H. H. Hobbs III

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NATIONAL SPELEOLOGICAL SOCIETY

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A Vertical Contour Method of Cave Representation

Theodore R. Steinke *

ABSTRACT

Understanding of the cave-forming process or processes has been hindered by the lack of an acceptable means of representing the three-dimensional form of caves. In this paper a set of illustrations is used to show how a vertical contour method can be used to develop realistic three-dimensional representations of caves. The technique uses information which is normally available on good cave maps, requires no special equipment, and can be used successfully by any person regardless of his artistic capabilities.

Introduction

Among the factors which hinder understanding of the cave-forming process or processes, speleologists would list the difficulty in delimiting the critical parameters of cave formation, the limited but growing understanding of the solvent action of ground water in limestone, and the difficulty in gathering descriptive information about caves. But another and equally important factor has contributed to our ignorance, and this has been the absence of an adequate graphic means of representing the cave system in three space which could facilitate the understanding of relationships within the cave important to its formation.

Most good cave maps relate information about both the horizontal and vertical characteristics of a cave. The planimetric representation of a cave includes passage outline as well as features such as water, breakdown, and flowstone. To show information in the vertical plane, cave cartographers rely on a number of conventions such as numerical ceiling heights to show magnitude of the cave in the vertical direction, cross sections to show passage shape, hachures to show slope or changes in slope, ticked and dashed lines to show ledges or undercuts, and a profile to show a single longitudinal section of the cave supposedly along the center line of the passage, along the survey line, or along a line of greatest interest.[1] There is a growing awareness that most of the conventions listed above are inadequate in terms of the readers' understanding of the vertical configuration of all but the most simple caves. This is probably true for all readers regardless of the nature of their interest in the cave. Certainly the ready comprehension of a cave's horizontal and vertical characteristics are as desirable to the sport caver as they are to the scientist.

While most of the conventions used on cave maps transfer information to the reader, certain ones are more helpful than others. In an article Brown (1970) reported that the quality and accuracy of a cave map was determined by means of a field test. The results of this test indicated ". . . that from looking at the map we couldn't conceive what the cave would look like." The author

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1 For examples of cave maps which make use of the above symbology see those of A. Williams in the *Cave Crawlers Gazette*, J. Hedges in the Iowa *Intercom* and *Wisconsin Speleologist*, J. Nieland and S. Knutson in *The Speleograph* (Oregon Grotto), and T. Raines, O. Knox, and others in *Caves of the Inter-American Highway;* and for cave maps of consistently high quality, see those which appear in *Missouri Speleology*.

goes on, however, to point out that the cross sections were perhaps one of the most helpful features of the map. This is also held by Breisch (1970) who states that, "The importance lies in that cross sections give a much clearer understanding of passage shape than is available from maps without this information. Therefore it is desirable that all maps contain passage shape information through the use of numerous cross sections. It is hoped that more use will be made of cross sections and that new and more graphic methods of depicting cave passages will be developed." In another article, Breisch (1969) describes a cave survey technique where all of the cave measurements are synthesized into a series of passage cross sections which are displayed in perspective. A number of people including this author are of the opinion that the passage cross section may be one of the most revealing features of a cave map. The method discussed in this paper is an attempt to show cave form by means of the cross section here referred to as the vertical contour.

Methods of Adding 3-D Detail to Cave Maps

Cave mappers have recognized the three-dimensional inadequacies of their products and have tried to develop new techniques or to make use of existing ones to supplement the typical cave map. Attempts to date at showing additional information about the vertical nature of the cave fall into several categories.

One of these superimposes the topography of the area overlying the cave onto a plan of the cave.[2] The purpose of such a representation is to place the cave in the proper regional topographic setting and to help determine the relationship that exists between the cave and the overlying slope and drainage. Such representations can be very helpful in determining the developmental history of the cave but usually do not aid the reader in visualizing the three-dimensional character of the cave. In fact, because the method usually necessitates the reduction of the cave plan, details of the cave itself may be lost. For this reason the illustration should always be accompanied by the usual cave map.

Ford (1965) has demonstrated a method of contouring caves. His method adds to the fund of information concerning the three-dimensional character of the cave by connecting all points on the floor or ceiling of a cave which lie at the same elevation. While the reader is now able to readily perceive regional slope in the cave, he is still unable to visualize the form of the cave.

In caves with considerable complexity in the vertical plane, the inadequate plan view should be supplemented with one or more three-dimensional illustrations of those portions of the cave least well shown on the plan. Brod (1962) discusses three techniques of this type—the isometric, the cut and fold back, and the conventional perspective—but points out that "All of these representations require a fair amount of artistic ability . . ." Such artistic sketching is certainly desirable whenever possible because it provides an excellent representation of the form of the cave.[8] Unfortunately, few cave cartographers have the talent necessary to render caves in this way.

In attempts to show passage form and relationship, Deike (1967) has made use of several rather rudimentary yet effective sketches which add greatly to the readers' understanding of the form of the cave passage. Unfortunately such sketches lack positional control and therefore preclude the use of this technique for all but very small caves or limited portions of larger caves.

While trying to represent cave systems developed in complex structure, Goodchild (1969) and others have experimented with

[2] See for example R. Bridgemon (1965), "The Caves of Baker Creek with Reference to the Baker Creek System, White Pine County, Nevada," *Arizona Caver,* 2(4):44-79; Central Indiana Grotto (1966), "Henderson Park Caves," *CIG Newsletter,* 10(10):189; and J. Gurnee (ed.) (1968), *National Speleological Society Field Trip to Aguas Buenas Caves, Puerto Rico,* p. 5.

[8] For an example of this type of sketch see the map of Tower Pit by T. Yokum (1966), *Missouri Speleology,* 8(1):46.

stereographic cave mapping. The technique is sound but so far has two serious drawbacks. It requires the use of a computer and plotter, and it has not yet been perfected to the point where passage form can be shown.

