1) and perhaps ice and other minerals deposited by vulcanism. A widely-publicized view that near-surface lunar caverns might present a major hazard to lunar explorers further emphasizes the importance of evaluating the possibilities of caverns on the moon.

Several reports have referred to lunar "karst-type formation," or to equivalence between certain types of lunar craters or sinks and the pockety limestone country of Indiana. Such concepts reflect a common misunderstanding of pseudokarst and its significant differences from karst (Halliday, 1960). True karstic phenomena cannot be present on the

Figure 1.

Subway Cave, a medium-sized lava tube cavern in northern California. Such a cavern could provide lunar explorers with shelter against micrometeorites and other hazards.

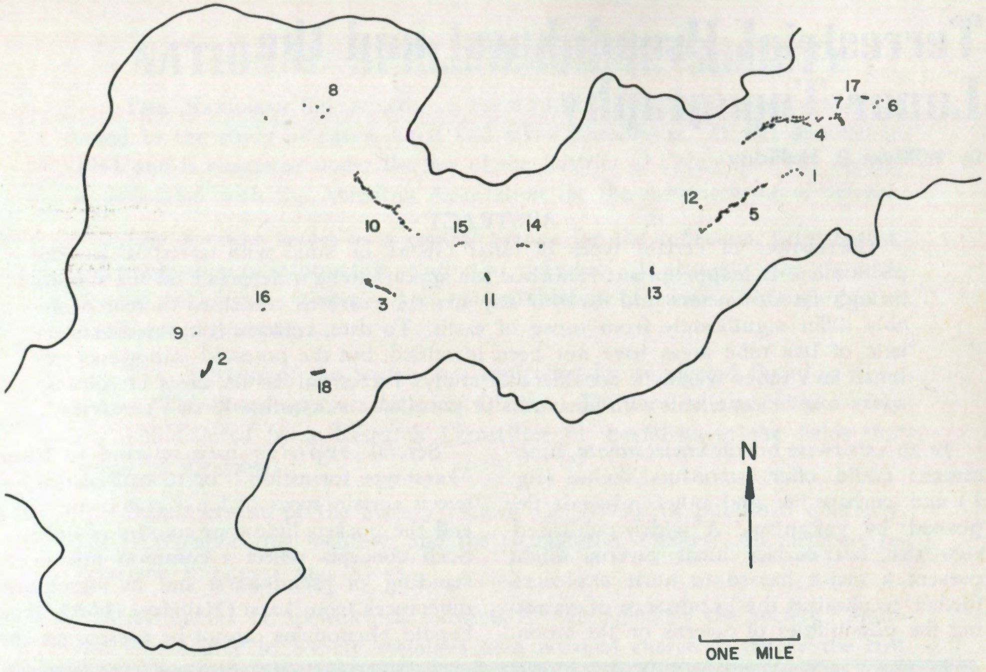

Figure 2.

Recorded collapse features of Peterson lava flows, Skamania and Klickitat counties, Washington, intensively studied for 15 years by the Cascade Chapter of the National Speleological Society. See fig. 3 for number code.

moon because they are dependent on soluble sedimentary rocks and a solute.

Terrestrial pseudokarst occurs in a wide variety of rocks, but by far the most important spelean forms occur in pahoehoe lava. Even before the recent lunar surface-level photographs, there was impressive evidence that lunar *maria* consist of tremendous lava flows with basic characteristics strongly suggestive of pahoehoe (Heacock, *et al.*, 1965, pp. 34, 38, 39). The Luna 9 photos show a surface remarkably like that seen in certain lava tube caverns of Washington. (It must be noted, however, that evidence is equally impressive that the surface of some lunar flows is very different from that of terrestrial flows.)

The parameters of terrestrial lava tube caverns vary remarkably from region to region, and even within a single small area. These caverns equally include huge, single tubular structures many meters below the surface, complexes of interwoven tubes, and shallow rudimentary tubes. Nevertheless their patterns fall into specific groups which I recently discussed (Halliday, 1963; a more detailed report is in preparation). Although not invariably so (Peterson and Groh, 1964), major terrestrial patterns of collapse features usually can be correlated with enterable tube caverns, thus serving as a basis for prediction of their occurrence. On earth, it appears rare for them to be associated with dangerously sizeable sub-crustal spaces which the explorer must beware.

To date, there is no conclusive evidence of lava tube caverns on the moon. If such exist, it would be unrealistic to expect their parameters to be identical with those of the earth. Their potential importance, however, would seem to justify considerable search for the presence of telltale lunar features – as well as expedition of badly needed terrestrial studies.

Terrestrial lava tube caverns occur in pahoehoe basalt flows, but often these flows

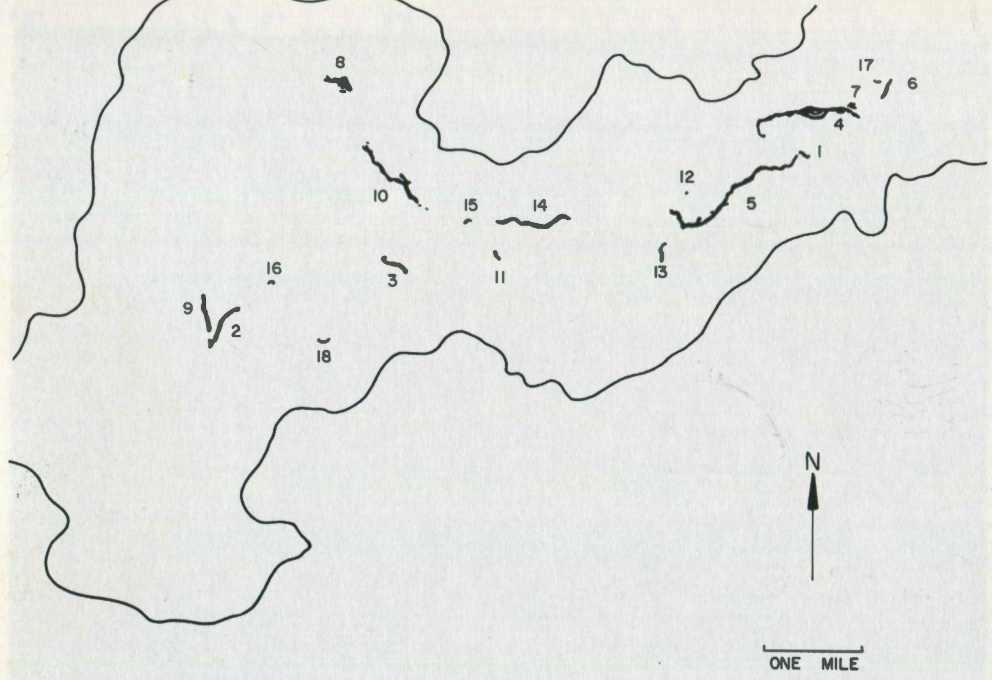

Figure 3.

Same map as fig. 2 with addition of recorded uncollapsed segments of lava tubes. 1. Beerbottle Caves, 2. Big Cave, 3. Big Trench system, 4. Butter-Stairwell-Red system, 5. Cave Creek Road system, 6. Cheese Cave, 7. Cowbones Caves, 8. Dry Creek Cave and annex, 9. Dynamited Cave, 10. East Peterson system, 11. Ice Cave, 12. Jan's Cave, 13. Lava Bridge Caves, 14. New Cave, 15. Peterson Ridge Road Caves, 16. Spearpoint Cave, 17. Trillium Cave, 18. Unnamed sink with no enterable cave.

are buried by other lava. Rarely is the course of a tube marked by a surface bulge. Some are entered through a single tiny, inconspicuous entrance, or several such orifices hundreds or thousands of meters apart. More show fairly characteristic collapse sinks aligned sinuously or in patterns reflecting flow complexes (fig. 2). Still other lava tubes, largely collapsed, present as long segments of characteristic sinuous trench, yards or miles in length (fig. 3). A very few such trenches show multilevel collapse. The largest terrestrial lava trenches are of the order of magnitude of a curious structure west of the Straight Wall of the Mare Nubium which appears to consist of pahoehoe basalt.

The frothy type of experimental lava ("rock-froth") which some consider to cover broad areas of the moon, has no apparent relationship to terrestrial pseudokarst. Some observers feel that "simple craters" are collapse features reflecting cavities in this "rock-froth." If so, no photograph to date has revealed an orifice of such a cavity. In general, the various rocket photographs have been as tantalizing to the vulcanospeleologist as telescopic photographs. Perhaps this in part reflects the target areas selected.