All of the aforementioned three-dimensional techniques either: 1) were developed for some purpose other than showing cave form, 2) require artistic talent beyond that of the average cave mapper, 3) are insufficiently accurate to represent an entire cave in anything more than a sketch, or 4) require the use of a computer plotter.

The use to which a given representation of a cave is going to be put is the primary factor influencing the nature of that representation. The type of representation helpful to the person studying internal cave geology or cave biology or to the person interested in cave commercialization might not be as helpful to the person interested in cave hydrology or speleogenesis. The following method of cave representation is proposed for the use of the latter group.

The Vertical Contour Method

From a geological point of view, a cave is an anomaly in the sense that it is an absence of rock in a lithologic environment. This is the point of view from which the cave cartographer tries to represent the cave. He is faced with the problem of trying to represent three-dimensional nothingness. What the cartographer in fact must do is represent the air/rock interface, and the question arises as to how he is best able to show this three-dimensional surface. The cartographer must reverse the properties of the cave and its surrounding bedrock so that he is now dealing with a three-dimensional cave of solid form surrounded by a void rather than a void hidden from view by the surrounding rock. In other words visualize the cave as a cast suspended in space rather than the mold it actually is. The vertical contour method[4] allows representation of this three-dimensional cave of solid form using nothing more than an existing high quality cave map and the usual drafting equipment.

Belle Star Cave, Stone County, Missouri, was chosen as the subject in this presentation.[5] The map, prepared by B. Taylor and D. Rimbach, was chosen for two reasons: (1) It possesses the two features necessary

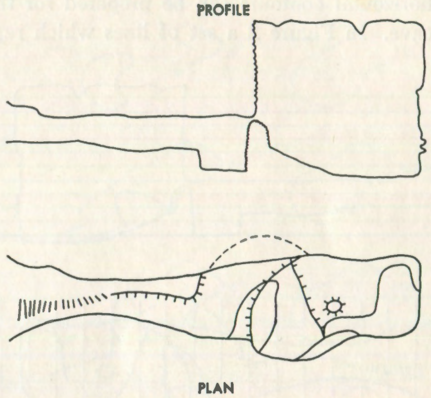

Figure 1. The cave profile at the top and the cave plan at the bottom are the two basic ingredients needed for the construction of a vertical contour map of a cave. Note that unnecessary information such as ceiling heights, water bodies, interior sediments and surrounding bedrock have been removed from the profile and plan. (Belle Star Cave, Stone County, Missouri.)

for this technique: (a) a plan with supplementary information and (b) a longitudinal profile. (2) It is a small and simple cave which will allow concentration on the tech-

[4] For more detailed discussions of this graphic technique see K. Tanaka (1932), "The Orthographical Relief Method of Representing Hill Features on a Topographical Map," *Geographical Journal,* 79:213-19; A. H. Robinson and N. J. W. Thrower (1957), "A New Method of Terrain Representation," *Geographical Review,* 47:507-20; A. H. Robinson (1969), *Elements of Cartography,* (New York: John Wiley & Sons), 3rd ed. pp. 189-196; N. J. W. Thrower (1963), "Extended Uses of the Method of Orthogonal Mapping of Traces of Parallel Inclined Planes with a Surface, Especially Terrain," *International Yearbook of Cartography III,* (Gutersloh: C. Bertelsman), pp. 27-28; and G. F. Jenks and D. A. Brown (1966), "Three Dimensional Map Construction," *Science,* 154(3750):857-64.

[5] *Missouri Speleology,* 9(2):23 (1967).

nique without introduction of the complexities resulting from the use of a larger cave. This by no means should be taken to indicate that the technique should not or cannot be used to represent larger caves.

Construction of the Map

The two basic requirements for this method, the cave profile and the cave plan (Figure 1), are needed so that a set of horizontal contours can be prepared for the cave. In Figure 2 a set of lines which represent a series of horizontal planes cutting through the cave are placed on the profile. The interval between these planes is arbitrary but is usually inversely related to the scale of the plan: the larger the scale the smaller the interval. When the number of planes is increased by decreasing the interval, the accuracy of the finished product is increased but so is the amount of work involved. For this cave I used an interval of 2.5 feet. A square grid whose density is again arbitrary is placed on the plan in Figure 2. The same relationship between accuracy and work holds for grid density as for plane interval. A 5-foot grid was used in this case. The function of this grid will become apparent shortly.

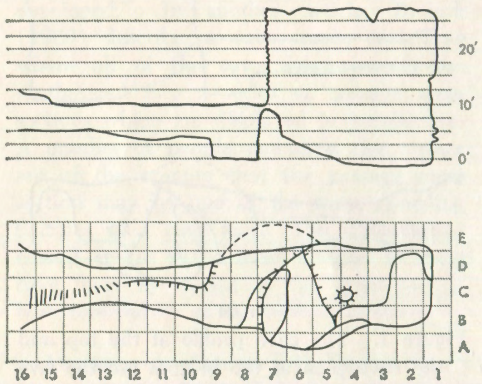

Figure 2. Horizontal cutting planes separated by an arbitrary interval of 2.5 ft are placed over the profile at the top while a 5-ft square grid is placed over the plan at the bottom. Such graphic additions allow for the systematic three-dimensional construction of the cave.

At the top of Figure 3 is seen the profile of the cave with the lowest cutting plane, which has been arbitrarily labelled the 0-ft plane. This plane cuts through the bottom of the cave and creates the trace or contour shown in heavy black at the bottom of the illustration. This becomes the 0-ft horizontal contour.

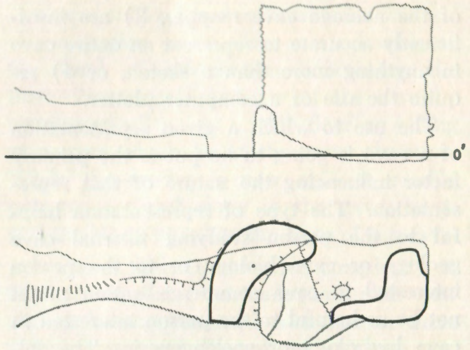

Figure 3. At the top is the lowest of the cutting planes which has been labeled the 0-ft plane. At the bottom is the cut line or horizontal contour created by the intersection of the 0-ft cutting plane and the air/rock interface of the cave. In a similar manner horizontal contours can be produced for all cutting planes from the bottom to the top of the cave.

The square grid mentioned above is now placed over the 0-ft horizontal contour as shown at the top of Figure 4. This grid is then put through a transformation, and the contour is transformed by transferring it to the transformed grid by the similar squares method.[6] This produces the 0-ft transformed horizontal contour shown at the bottom of Figure 4. The reason for performing the transformation is to move the readers' point of view from directly above the cave to some other more advantageous position. The same thing is done when looking at the three-dimensional properties of a box. You

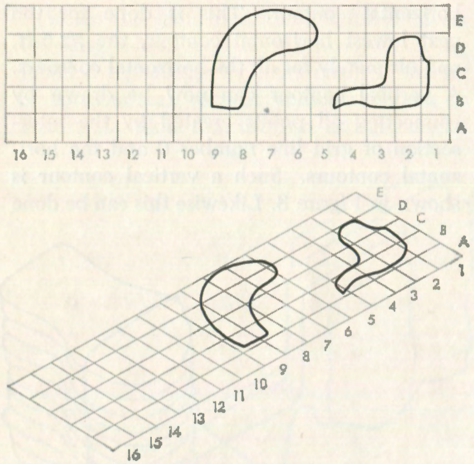

Figure 4. At the top the square grid shown in Figure 2 is placed over the 0-ft horizontal contour developed in Figure 3. This square grid is then put through a transformation to alter the readers' viewing position, and the horizontal contour is transferred to the new grid by the similar squares method. The result is the transformed horizontal contour shown at the bottom.

do not look straight down at the box, you hold it out in front of you below eye level with a corner facing you. For the best three-dimensional view of the cave, the same thing is done. By varying the transformation, the viewing azimuth can be varied through 360°. Thus the cave can be looked at from the north, south, east, or west—or anywhere in between. In the same way the viewing angle or elevation can be varied from 0° on the horizon (so the cave is looked at directly from the side) to 90° above or below the horizon or anywhere in between. That viewing position which exposes the greatest amount of cave should be chosen.[7]

The next highest cutting plane, the 2.5-ft, is then projected down onto the plan to produce the 2.5-ft horizontal contour. The grid is superimposed on the 2.5-ft horizontal contour, and the transformation is performed in the same way as for the 0-ft contour. When this is done for the entire cave, a complete set of transformed horizontal contours (0 through 25-ft) are produced as shown in Figure 5.

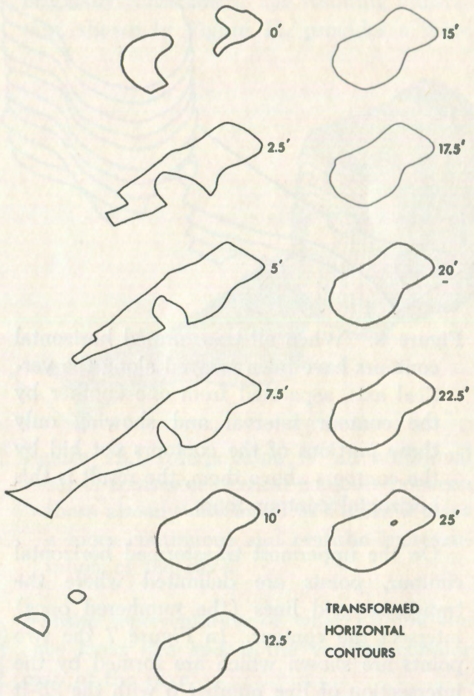

Figure 5. This illustration shows all horizontal contours after they have been transformed.

Now the uppermost of the transformed horizontal contours shown in Figure 5 (25-ft) is traced onto a sheet of paper. Then that portion of the next highest contour (22.5-ft) that is not obscured by the uppermost contour is added to the drawing one contour interval below the first. At this point the entire 25-ft transformed contour is seen plus that portion of the 22.5-ft contour which is not obstructed by the 25-ft contour.

6 This transformation can be performed with less effort by using the crossed-slit anamorphoser as reported by Jenks and Brown, *op. cit.* (footnote 4), pp. 860-63.

7 For guidelines in selecting proper viewing angle, see G. F. Jenks and P. V. Crawford (1967), "Viewing Points for Three-Dimensional Maps," ONR Technical Report No. 3, NR 389-146 Nonr 583 (15), Department of Geography, The University of Kansas, Lawrence, Kansas, September 1967, 26 pp.

This addition of contours continues until all transformed horizontal contours are arrayed along the vertical axis separated from one another by the 2.5-ft contour interval. The results are shown in Figure 6. The cave is already taking form. The set of horizontal contours is now complete, and the construction of the vertical contours can begin.

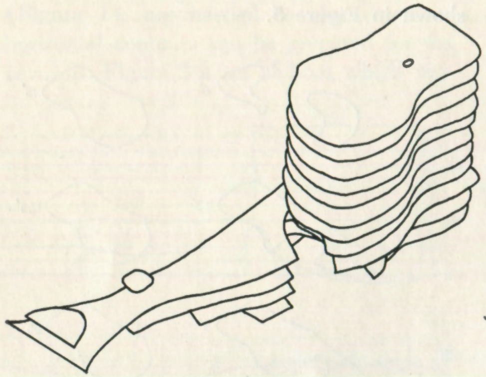

Figure 6. When all transformed horizontal contours have been arrayed along the vertical axis, separated from one another by the contour interval and showing only those portions of the contours not hid by the contours above them, the result is this horizontal contour map.