Even if lava tube caverns prove not to be present on the moon, another terrestrial pseudokarstic feature may form significant caverns there. Urey (Heacock, *et al.*, 1965, p. 135) has delineated evidence for the existence of tremendous "crevasses" on the moon, albeit he anticipates that they originated through impact rather than vulcanism. Of four maj-

Figure 4.

The Crystal Ice Caves rift, extending for many miles in south-central Idaho, contains several spelean segments. Some have been explored to a depth of several hundred feet. Photo by James Papadakis.

or terrestrial fissures and/or sets thereof in volcanic rock recorded in Western Speleological Survey files, one (the Crystal Ice Caves rift, Idaho) contains major spelean sections (fig. 4). Study may show such caves helpfully similar to Urey's "crevasses" or other types of lunar rills.

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Truncated Cave Passages and Terminal Breakdown in the Central Kentucky Karst

By Roger W. Brucker

ABSTRACT

In the Flint Ridge and Mammoth Cave Systems in Mammoth Cave National Park, Kentucky, *truncated cave passages* are segments of formerly continuous passages which have been terminated at one or both ends by a process of collapse. Valley erosion truncates an impermeable caprock, concentrating vertically seeping water along specific areas of descent. Solution weakens the rock which collapses into cave passages. *Terminal breakdowns* are piles of rock debris which terminate passages as a result of this process of truncation. Segments of formerly continuous passages have similar size, shape, elevation, alignment, and cross-section. Wall scallops indicate a former common direction of water flow. Segment ends are usually within a few hundred feet apart, though farther separations are within the known limits of continuous passages. Understanding of the process, and recognition of its results leads to reconstructions of past cave patterns essential to studies of cave genesis, and to the location of existing, but unknown passage segments.

INTRODUCTION

Many distinct passages in the caves of the Central Kentucky Karst appear to be segments of once longer passages. The idea that two adjacent but now unconnected passages may have been continuous in the past is not new. Hovey (1897) said that White Cave is "really a branch of Mammoth Cave, being connected with it by a passage, now occluded, leading to Klett's Dome and the Mammoth Dome." Martel (1913) stated that certain passages in Mammoth Cave are parts of once longer passages. Recent investigations have substantiated these opinions and determined the extent, cause, and significance of passage segmentation.

Field work was done in Mammoth Cave National Park, 100 miles south of Louisville, Kentucky. Within the Park are three principal northwest-trending cavernous ridges: Joppa Ridge, Mammoth Cave Ridge, and Flint Ridge, all three with an average elevation of 800 feet. They are terminated on the north by the Green River, which is entrenched more than 400 feet below the ridge crests. The river establishes regional base level. Drainage from the Park and a large portion of the surrounding area flows underground into the Green River. Average annual rainfall is 45 to 55 inches.

The extensive cave systems of the area are developed in the Upper Mississippian, thick-bedded Ste. Genevieve and Girkin limestones with a maximum exposed thickness of more than 370 feet (Haynes, 1964). Overlying these beds is the Big Clifty sandstone, a member of the Golconda formation, approximately 60 feet thick with thin basal shales, which forms the caprock of the ridges. The Big Clifty is overlain by the Haney limestone member, 10 to 15 feet thick, with interbedded shales including a basal impermeable shale 12 to 18 inches thick which grades downward into the sandstone. Regional dip averages 30 feet per mile northwest.

E.R. Pohl (1955) showed that the Golconda shales and Big Clifty sandstone effectively prevent ground water from descending directly to the Green River base level wherever these beds are intact. Ground water in the uppermost rocks of the ridges thus moves along the topographic lows of the

Figure 1.

Terminal breakdown at the north end of Dyer Avenue, Crystal Cave.

capping beds until it reaches their truncated edges along valley walls. Here, approximately at the 700 foot contour, ground water seeps or flows more or less vertically to base level. Because runoff and ground water enter the cave system at these controlled locations, it is possible to relate certain cave features to vertical solution. Beneath the intact caprock, solutionally widened joints and vertical shafts are generally absent. In the areas immediately adjacent to the truncated edges of the capping beds, vertical shafts and minor features of vertical solution are abundant. It is in this area of most active vertical drainage that one finds the massive breakdowns which divide passages into segments. Figure 1 shows a typical terminal breakdown at the north end of Dyer Avenue in Crystal Cave.

Support and cooperation in this project was provided by the Cave Research Foundation and the National Park Service, particularly in an extensive cartographic program. I wish to thank E.R. Pohl, P.M. Smith, R.A. Watson, and W.B. White for valuable criticisms.

Passage Segmentation by the Process of Truncation

Many distinct passage segments in the Flint Ridge and Mammoth Cave Systems can be inferred to have once been continuous. A *truncated cave passage* is one which has been cut at one or both ends by geological processes after the genesis of the passage. A *terminal breakdown* is a portion of the collapsed rock debris which collects during truncation to terminate the cave passage. Basic criteria for identifying truncated passages are as follows:

1) The segments are similar in size, shape, and cross-section.
2) Wall scallops indicate a former common direction of water flow.
3) The two segment ends are within a

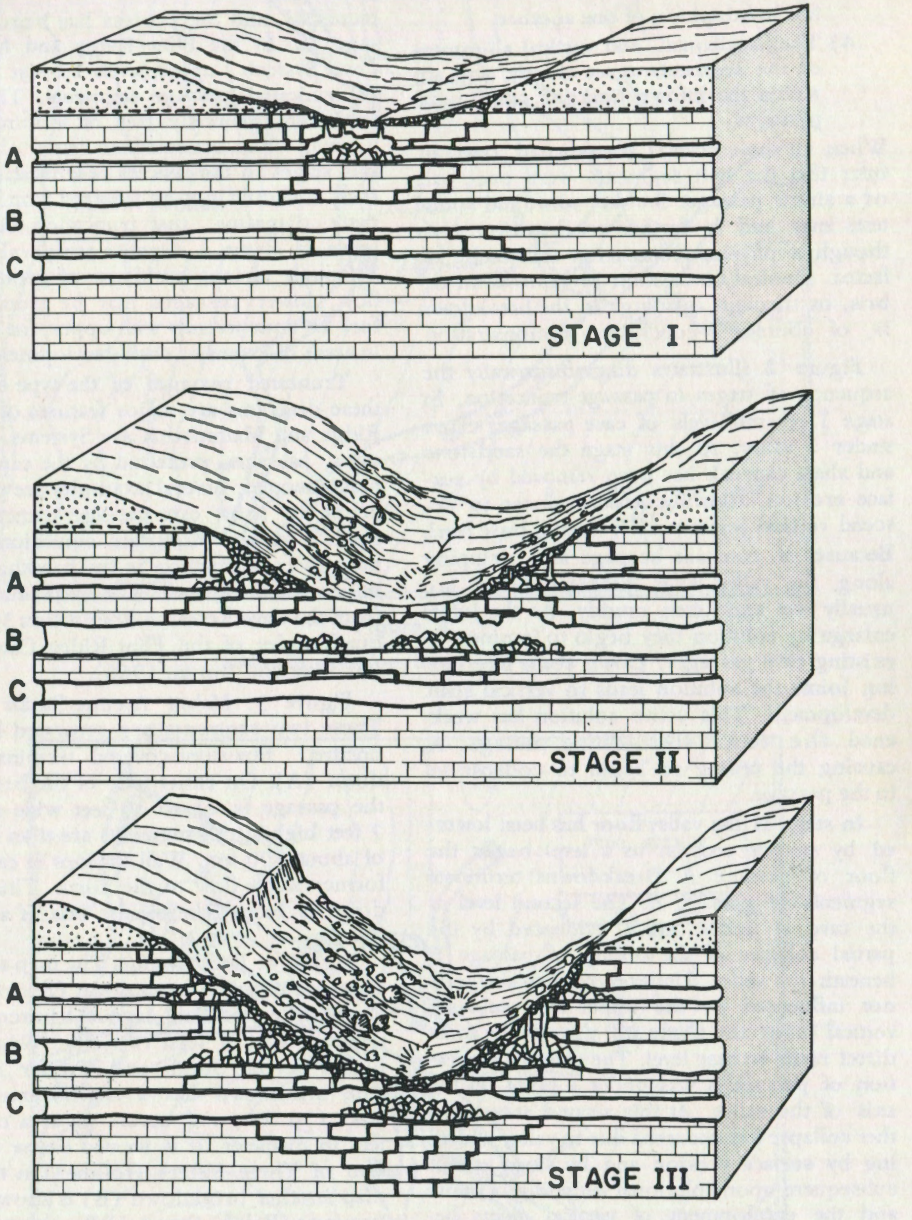

Figure 2.