On the uppermost transformed horizontal contour, points are delimited where the transverse grid lines (the numbered ones) intersect the contour. In Figure 7 the two points are shown which are formed by the intersection of line number 6 with the 25-ft

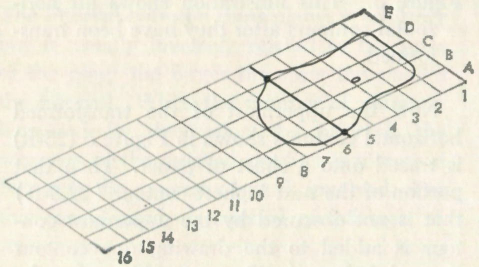

Figure 7. Here the two points are delimited where the number 6 transverse grid line intersects the uppermost transformed horizontal contour.

horizontal contour. This is done for the next lowest horizontal contour, the 22.5-ft, and ultimately for all the horizontal contours. A vertical contour can now be drawn by connecting all points created by the intersection of grid line number 6 and the horizontal contours. Such a vertical contour is shown in Figure 8. Likewise this can be done

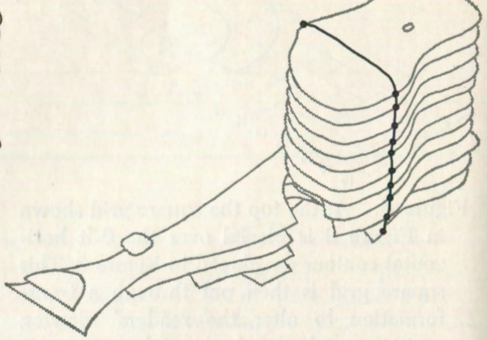

Figure 8. When intersections of the number 6 transverse grid line and all other transformed horizontal contours are delimited, all these points can be connected with a line which becomes the transverse vertical contour shown.

for all transverse grid lines. The result is the set of vertical contours shown in Figure 9.

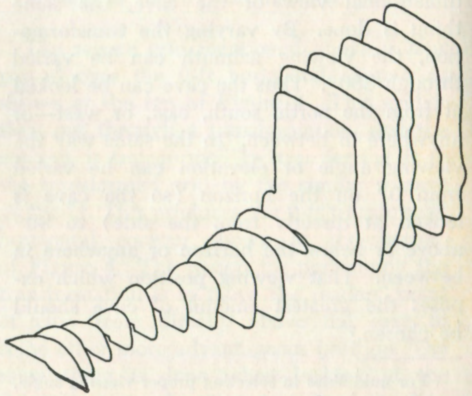

Figure 9. Transverse vertical contours can be developed for all transverse grid lines and, when arranged in the above manner, become the transverse vertical contour map of the cave.

When the same procedure is followed for the longitudinal grid lines (those which are labelled alphabetically), the result is the set of longitudinal vertical contours shown in Figure 10. Note that they are at right angles

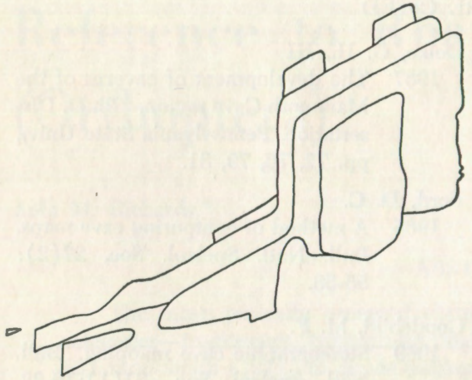

Figure 10. In the same way as shown in Figures 7, 8, and 9, vertical contours can be developed for all longitudinal grid lines. The complete set of longitudinal vertical contours is shown.

to the first set of vertical contours shown in Figure 9.

The transformed horizontal contours, the transverse vertical contours, and the longitudinal vertical contours can all be put together with the result being the fishnet of the air/rock interface shown in Figure 11. While some people find this rendition of the cave pleasing, I find the fishnet too loose to be perceptually pleasing and the intersecting lines somewhat distractive. I much prefer the product that results from going back to the set of transverse vertical contours (Figure 9) and interpolating a set of additional transverse vertical contours between those originally constructed. The resulting illustration, shown in Figure 12, provides a more realistic representation of what I think the cave looks like and is the vertical contour map of the cave.

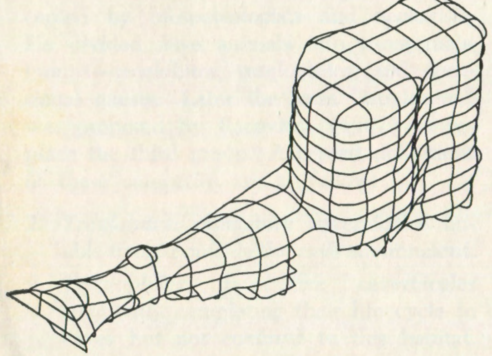

Figure 11. This fishnet of the cave results from the combination of the transformed horizontal contours (Figure 6), the transverse vertical contours (Figure 9), and the longitudinal vertical contours (Figure 10).

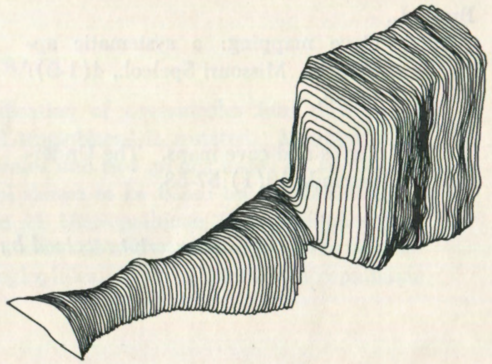

Figure 12. Interpolation of an additional set of transverse vertical contours between those already developed in Figure 9 gives a more continuous and realistic representation of the cave.

Conclusion

The vertical contour method of cave representation provides a realistic rendition of cave form and does so using information commonly found on existing cave maps. The technique is not meant to replace but to supplement presently produced cave maps. Since time inputs are great, use of the method may not be practical for extremely large caves, but the method should be useful for displaying small and intermediate portions of large cave systems.

size caves as well as the more interesting

ACKNOWLEDGEMENTS

The author wishes to thank Professor George F. Jenks of the Department of Geography at The University of Kansas for his many helpful suggestions during the construction and selection of illustrations for this paper.

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The Classification of Australian Cavernicoles With Particular Reference to Rhaphidophoridae (Orthoptera)

Aola M. Richards *

ABSTRACT

The most generally accepted classification of cavernicoles into three main categories—trogloxenes, troglophiles, and troglobites—is restated. A proposal by Hamilton-Smith (1971) to divide troglophiles into two groups based on knowledge of the Australian fauna is invalidated and shown to be based on insufficient data. The cavernicolous status of some species of Macropathinae (Rhaphidophoridae) is discussed, and, on the basis of their ecological and reproductive behavior, all species studied so far are classified as troglophiles. No trogloxenic Macropathinae are known.

Cavernicolous animals are usually classified into different categories depending on their degree of adaptation to the cave environment. Over the last 120 years various classifications have been proposed, but that of Schiner (1854) has been generally accepted by biospeleologists and ecologists. He divided cave animals into three main groups—troglobites, troglophiles, and occasional guests. Later the term "trogloxene" was proposed by Racovitza (1907) to replace the third group. Accepted definitions of these categories are as follows:

1. *Troglobites:* obligatory cavernicoles unable to exist outside the cave environment.
2. *Troglophiles:* facultative cavernicoles frequently completing their life cycle in caves but not confined to this habitat.
3. *Trogloxenes:* facultative or adventive cavernicoles spending only part of the life cycle in the cave habitat.

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This ecological classification has given rise to many difficulties because of lack of knowledge of the ecology and reproductive behavior of most cavernicoles. Nevertheless these terms are accepted by most biospeleologists. To them I would add a fourth category, "accidentals," as they are potential colonizers of the cave habitat.

In his latest classification of covernicoles, Hamilton-Smith (1971) separates cave animals into seven categories and splits troglophiles into two divisions—first level and second level—depending on whether or not they are known only from caves. This is based on a review of Australian cave fauna (Hamilton-Smith, 1967a) in which 33 species are listed first-level and 30 species as second-level troglophiles. Hamilton-Smith (1971) also repeats his objection (Hamilton-Smith, 1967a) to my use of the term troglophile (Richards, 1968a) to describe the status of cavernicolous members of the Rhaphidophoridae (Orthoptera). Unfortunately his proposed classification of troglophiles is based on insufficient information, and many of his assumptions are not valid for known data.

Classification of Troglophiles

Subterranean ecology has received little attention from biospeleologists, and the information available is considered to be fragmentary, often superficial, and often incorrect (Vandel, 1965). Close study has been restricted to a few caves in Europe, North America, Malaysia, Australia, and the Congo. As current knowledge on anything but the taxonomy of cave animals is very limited, at this stage the definitions of different categories of cave animals should preferably be kept as broad and as flexible as possible. This is particularly the case when discussing Southern Hemisphere species, for generalizations based on Northern Hemisphere fauna have erroneously been made to include the cave fauna of the world.

Hamilton-Smith (1967a) lists three Nullarbor carabid beetles—*Notospeophonus pallidus* Moore, *Thenarotes speluncarius* Moore, and *Speotarus lucifugus* Moore—as second-level troglophiles known only from caves, and in another paper (Hamilton-Smith, 1967b), he adds two further Nullarbor cave species to this second-level category—the pseudoscorpion, *Protochelifer cavernarum* Beier, and the cave-weta, *Pallidotettix nullarborensis* Richards. He considers these five species to be forms "which, although not troglobitic, appear to be confined to caves." He adds, "It seems likely these are all relicts of wetter surface conditions and were stranded in the caves as aridity increased . . . Perhaps the most hygrophilous of all these is the cave-weta."

My studies on the biology and ecology of Nullarbor cave arthropods (Richards, 1970 and in press a), the first such studies undertaken on Australian cavernicoles, show that the Nullarbor species wander throughout the cave systems. Of the 46 species from the Dark Zone biotope, 13 have been recorded over a distance extending from 1.6 to 0.8 km within the caves, to the Twilight Zone of the entrance talus slope, or to the cave doline. Amongst these 13 species are the five listed by Hamilton-Smith as second-level troglophiles. *Pallidotettix nullarborensis* has also been recorded from the surface of the plain.

A study of the microclimate of the Nullarbor caves and the epigean environment (Richards, in press a) has shown that while there is a very marked difference between the two regions in the daytime, so that many cavernicoles die on exposure to the epigean climate, at night similarity in climate enables certain cavernicoles to explore the entrance doline or even the surface of the plain. Food cannot be the main incentive for their behavior as there is a plentiful food supply inside the caves. While I regard *Pallidotettix* as more cave adapted than most of the Nullarbor cavernicoles, neither it nor the other species listed by Hamilton-Smith qualify as second-level troglophiles, but they all fit into the broader definition of a troglophile. Their behavior does not support his concept of a well established cave fauna.

Hamilton-Smith (1967a) considers that *Speotarus lucifugus*, as a second-level troglophile, "demonstrate(s) in a striking way the relictual distribution pattern which is not uncommon among cavernicoles." However this species is now known to occur in caves from Ashford in northern New South Wales to Jurien Bay in coastal Western Australia (Richards, in press a); so it is widely distributed across southern Australia. Its presence in 10 Nullarbor caves and in the dolines of two of these suggests that the species probably also occurs on the surface and that its distribution pattern is due to surface migration rather than relict distribution.

Thus Hamilton-Smith's classification of second-level troglophiles from Nullarbor caves is not valid, and as a result, doubt is cast on his classification of second-level troglophiles in the little known faunas of other regions. A detailed study of the fauna around cave entrances would not only establish relationships with certain members of the epigean fauna but would also reveal how large a proportion of the cave population emerges from caves at night and under what conditions these movements are triggered. It could clarify whether certain species have relict distributions. A wide and interesting field of research is open to biospeleologists studying the behavior of cavernicoles, which could lead eventually to a more meaningful classification.