Stages in cave passage truncation.

few hundred feet of one another.

4) The horizontal and vertical alignment of the segments agree closely, and are within the known limits of continuous passages.

When all these criteria are satisfied, one can infer that the two segments were once part of a single passage. Smoke, odor, and sound tests may lead to further confirmation, even though a physical connection cannot be effected. Physical connection by removal of debris, or through openings in the breakdown is, of course, a conclusive demonstration.

Figure 2 illustrates diagrammatically the sequence of stages in passage truncation. In stage I several levels of cave passages cross under a valley. At this stage the sandstone and shale caprock has been removed by surface erosion, allowing ground water to descend vertical joints until it reaches base level. Because of constant seepage and dripping along the valley axis, passages below are usually wet and often muddy. As the joints enlarge by solution they begin to impinge on existing cave passages. Down some intersecting joints the solution leads to vertical shaft development. This active solution has weakened the rocks surrounding passage A, causing the ceiling to begin to collapse into the passage.

In stage II the valley floor has been lowered by surface erosion to a level below the floor of passage A. Breakdowns terminate segments of passage A. The second level of the cave is under attack, evidenced by the partial collapse of the ceiling of passage B beneath the valley. Underground drainage is not influenced by the upper cave passage; vertical joints and shafts still provide the most direct route to base level. The original truncation of passage A was under a point on the axis of the valley. At this second stage, further collapse has occurred due to valley widening by surface erosion and by slope retreat subsequent upon solutional widening of joints and the development of vertical shafts beneath the valley walls. The passage segments are shortened by the retreat of the valley walls; thus, the points of passage truncation themselves retreat congruent with the retreat of the valley walls, the terminal breakdowns renewing themselves by valley wall collapse.

At stage III, the upper two levels have been truncated, and the process has begun in passage C. In the Flint Ridge and Mammoth Cave Systems, upper levels consist primarily of truncated passage segments. The lowest levels are generally free of terminal breakdowns, while intermediate levels show various stages in the process of truncation. However, it should not be inferred from the schematic diagrams that truncation of various levels is always a stepwise temporal process. Through various accidents of ground water flow, lower passages may be truncated before or concurrently with upper, for example, in areas of extensive shaft development.

Truncated passages of the type shown in these diagrams are major features of the Flint Ridge and Mammoth Cave Systems. In most cases, passages protected by the caprock are not truncated. Several examples are presented below to show cave passage truncation beneath a variety of surface conditions. Common to each situation is the breaching of the impermeable caprock. The maps are adapted from the Cave Research Foundation 30-second quadrangles of the Flint Ridge Cave System (Brucker and Burns, 1966).

Figure 3: Malott Avenue/Smith Avenue. These two segments are separated by a distinctive, flowstone-covered terminal breakdown (A). On either side of the breakdown the passage is 25 to 30 feet wide and 5 to 7 feet high. Both segments are at an elevation of about 500 feet. Wall scallops in each show former water flow to the north. This breakdown is located below the axis of a narrow valley.

Figure 4: Pohl Avenue. The map shows an immense terminal breakdown (A) which has almost truncated Pohl Avenue. It has completed truncation of at least two other passages on higher levels, Smith and Turner Avenues. The breakdown has a vertical extent of at least 150 feet, and covers an area over 100 feet in diameter. It is located below the west arm of Three Sisters Hollow. On the same map another breakdown (B) is shown which truncates Ralph Stone Hall, about 70 feet above Pohl Avenue. The two passage segments are 12 feet wide and 7 feet high near the breakdown.

Figure 5: Grand Avenue/Mather Avenue. The map shows the terminal breakdown (A') at the north end of Grand Avenue in Colossal Cave and the terminal breakdown (A)

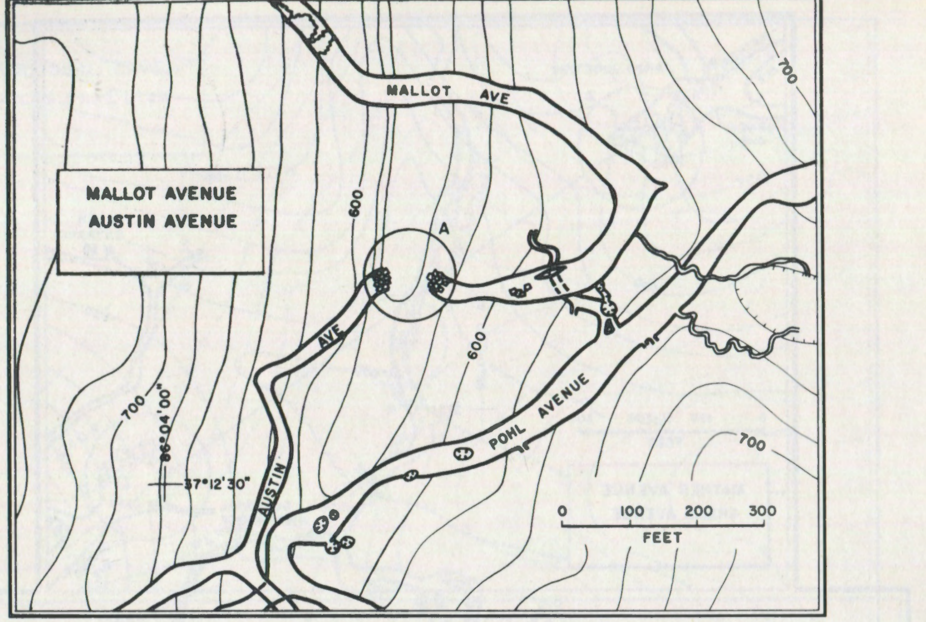

Figure 3.
Malott Avenue/Smith Avenue.

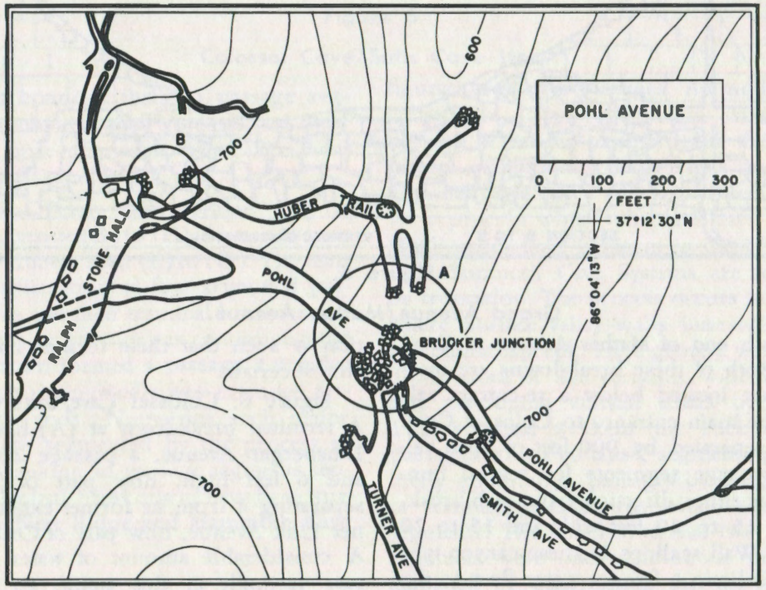

Figure 4.
Pohl Avenue.