Troglophilic Status of Rhaphidophoridae

The Rhaphidophoridae are a family of Gryllacridoidae which are secretive in their habits, seeking out dark, humid habitats. They occur in the bush under stones, logs, dead leaves, or loose bark; some may dig holes in the ground, others occupy used or disused burrows of vertebrates, and many may congregate in natural or man-made cavities such as caves, rock shelters, or tunnels. The absence of sound and their mottled brown coloration make them very inconspicuous.

Cavernicolous Rhaphidophoridae exhibit various modifications and adaptations to the cave environment. Their legs and antennae may be greatly elongated, the degree of pigmentation may vary, and the eyes may be reduced. Chopard (1929) has recorded an example of unusually wide variability in the size of the regressing eye in *Tachycines cuenoti* Chopard. So far only two troglobitic rhaphidophorids have been described, and both are anophthalmic. They belong to the genus *Diestrammena* Brunner. *D. caeca* Chopard is recorded from a cave in Assam (Chopard, 1924), and *D. cassani* Chopard from a cave in Laos (Chopard, 1954).

Following Barr's (1968) classification of Rhaphidophoridae as trogloxenes, Hamilton-Smith (1971) has again questioned my interpretation of the ecological status of the Southern Hemisphere Macropathinae (Rhaphidophoridae) as troglophiles. He says, "The treatment of the Rhaphidophoridae as troglophiles by Richards rests upon her distinctive and atypical interpretation of the category definition which appears to embrace forms usually considered as 'habitual trogloxenes.' It therefore seems confusing and inappropriate." Hubbell (1936), Jeannel (1943), and Vandel (1965) consider that, with the exception of the two troglobites, all cavernicolous Rhaphidophoridae are troglophiles. Nicholas (1964) classifies the North American cave cricket, *Hadenoecus subterraneus* Scudder, as a troglophile. Consequently they also give a "distinctive and atypical interpretation" of Rhaphidophoridae as troglophiles.

Hamilton-Smith has not made a detailed study of Rhaphidophoridae, and he has a very confused picture of their behavior. In a paper (1967a), he considers that the ecological categories for cavernicolous animals are not applicable for the Rhaphidophoridae because they have "a diurnal movement cycle," and he erroneously quotes me (Richards, 1965) as saying such a cycle occurs in *Novotettix naracoortensis* Richards. Yet in the same paper, he gives the species *Micropathus tasmaniensis* Richards as an example of a trogloxene because it "spend(s) the day within the cave, but emerge(s) at night to seek food;" and in another paper (Hamilton-Smith, 1967b), he regards *Pallidotettix nullarborensis* as a second-level troglophile "confined to caves" and "the most hygrophilous" member of this category.

Among the Macropathinae, cavernicolous and bush species usually occupy separate ecological niches and show no intergrades between a cavernicolous and epigean way of life. However in certain cases, cavernicolous species may migrate from one cave system to another, and individuals have been recorded some distance from cave areas (Richards, 1968b and in press b). There are only two known examples of cavernicolous species of Macropathinae that are also established in the epigean region. *Parvotettix goedei* Richards occurs in caves or mine adits in northern and northeastern Tasmania, and isolated specimens have recently been found in rain forest in southern Tasmania. *Cavernotettix flindersensis* (Chopard) has been found in a cave in the southeast of Flinders Island and also in and around a hut situated in bush in the centre of the island (Richards, in press b). In New Zealand, *Gymnoplectron edwardsii* (Scudder) occurs in caves and tunnels on the North and South Islands and has also been recorded in large numbers in animal burrows on off-shore islands in Cook Strait (Richards, 1954). The burrows may substitute for the cave niche in this species, and this is probably not a valid epigean habitat.

The definition of a troglophile supposes that, while the animal is not confined to the cave environment, the life cycle is usually completed in the cave. The whole life cycle of *Pallidoplectron turneri* Richards and *Gymnoplectron waitomoensis* (Richards) has been conclusively shown to be completed in the Waitomo Caves, New Zealand (Richards 1961). The eggs are laid in the mud on the walls and floor of the caves, and all nymphal instars and adult insects spend the greater part of their life in the cave environment. These species do not have a diurnal rhythm as suggested by Hamilton-Smith, but they exhibit a bimodal activity rhythm initiated by rapidly changing light intensity at dusk and dawn and at these times move towards cave entrances (Richards, 1965 and 1966). Under suitable conditions, some may emerge a short distance into the epigean region where they have been observed sitting on the surrounding vegetation (Richards, 1962). As a plentiful food supply is available in most caves where they occur, feeding need not be the primary or only factor which stimulates them to leave caves, and it appears to be of secondary importance. Under suitable conditions, 20 to 30% of the total population may emerge and, after a period of 2 to 3 hours, return inside the cave. The presence of this rhythm does not automatically classify these insects as trogloxenes as suggested by Barr (1968) and Hamilton-Smith (1971). Barr does admit the presence of circadian rhythms in troglophiles, and the completion of the life cycle within the cave shows that the two New Zealand species conform with the definition of a troglophile.

The biology of two Tasmanian species, *Micropathus cavernicola* Richards and *M. tasmaniensis*, has also been described (Richards, 1968c). It is very similar to that of the New Zealand species, and both Tasmanian species have been classified as troglophiles (Richards, 1968a). Hamilton-Smith (1967a) claims that *M. tasmaniensis* "is known to be a trogloxene," but he gives no reference or evidence in support of this statement. The only other papers on this species are by Richards (1964, 1968b, and in press b) and Goede (1967), and neither author refers to its ecological status. *M. tasmaniensis* must be regarded as a troglophile and not as a trogloxene.