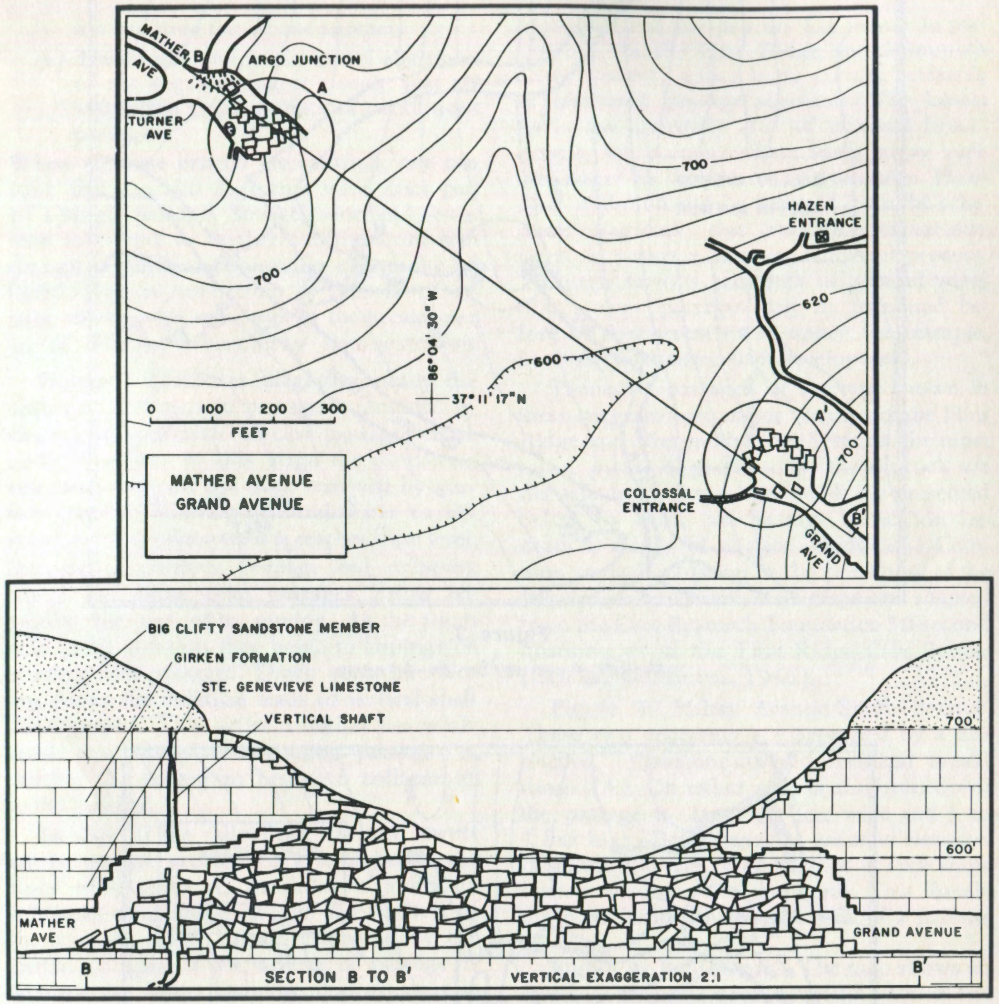

Figure 5.

Grand Avenue/Mather Avenue.

at the south end of Mather Avenue in Crystal Cave. Both of these breakdowns are massive and are located below a re-entrant valley near the main entrance to Colossal Cave. They are separated by 900 feet of open valley. The passage segments for several hundred feet in either direction from each breakdown are 15 to 20 feet wide and 15 to 20 feet high. Wall scallops in these canyon-type passages indicate a former water flow to the north. Although the distance between these two segments is relatively great, their size, elevation, alignment, and general configuration is such that their former continuity is almost certain.

Figure 6: Colossal Cave/Salts Cave Link. A terminal breakdown at (A) has truncated Lehrberger Avenue, a passage 20 feet wide and 6 feet high, now part of Salts Cave, separating it from its former extension, Werner Link Avenue, now part of Colossal Cave. A considerable amount of water enters the cave vertically at this point, so the breakdown and surrounding area is very damp and muddy. Beneath the breakdown a low drainage passage with average dimensions of 2 by 2 feet connects the two passage segments. It is obvious that Colossal and Salts Caves were once connected by a large, now segmented, passage.

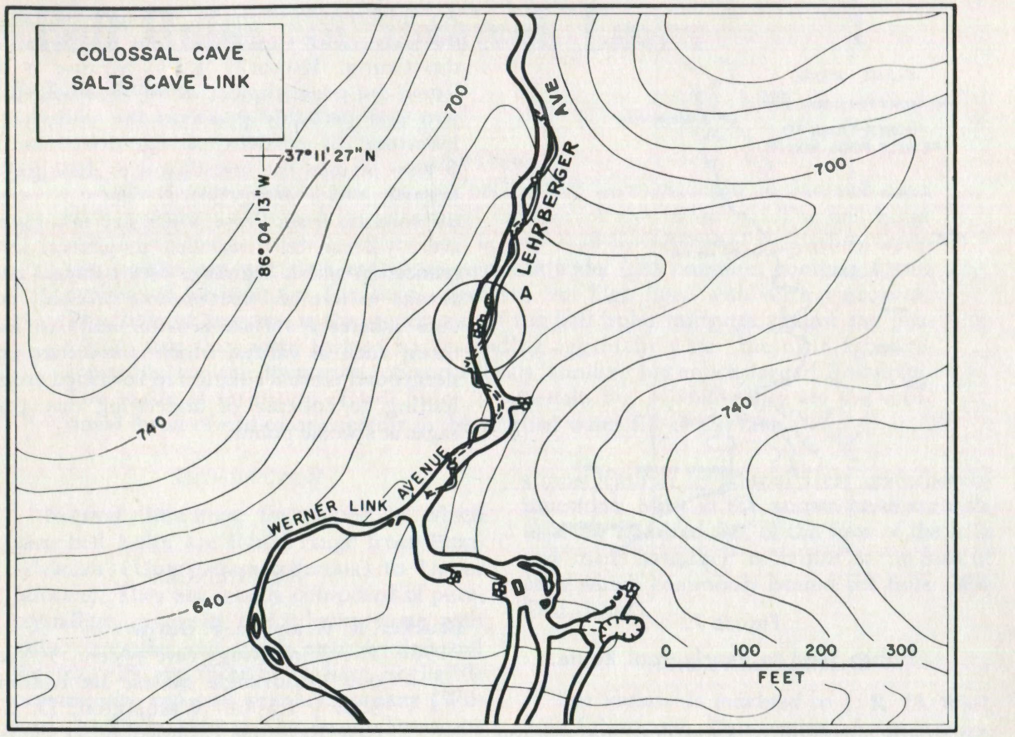

Figure 6.

Colossal Cave/Salts Cave Link.

Figure 7: Pearly Pool Route (A) to (B)/Grand Avenue (B) to (C)/Turner Avenue (D) to (E)/Huber Trail (F) to (G). The map shows the orientation of four truncated passage segments and their terminal breakdowns. When this major passage was continuous, the segments shown formed a passage 2.9 miles long, which undoubtedly was extended farther at both ends. Numerous such major passages, now segmented by the process of truncation resulting in passage segments separated by terminal breakdown, have been surveyed in the Flint Ridge and Mammoth Cave Systems.

SUMMARY AND CONCLUSIONS

Any theory of cave genesis must take into consideration the original extent and configuration of cave passages. All modifications subsequent to passage origin must be recognized if one is to interpolate the original pattern. Truncation of passages resulting in terminal breakdown and segmented passages is a process which obscures cave patterns. Many upper level passages in the Flint Ridge and Mammoth Cave Systems are segmented by truncation. The process occurs in passages where surface valley walls intersect the impermeable caprock. Here ground water moves down more or less vertically, widening joints and developing vertical shafts by solution. This solution weakens the rock over cave passages which collapse, segmenting the formerly continuous passages by the formation of terminal breakdowns which separate the segments. The conclusion that two truncated segments were once continuous may be established by determining that the horizontal and vertical aligments are in close agreement, that there is similarity in segment size and cross-section, that scallops indicate a former

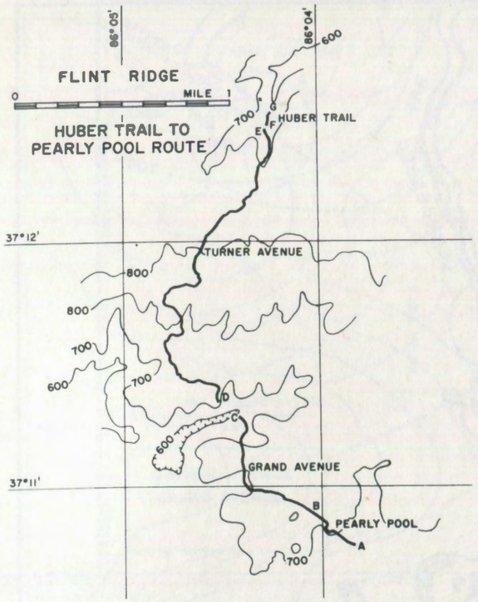

Figure 7.

Huber Trail to Pearly Pool Route.

common direction of water flow, and that the passages are within a few hundred feet of one another.

Once terminal breakdowns are recognized, the investigator can come to further conclusions. Most importantly, the former unsegmented passage extent and pattern can be determined. This might prevent, for example, a dendritic pattern from being mistaken for a network pattern of segments. Second, physical connection might be effected through removal of breakdown or through extensive exploration. Finally, the probable existence of unexplored passage segments might be established. Thus, an understanding of the process of passage truncation, and a recognition of the resulting terminal breakdown, can lead to accurate reconstruction of past passage extents, and to predictions of future passage discoveries.

These conclusions about caves in the Central Kentucky Karst have been only generally correlated with observations made in caves in other regions. However, it is clear that terminal breakdowns which separate passage segments are found in caves in many areas. An impermeable caprock is not essential to the process of truncation. It is important in the Central Kentucky Karst because it allowed the establishment of the erosional pattern and probably protected the underlying limestone for extensive passage development. It also permits the investigator to distinguish features which are primarily related to vertical solution from those which are not. However, it can be concluded in general that truncation which segments cave passages and results in terminal breakdowns probably occurs wherever surface erosion leads to features, such as valleys, which concentrate underground vertical solution to restricted areas, leading to collapse of underlying cave passages at specific points.

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"Bell Holes" in Sarawak Caves

By C. E. Wilford

ABSTRACT

Vertical roof cavities, here termed 'bell holes', have developed in Sarawak caves with apparent disregard for structural features of the limestone. The bell holes vary from saucer-shaped indentations in the roof to cylindrical or slightly tapering cavities six feet high and about one foot wide. Less common complex forms consist of cavities five feet across and six feet high lined with vertical grooves. The lack of fissures at the upper end of the bell holes mitigates against the possibility that they were formed by descending aggressive water, the main agent responsible for the formation of superficially similar, but much larger, domepits. The mode of formation of bell holes is uncertain but probably they are the solutional result of eddies or currents in the original water fill of the cave.

INTRODUCTION

Sarawak limestone formations in which cave bell holes are found range from Pennsylvanian (Upper Carboniferous) to Upper Miocene. They are mostly composed of pure, crystalline, poorly bedded limestone with rather irregular and widely spaced joints and the majority are thought to have negligible permeability and low primary porosity (Wilford & Wall, 1965). The larger limestone outcrops weather to form hills (many resembling *turmkarst* which, in the lower parts of drainage basins, are commonly surrounded almost entirely by alluvial areas underlain by limestone. Most of the known caves are within a few hundred feet of the foot of the hills and many have their entrances at the foot of cliffs which commonly bound the hills (Wilford, 1964).

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The author is indebted to J. R. D. Wall, Soil Laboratory, Department of Agriculture, Sarawak for comments. This note is published with the permission of the Malaysian government.

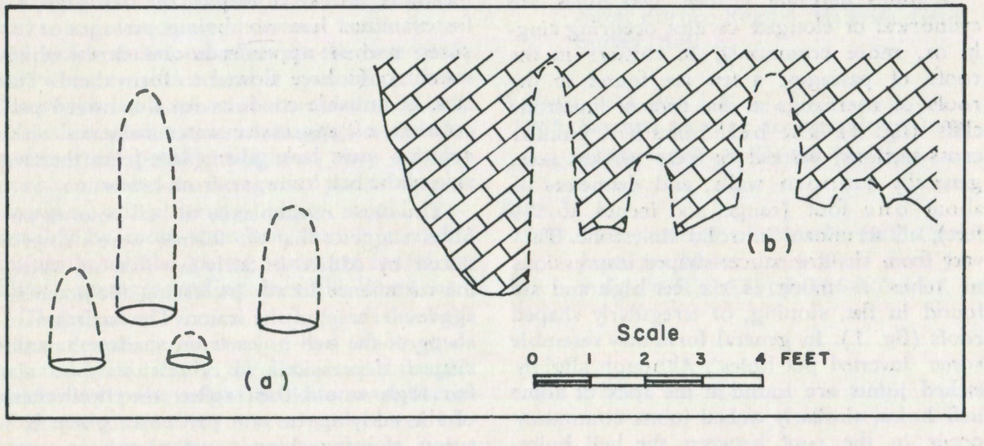

Figure 1.

Bell holes showing (a) their shape and (b) a section showing their positions in a typical cave roof.

Figure 2.

Complex bell hole type roof cavities in Niah Great Cave, northeast Sarawak. The smaller holes are about one foot in diameter and several contain nesting swiftlets (Sarawak Museum photograph).

The Bell Holes

Features hereafter termed 'bell holes' are cylindrical or elongate cavities occuring singly or, more commonly, in clusters in the roofs of passages; a few are found in the roofs of overhangs at the foot of limestone cliffs (fig. 2). The bell holes have circular cross-sections, vertical or near vertical axes, generally smooth walls, and diameters of about one foot (range six inches to 2½ feet); all terminate in solid limestone. They vary from shallow saucer-shaped impressions to 'tubes' as much as six feet high and are found in flat, sloping, or irregularly shaped roofs (fig. 1). In general form they resemble some 'inverted pot holes'. Although slightly etched joints are found at the apex of some bell holes, similarly etched joints commonly occur in the roof between the bell holes. The vertical axes and circular cross sections of the bell holes do not appear to be affected by the variations in dip or direction of either bedding planes and joint planes traversing the limestone roof, or by slight changes in the lithology of the limestone through which they cut.

More complex, but probably genetically related forms have been found in the Selabor Caves (Wilford, 1964, p. 106) and consist of cavities five feet across and six feet high which are lined with vertical grooves of comparable 'diameter' to bell holes (fig. 3). In Niah Great Cave in northeast Sarawak a wall adjacent to a steep roof with bell holes is vertically grooved, the 'diameter' of the grooves ranging up to three feet, considerably greater than those of the average bell holes nearby (fig. 4). In another part of Niah Great Cave a cluster of bell holes occurs at the apex of an irregular roof cavity, parts of which tend toward a cylindrical shape with diameters several times that of the average bell hole (fig. 4).

Origin of Bell Holes

Bell holes bear a superficial resemblance to many domepits (Merrill, 1960) in that they have almost circular cross-sections, vertical axes and, in the complex larger forms, a few vertical grooves. However, they differ fundamentally in that they are much smaller, their dimensions being measured in feet rather than tens of feet, and that they have no connection with surface topography. Furthermore, unlike domepits, the bell holes so far examined have no obvious passages or fissures at their upper ends and down which water could have flowed to form them. The lack of suitable conduits for downward percolation of aggressive water indicates that solution must have taken place from the cave side of the bell holes; *i.e.* from below.

Figure 3.

Complex bell holes in a Selabor Cave, West Sarawak. The cavities, about five feet across and six feet high, are lined with part-cylindrical vertical grooves of comparable diameter to the bell holes.

The close resemblance of bell holes to pot holes suggests that the former were also produced by eddies in fairly fast flowing water, the turbulence locally increasing the potential aggressiveness of the water. The variation in shape of the bell holes from shallow, saucer-shaped depressions to cylindrical holes six feet high would then reflect the effectiveness of the eddying in one particular place. Rotation of water about a vertical axis in some bell holes is indicated by a slight widening of the cylinder at one or more places along its length. Pothole formation, however, is clearly the effect of solution plus the abrasional effect of gravel which commonly results in the bases of the potholes being wider than the rims, and bulb shapes are quite common. Bellholes, though of comparable diameter to potholes, are usually much longer, and the only material likely to stay near to the roof of a flooded cave is vegetation. Sticks and leaves are, however, unlikely to have much abrasional effect on the cave roof even when swirled round at speed in eddies. The somewhat haphazard distribution of bell holes throughout caves also mitigates against an 'inverted' pothole origin as they are no more common in irregular parts of cave passages, where strong eddies would presumably be most abundant, than in straight uniformly tubular parts; some are found in 'blind' passages ending in solid limestone.

The marked vertical nature of the bell holes, despite variations in the lithological structural features of the limestone through which they pass, might indicate some form of gravity or convection current control of water movement in otherwise almost stagnant water as suggested, for instance, by Curl (1966). This is perhaps indicated by the common occurence of associated vertical features such as wall grooves (right hand side of fig. 1) which in some caves may be 50 feet high (Wilford, 1964, p. 19). These wall features and grooves lining some of the more complex bellholes (fig. 3) appear to be too large, and too uniformly vertical, to be the result of eddies in fast flowing water. On the other hand it is difficult to imagine how a current can form in almost static water for sufficient length of time in one place to dissolve these bell holes.

The writer would welcome alternative suggestions.