More recently, the biology of *Pallidotettix nullarborensis* has been described (Richards, 1970). While the seasonal cycle is different from other Macropathinae studied, the life cycle is also completed in caves. At night, the insects emerge from caves when the relative humidity is over 90% in the epigean region or when it exceeds that in the caves. Analysis of the crop content of specimens from nine Nullarbor caves shows that this species is primarily carnivorous and that arthropods are its main food source. Of 33 crops examined, angiosperm tissues were found in three, and they could have been obtained by feeding on the decaying vegetation washed into most of these caves. In one specimen only was an anther and masses of pollen found. The behavior in this species argues against Hamilton-Smith's (1971) statement that "their relationship to the cave ecosystem is certainly that of a trogloxene, as their behavior would result in a considerable energy input to the system." It also invalidates Barr's (1968) contention that cave crickets "are ecologically the most important trogloxenes" in terms of energy input to the ecosystem. *Pallidotettix* is undoubtedly a troglophile. Obviously there are a number of behavioral and environmental factors involved in the emergence of rhaphidophorids which require further study. Feeding is a secondary activity which may or may not occur.

Unfortunately, knowledge of the life cycle and behavior of species within the Rhaphidophoridae is still very limited, but a general pattern is beginning to emerge which supports the continuing use of the term troglophile. Until such time as it can confidently be refuted, it must remain as an acceptable description of a major ecological group within the family.

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Brandon, R. A. 1971. Correlation of seasonal abundance with feeding and reproductive activity in the grotto salamander (*Typhlotriton spelaeus*). American Midland Naturalist 86:93-100.

The author systematically collected post-metamorphic grotto salamanders for four years in a cave in Missouri. Peak abundance was in the spring and summer when rock walls were wettest and food organisms most abundant. Details of the reproductive cycle are given.

Culver, D. C. 1971. Analysis of simple cave communities. III. Control of abundance. American Midland Naturalist 85:173-187.

The author examines three amphipod and isopod species from caves in West Virginia. The amphipod population sizes are apparently controlled by spring flooding while the isopod populations are probably food-limited.

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In contrast to other cave animals, the metabolic rate of cave *Gammarus* and *Stygonectes* (Amphipoda) was not reduced compared to surface populations.

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The authors describe two new amphipods from thermal springs in Cuatro Ciënegas. Although caves in the area have been checked carefully, no amphipods of this genus were found. The genus is related to Mediterranean forms and probably dates from considerable antiquity.

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Peck, S. B. 1970. The terrestrial arthropod fauna of Florida caves. Florida Entomologist 53:203-207.

The author lists all records of arthropod species known to have permanent populations in Florida caves. There is also a brief discussion of the biology of the species.

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The author gives species descriptions and a key to the Conotylidae, which contains many troglophilic and one troglobitic species (*Plumatyla humerosa*). He also discusses the relationship between the Pleistocene glaciation and the occurrence of Conotylidae in caves and high altitude forests.

Proceedings of the Society

MEETING IN BLACKSBURG, VIRGINIA, JUNE 1971

GEOLOGY SESSION

KARST RECONNAISSANCE IN THE HIMALAYAS

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From August to December, 1970, a British Expedition studied the karst and caving potential of two areas in the Himalayas. In the Sind Valley, Kashmir, the Carboniferous-Triassic limestone was found to be shaly and dolomitic, but no sign of caves was found. The religious 'Amarnath Cave' was found to be a large frost pocket. However, some karst development has taken place in this region, and five large (50 ft^3/sec) springs in the Vale of Kashmir were studied.

In central Nepal, near Tukche, the 15,000-ft-thick Cambrian-Silurian limestones crop out in a wide band dipping north-northeast. Exposures extend vertically from the valley at 9,000 ft elevation to the summit of Annapurna at 26,545 ft. The area was investigated for karst development and caves, but no caves and little karst was found. Two caves in the foothills of southern Nepal were visited. One near Kusma was a 600-ft-long resurgence cave formed in conglomerate and containing some good dripstone formations and rimstone pools. The other cave, near Pokhara, was 4,500 feet long and was also developed in conglomerate and very young limestones. This cave carried the entire flow of the Harpan River, with a discharge of about 100 ft^3/sec.

CHARACTERISTICS OF CAVERN DEVELOPMENT IN THE DOLOMITE-LIMESTONE SEQUENCE OF NEW JERSEY

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Caves of various sizes and shapes exist in the "Kittatinny Limestone"; however, until the recent subdivision of this thick carbonate section, the formation or formational members in which the caves occurred was not known. A compilation of the cavern data and recognition of the formation or formational member in which the caves occur has resulted in interesting conclusions and provides clues for future cave findings.

Recent mapping in northern New Jersey, detailed core logging in conjunction with an examination of the open rock trench at the Spruce Run Reservoir site, examination of the Round Valley Reservoir pipe-line trench, and preparation of the New Jersey Cave Bulletin forms the basis for the results obtained in this study.

The relationship of cavern development with the stratigraphy and lithology of the "Kittatinny Limestone" is compared with that found in other carbonate formations in New Jersey. The results show that the coarser grained dolomitic units are more susceptible to solution, consequently there is a greater chance of finding caves in those formations that contain coarse-grained units. The dolomite cave study results are compared to the limestone caves found in the Ordovician-Silurian-Devonian formations and in the Precambrian Franklin Marble. Studies of limestone cave development in other areas indicate that finer grained limestones are the better cavern developers, which is in contrast to what is found in the dolomitic sequence of New Jersey.

TOPOGRAPHIC AND STRUCTURAL CONTROL OF CAVE-PASSAGE ORIENTATION IN GENTLY FOLDED LIMESTONES: APPALACHIAN PLATEAUS PROVINCE, WEST VIRGINIA

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Several hundred caves in northern Pocahontas, Randolph, and Tucker counties, West Virginia, have been explored and mapped in the past few years. All of these caves are in Mississippian limestones of the Greenbrier Series that generally crop out in bands 150 to 500 ft thick along the flanks of ridges in the Appalachian Plateaus physiographic province, near its border with the Valley and Ridge province. The tops of the ridges are commonly 2000 to 2500 ft above local drainage levels. The dip of the limestones is 10° or less, and the strike is generally parallel to the major axes of the ridges.