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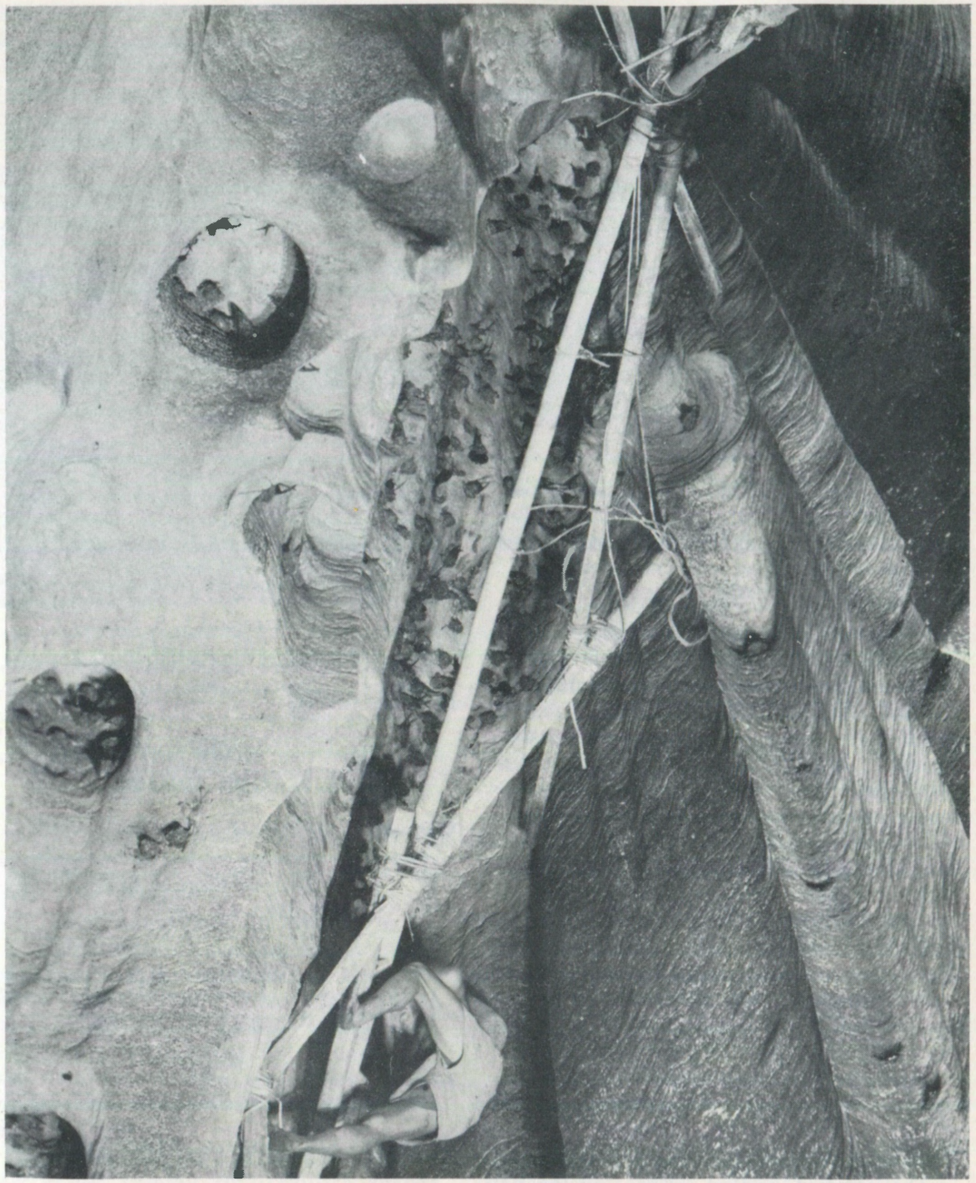

Figure 4.

Bell holes in Niah Great Cave, northeast Sarawak. A view looking almost vertically upward and showing bell holes (left) in a steeply sloping roof and a vertically grooved wall (right). The man is climbing a scaffolding to collect edible birds nests (Sarawak Museum photograph).

Geological Survey
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Armadillo Remains From Tennessee and West Virginia Caves

By John E. Guilday and Allen D. McCrady

ABSTRACT

Pleistocene remains of armadillo (*Dasypus*) are recorded from Robinson Cave, Tennessee and Organ-Hedricks Cave, West Virginia.

Fitch, Goodrum and Newman (1952) documented the northern spread of the nine-banded armadillo (*Dasypus novemcinctus* Linneaus) during the past 70 years from the Rio Grande Valley of Texas north and east to Oklahoma, Arkansas, Louisiana, and Mississippi. Sporadic records as far north as Missouri and Kansas are thought to be introductions by man. The armadillo has been successfully introduced in Florida where it is increasing in numbers. The animal is quite sensitive to cold and periods of prolonged freezing weather prove fatal as far south as Louisiana.

A related species *Dasypus bellus* (Simpson), a large hog-sized carbon copy of the nine-banded armadillo is now extinct. It is known to have inhabited the southeastern United States during Sangamon/Wisconsin times, and has been reported in fossil deposits from Texas, Florida, Oklahoma, Missouri (Slaughter, 1961), and Georgia (Clayton E. Ray, letter).

Two additional records have come to light, both from cave deposits, one in northcentral Tennessee, the other in central West Virginia, both of unknown age but presumed Sangamon.

1. Robinson Cave, Overton County, Tennessee, Lat. 36° 17' 25" N. Long. 85° 22' 25" W., alt. 1200 ft., CM 8048, buckler and band scutes. (fig. 1, c.)
2. Organ-Hedricks Cave, Greenbrier County, West Virginia, Lat. 37° 42' 02" N., Long. 80° 22' 00" W., alt. 2,200 ft., CM 12605, partial band scute. (fig. 1, d)

Although the record from Cherokee Cave, St. Louis, Missouri, Lat. 38° 40' N. (Simpson, 1949) remains the most northerly record of armadillo in the Pleistocene, its altitude is approximately 2,000 feet lower than that of Organ-Hedricks Cave, West Virginia, which is almost as far north. Environmental conditions must have been relatively milder than in the Appalachian Mountains of West Virginia. Perhaps the relative harshness of the environment is reflected in the smaller size of the Tennessee and West Virginia specimens as compared to those from Missouri and Florida Pleistocene sites.

The Robinson Cave armadillo remains, a few fragmentary scutes, were found intermingled with a relatively well preserved fauna that suggested a cool episode (Arctic shrew *Sorex arcticus,* Northern bog lemming *Synaptomys borealis,* Red-backed vole *Clethrionomys gapperi,* were present.) Fluorine analysis indicated that the armadillo material was older than the boreal element of the fauna and secondary deposition is suspected.

The Organ-Hedricks specimen, one fragmentary band scute, was found as float with peccary *Mylohyus* cf. *nasutus,* bear *Ursus* sp., horse *Equus* sp., and the bat *Myotis grisescens.* The presence of *Myotis grisescens,* a species currently confined to the southcentral United States, suggests conditions somewhat warmer than at present, (Handley, 1956) but temporal association between bat and armadillo cannot be conclusively demonstrated. It is highly suggestive, however.

We wish to thank Mr. and Mrs. Walter Robinson, owners of Robinson Cave and Mrs. Sively, owner of Organ Cave for their cooperation; the West Virginia Association for Cave Studies, Inc. especially, Mr. Robert H. Handley and Mr. John Rutherford for locating and guiding us to the Organ-Hed-

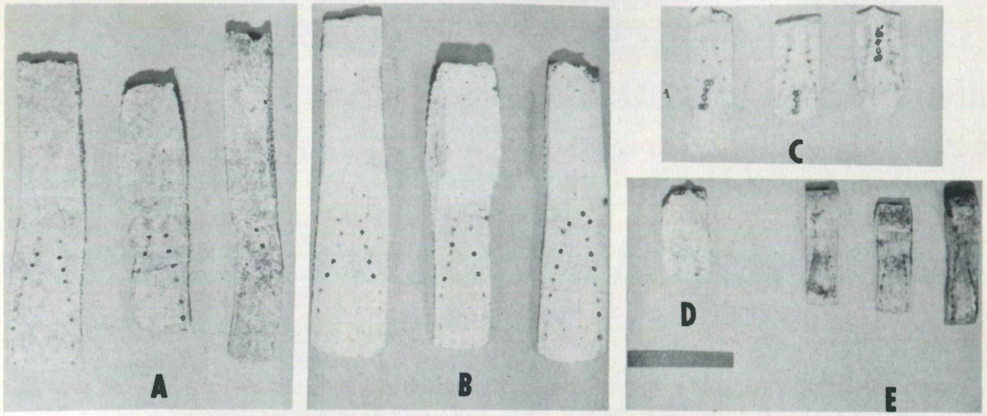

Figure 1.

Band scutes, **Dasypus,** Pleistocene and Recent.
a. **Dasypus bellus,** CM 12606 Reddick (IA), Florida.
b. **Dasypus bellus,** Crankshaft Pit, Missouri. Oesch collection.
c. **Dasypus** sp., CM 8048, Robinson Cave, Tenn.
d. **Dasypus** sp., CM 12605, Organ-Hedricks Cave, West Virginia.
e. **Dasypus novemcinctus,** G-775, Recent Florida.
Bar = 20 mm

ricks deposit. We wish to thank Dr. Clayton E. Ray, Associate Curator, Division of Vertebrate Paleontology, U. S. National Museum for providing us with the Florida *Dasypus* material both fossil and Recent, Mr. Ronald D. Oesch for permission to figure the Crankshaft Pit specimen, and Mr. Joseph Ryan, Harbison Walker Refractories, Pittsburgh, Pa. for fluorine analyses. Research conducted under N.S.F. grant number GB 3083.

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Pollen Analyses of the Sediment From Sinkhole Ponds in the Central Kentucky Karst

By H. E Wright, Jr., Barbara Spross, and R. A. Watson

INTRODUCTION

The pollen of most trees and shrubs and many other plants is dispersed and thoroughly mixed by the wind. Pollen falling in a particular area reflects in a general way the composition of both the local and regional vegetation (McAndrews, 1965). The preservation of pollen generally depends on its inclusion in the sediment of a lake, bog, or other wetland that has been free from the chemically deteriorating effects of oxygenated water. Study of the sequence of changes in the pollen composition of pond sediments provides the basis for reconstructing vegetational history.

In the Central Kentucky Karst, ponds in limestone sinkholes provide hundreds of sites for deposition of pollen. In the present study we hoped to examine the forest migration during the glacial period and subsequent time, and to work out thereby a climatic sequence that might have significance in the interpretation of cave history.

Cores a few decimeters long were collected for pollen analysis in 1963 by R. A. Watson and R. H. Rose from Ruth Dale Pond (37°11'52"N, 85°56'10"W, Horse Cave 7½-minute topographic map, U.S. Geol. Survey, 1954), Melloan Pond (37°12'12"N, 86°38'48"W, Mammoth Cave map, 1954), and Creacy Lake (37°09'36"N, 85°54'35"W, Horse Cave Map). Melloan Pond is on the Mammoth Cave Plateau; the other two are in the Sinkhole Plain. Preliminary pollen analyses of the Melloan and Creacy sediments indicated that preservation and abundance justified further study. Accordingly, funds for pollen analyses were provided by the Cave Research Foundation, and in 1964 a core almost 8 m long was taken from Ruth Dale Pond by H. E. Wright, R. A. Watson, R. F. Wright, and J. R. Wright, and one almost 3m long from Melloan Pond. Second access to Creacy Pond was denied. Attempts were made to sample two other ponds on the Mammoth Cave Plateau (Sloans Crossing Pond, Lat. 37°09'02"N, Long. 86°05'58"W, Mammoth Cave map; Doyel's Big Pond, Lat. 37°08'58"N, Long. 86°04'25"W, Mammoth Cave map), but the bottoms proved too hard. Davis and Livingston corers were used (Wright *et al.*, 1965).

The sediment of Ruth Dale Pond, which was analyzed to greatest depth, consists of about 1 m of red-brown clay overlying almost 7 m of gray clay. The clay is derived by wash from the adjacent hill slopes, which have an irregular veneer of red-brown clayey residual soil. The soil results from the concentration of impurities in the underlying Mississippian Ste. Genevieve limestone (Pohl and Cushman, 1964) during solution weathering and warm-climate oxidation.

The clay is so fine-grained that it has generally provided an effective seal to the downward infiltration of oxygenated water. The presence of decomposing organic matter in the pond water has produced reducing conditions, so that the red-brown form of the iron oxide in the clay has been changed to the gray form through most of its thickness. The upper 50 cm of sediment may still be red because of insufficient time for reduction of the iron since deposition.

The modern forest vegetation of the Mammoth Cave region was examined with the as-

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sistance of Dr. Lionel Prescott. An oak-hickory association dominates the area, with *Quercus alba* (white oak), *Q. marilandica* (blackjack oak), *Q. muehlenbergii* (chinkapin oak), *Q. prinus* (chestnut oak), *Juglans cinerea* (butternut), *J. nigra* (black walnut), *Carya cordiforms* (bitternut), *Liriodendron tulipifera* (tulip tree), *Ulmus thomasi* (rock-elm), *Nyssasylvatica* (black gum), *Acer rubrum* (red maple), and *Fraxinus americana* (white ash), Seedlings and saplings of the almost extinct chestnut (*Castanea dentata*) are present in the understory, which also included *Cercis canadensis* (redbud), *celtis laevigata* (hackberry), *Ostrya virginiana* (hop-hornbean), *Sassafras albidum* (white sassafras), and *Cornus florida* (dogwood).

RESULTS

Samples were analyzed for pollen content according to standard methods (Faegri and Iversen, 1954). About 200 grains were counted for each sample. Tree pollen is largely representative of the forest of the region, oak being the dominant tree-pollen type (fig. 1). *Taxodium* (bald cypress) pollen must have come from trees in flood plain forests. *Pinus* (pine) pollen was carried in from distant pine forests, as is the case in almost every part of the United States. Among the other tree-pollen types counted but not recorded in figure 1 are juniper (or related genera), alder, poplar, willow, beech, chestnut, mulberry, and hemlock.

Among the non-arboreal pollen, *Ambrosis* (ragweed) constitutes 20-65% of total pollen. Ragweed pollen at sites in forested regions prior to the time of extensive land disturbance usually amounts to only a few percent (Wright *et al.,* 1963). The very high percentages of ragweed in the karst ponds therefore indicate that the sediments examined were deposited after the beginning of forest disturbance and agricultural development, perhaps 150 years ago in this region.

Among the herbs identified but not recorded on figure 1 were *Cyperceae, Artemisia, Iva, Xanthium, Rumex, Plantago* cf. *lanceolata,* and mostly single grains of a dozen different undifferentiated families, as well as pollen grains of aquatic plants and spores of mosses and ferns.

In most lakes in areas of forest clearance, the sediment deposited since the time of settlement is only a few decimeters thick. The presence of more than 4 meters of modern sediment at Ruth Dale Pond implies rapid soil erosion and deposition. The apparently complete absence of pollen from the clay below 450 cm implies even more rapid erosion and deposition – so rapid that a negligible amount of pollen from atmospheric fall-out collected in the sediment. Because of failure of the long core at Ruth Dale Pond to yield pollen to depth, no further tests were made of the 3 m core from Melloan Pond.

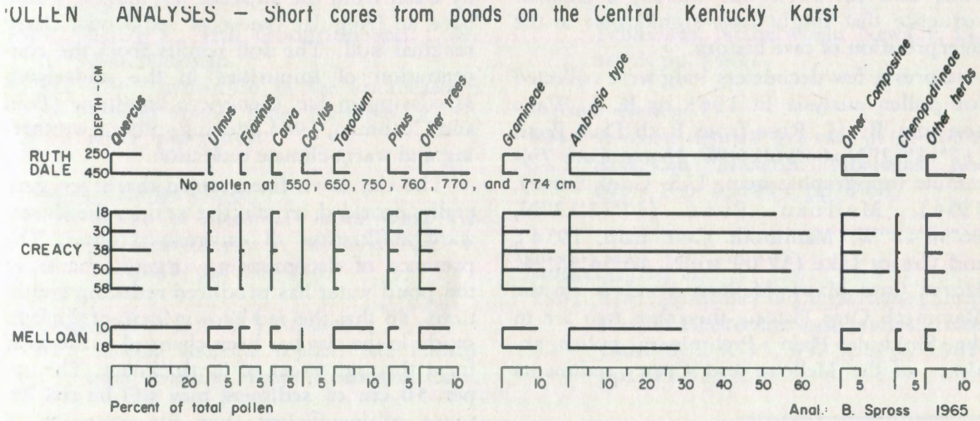

Figure 1.

Selected pollen counts for the sediments of three sinkhole ponds on the Central Kentucky Karst; percentage of total pollen based on a count of about 200 grains for each analysis.

Many depressions contain in the center a swallow hole, which presumably leads to bedrock crevices that become enlarged by solution. A clay plug in the swallow hole permits the depression to hold water temporarily, but drainage may be abrupt if the seal is broken. Several farmers refused to permit core sampling in their stock ponds because they feared that the "plug would be pulled."

DISCUSSION

The failure of the ponds sampled in the Central Kentucky Karst to provide a long record of sedimentation suggests that pollen analysis and other stratigraphic methods cannot furnish the information on vegetational and climatic history that was the objective of the investigation. Such history will evidently have to be extrapolated from sediment studies of lakes of different origin in other regions. The nearest possibilities are the southernmost glacial lakes in Indiana and Ohio 150 miles to the north, which may have formed as much as 20,000 years ago with retreat of the Wisconsin ice sheet (Goldthwait *et al.,* 1965). It might even be possible to find on the still older Illinoian glacial drift of southernmost Indiana and Ohio an old depression completely filled with local sediments, not only of the last glacial age but also of the last interglacial age.

The sediment study of the sinkhole ponds does provide further evidence, however, that the sinkholes are actively forming and are subject to rapid sedimentation. Extensive cultivation in the area during the last century has permitted rapid erosion of the residual clay from the hill slopes, followed by deposition in surface depressions, in crevices and cave passages underground, and in other areas of slow water movement. The removal of soil cover exposes the jointed bedrock to more rapid infiltration of water. Practically all the surface water in the area goes underground; few streams reach the Green River on the surface. Much of the clay and silt found throughout the region in cave passages, particularly those close to the surface, must have been deposited in recent times by water entering through sinkholes. Considering the amount of soil erosion in the region, and the thousands of sinkholes that do *not* support ponds and thus conduct water and sediment underground, it may be wise to reexamine the conclusions of Collier and Flint (1964) that the clay and silt in the lower levels of the cave systems were deposited predominantly by flood waters of the Green River backing up into the caves. Whatever the detailed effects underground, the area is one with relatively rapid change on the surface, a regime that has probably accelerated since land disturbance began.

Conceivably the pollen-bearing sediments of earlier sinkhole ponds dating from the glacial period were similarly conducted underground and may have been deposited by stream diversion. If the pollen of such sediments has been protected from deterioration by conditions of extreme dryness, then perhaps a record of past vegetation may yet be found in the area. But the depositional irregularities in strictly alluvial sediments, along with problems in sampling, the low pollen concentration, the chances of damage to pollen grains during transport by underground streams, and difficulties in dating, make success in such an investigation very unlikely.

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Some Techniques for Cave Exploration: Discussion

By James F. Quinlan

Mr. Plummer has written a useful and informative, albeit often puerile, summary of exploration practices in the U.S., but there are some opinions with which I take exception, and there is a conspicuous ommission that I shall describe.

Plummer refers to the body rappel as being "essentially unsafe." It is quite debatable whether the body rappel is inherently any more unsafe than a snaplink or carabiner rappel. Both are dangerous, but both, when used with a prusik safety, are made much safer. I believe the matter is largely one of taste. Speaking for myself, I strongly prefer a body rappel (with properly designed pads) for most drops, but I recognize that for long drops of 200 or more feet the weight of the rope makes a carabiner rappel much more comfortable. I might comment that I have seen nylon rope ruined by use of carabiner rappels, but this does not often happen.

I fully agree with Plummer's sentiments on the general impracticality of a separate belay line for use in rappel. However his failure to mention even the existence of a prusik safety for use in rappel is a gross breach of his responsibility for the advocacy of safe exploration techniques. A prusik safety should always be used on all rappels of more than perhaps 10 feet. It should be used by novice and expert alike – regardless of whether they use a body rappel or a carabiner rappel. Prusik safeties are most convenient when used with a "detachable rig" similar to that which Plummer has described and illustrated.

Let me add a historical note. To the best of my knowledge, the earliest usage of prusik knots for caves in America was that made by three or four members (including Bob Handley and Joe Lawrence, Jr.) of the V.P.I. Grotto during 1949 or 1950. The technique was "discovered" in a mountaineering book, and it was experimentally used on the walls of the entrance sink to Starnes Cave, Giles Co., Virginia. The prusiks were used in practice only and they were not used within the cave (Joe Lawrence, Jr., 1966, personal communication). Prusik knots were independently rediscovered, again in an old mountaineering book, by Bill Cuddington in 1952 (Bill Cuddington, 1966, personal communication). Bill perfected the technique and was the first person in the U.S. to extensively use prusiks for vertical caving. This was at the time when many American cavers were making the transition from block and tackle to ladders. There were many who regarded with horror Bill's use of a single line and rappels without a belay from above. It would be interesting to hear of any earlier American usages of prusik knots in caves.

One other comment: Plummer suggests the use of one or more semi-permanent camps which can be stocked with equipment. Although this technique has been used in Hölloch Höhle, in Switzerland, it has seen very limited use in the U.S. Experience and results in Crystal and other caves of the Flint Ridge Cave System of Kentucky has indicated that the most effective exploration and mapping has been accomplished on 20 to 30 hour trips.

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PAPERS IN PRESS FOR FORTHCOMING ISSUES

Physical and Physiological Factors in Fatal Exposures to Cold. *Marlin B. Kreider*

Mud Stalagmites and the Conulite. *Charles B. Thayer*

The Jordbruen Area of Northern Norway — an Example of High Latitude Karst. *Thomas E. Wolfe*

Conservation Through Commercialization — Rio Camuy Development Proposal (Complete Issue). *Jeanne Gurnee, Guest Editor*

Geology of Dutton's Cave, Fayette County, Iowa. *James Hedges*

Comparative Investigations Into Recent Methods of Tracing Subterranean Water. *V. Maurin, et al.*

Some Techniques for Cave Exploration: Reply

By William T. Plummer

Many years ago the steam locomotive was introduced for transportation, and spectators deplored that speeds beyond ten miles per hour would "shake our bodies to pieces." Mr. Quinlan's objections to snaplink rappels are of the same category. I've made many hundreds of snaplink rappels without damaging a rope, and I suspect that if he has seen a rope damaged, the rappel was not rigged as described in the article. Few cavers seriously consider the use of a body rappel for more than a short pitch.

The suggested use of a prusik knot safety on rappels deserves comment. I used one for about three years, but gradually found that inexperienced cavers were caused much trouble by it, particularly where the descent was not a simple drop. In practice sessions some cavers have accidentally become entangled by the safety, and have neglected to rig foot slings ahead of time for getting loose. Recent accidents at Newberry-Bane Cave and at Fern Cave have shown that a prusik safety may not be much help in an emergency unless it can somehow be knocked out of one's hand. Cavers in Virginia have made extensive tests which show the inherent psychological tendency to cling to the prusik knot in a fall, and render it useless. For these reasons I do not advise the illusory protection of the prusik safety on a rappel. It was suggested however, for ladder climbing.

Mr. Quinlan's historical note on the use of prusik knots in this country is most interesting. It is a pity that none of the missionaries between Karl Prusik and Dan Bloxsom took the trouble to write about their attempts, unpolished as those attempts might have been.

No doubt Mr. Quinlan is proud of his 20 to 30 hour cave trips, but I am sure he is aware of their limitations. Particularly in a single-access system such as Overholts (Blowing) Cave, where one must retrace miles of familiar passage on each trip before reaching the frontier, little serious exploration could be accomplished on a single visit without a permanent camp. Cavers become dangerously over-extended after the first 15 or 20 hours, and are risking injury if the cave requires technical work. I have participated in several trips lasting more than 25 hours, and have found that there are caves which are more efficiently explored with a camp or two. This is what the article said. One must of course keep it simple, or the camping may quickly interfere with the caving. If experience and results in Crystal and other caves of the Flint Ridge Cave System are examples of anything, it is *not* efficiency.

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ERRATA

· Volume 28, Number 1, January 1966

Some techniques for cave exploration, by William T. Plummer

Page 29, line 9, read . . . the left foot . . .

Page 31, figure 6 appeared upside down; it is reprinted below in correct orientation, although the knots will hold either way.

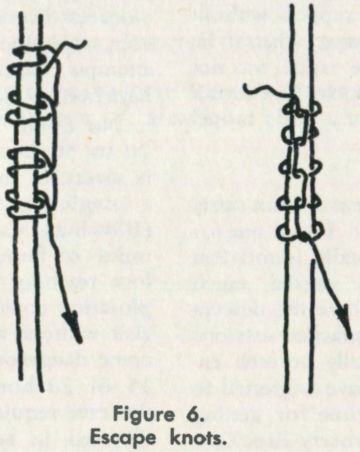

Figure 6.
Escape knots.

Page 29, col. b, line 5, read . . . just tight . . .