The relationship between local geologic structure and surface topography has resulted in the development of several major types of caves. Cave types can be described in terms of the direction of strike and dip of limestone, the relationships between these directions and the trends of major ridges and valleys, and the influence that these factors have on the orientation of cave passages. Forecasts can also be made of the types of as-yet undiscovered caves that can be expected to be found in the area.

GLOBULARITE CRYSTALLIZATION IN THORN MOUNTAIN CAVE, WEST VIRGINIA

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An apparently new globularite speleothem type is forming in Thorn Mountain Cave, West Virginia. Spherical aggregates of radiating, micro-faceted calcite fibers form on the termination faces of calcite crystals. This change of growth habit may have been influenced by (1) high insoluble residue content of the spherical aggregates relative to the basal crystal; (2) low Sr, low Ca, high Mg, or high Fe content of the aggregate relative to the crystal; (3) surface tension in a surrounding water droplet; and (4) entropy considerations.

GEOLOGICAL AND BIOLOGICAL RECONNAISSANCE OF NEW DISCOVERY, MAMMOTH CAVE NATIONAL PARK, KENTUCKY

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New Discovery is an isolated segment of Mammoth Cave that occurs under the southern spur of Mammoth Cave Ridge known as Jim Lee Ridge. It is, for most practical purposes, a separate cave. The connection with the rest of Mammoth is through small passages near the base level. The objective of the present study is to provide background reconnaissance geology and biology of the cave. The cave was surveyed using tripod and computer data reduction techniques to provide accurate horizontal and vertical control.

The New Discovery main trunk is Big Avenue, a passage of comparable size to the largest trunks in Flint Ridge or Mammoth Cave, which extends more than a mile into a complex of passages near Green River. The main portions of the trunk are completely dry, but the downstream terminus is in the floodwater zone. The upstream tributaries of Big Avenue are apparently extensions of known passages of Mammoth Cave. The Rimstone Dam Passage appears to be the continuation of Cleaveland Avenue beyond the Carmichael Entrance collapse sink. The New Discovery entrance passage, Fossil Avenue, is apparently related to the Fairy Grotto passage in the historic section of Mammoth Cave.

Sedimentation processes have been complex. At the mouth of Fossil Avenue is a bar of sandstone pebbles and cobbles. Coarse clastic debris is strewn over the breakdown blocks farther down Big Avenue, and small remnants of the cobble armor from a stream channel remain some feet up on the wall of the passage. Apparently a major high-velocity stream used Big Avenue for a period in its early history. High-lying sediments in the side loops of Big Avenue contain a thick red silt sediment. Large selenite crystals occur at depth in this material, the first such found in the cave systems. Gypsum flowers occur profusely but locally.

ORIGIN OF THE PSEUDOKARST IN THE SCHAWANGUNK MOUNTAINS, SOUTHEASTERN NEW YORK

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Massively bedded Schawangunk Quartzite overlies the relatively incompetent Hudson River Shales in southeastern New York State. Slippage of quartzite blocks on the shales has caused widening of joints, in some cases as much as 30 ft. Rock collapse has led to the development of a pseudokarst, and features analogous to most of the limestone karst forms have been found. There is also a well-developed integrated subterranean drainage.

Evidence indicates that slippage of the quartzite was caused, or at least accelerated, by overriding by ice during the Pleistocene. The direction of ice movement, as indicated by glacial striae, is proper to have caused much of the joint widening now seen.

INFLUENCE OF SHALE IN THE DEVELOPMENT OF WILDCAT CAVE, ORANGE COUNTY, INDIANA

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Wildcat Cave has developed in limestones and silty shales of the lower West Baden and upper Blue River Groups of Mississippian age. In this vicinity these units generally dip to the west-southwest at 25 to 30 ft/mile. The cave has three major levels. The upper two have formed upon and incised into shale units, and the bottom one has formed along high-angle joints in limestone. Most present-day drainage, including that of the bottom level, is toward Riverside Cave, downdip to the southwest. However, the upper two levels have formed by drainage in a northward direction. Several possible reasons for this drainage reversal are in evidence:

1. Paleotopography: the existence of a channel in the top of the shale in the uppermost level. This channel, formed during Mississippian time and subsequently filled by the overlying limestone, appears to have concentrated and directed groundwater flow in the relatively recent past.

2. Varying thicknesses of the lithologic units. Despite its solubility, shale in the middle level lacks distinct joints, thus arresting downward movement of groundwater, causing it to flow in the direction of thinning of the shale. The active role of shale in cave formation is, therefore, stressed.

SOME EFFECTS OF THRUST PLANES ON CAVERN DEVELOPMENT

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Faults are known from several caves in the Virginias, but as a significant factor in cavern development little attention has been devoted specifically to faults and thrust planes. Observations in many of the caves of the Great Savannah and the surrounding area in Greenbrier County, West Virginia, indicate that thrust planes are common and that they have affected the processes of cavern development in several ways.

Most common are effects related to the weakness introduced into the limestone by these fracture planes, and such effects can be noticed in passage cross sections, the abundance of breakdown, and abrupt changes in passage character.

In contrast to these manifestations of weakness, an effect based on strength sometimes results from the shear structures generated at the thrust plane. In some cases, polished slickensides are sufficiently resistant to ground water action that they give rise to such perching effects as passages and anastamoses developed upon these surfaces.

Apparently some of the larger thrust planes are associated with folds in the limestone. Drag folding is not uncommon, and room development tends to occur where these folds encounter the fault planes.

THE KARST MORPHOLOGY OF THE MILLIGAN CREEK BASIN, GREENBRIER COUNTY, WEST VIRGINIA

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Milligan Creek is an interrupted surface stream which drains a 6-mile long, 22-square mile, blind valley in central Greenbrier County, West Virginia. The creek is fed by several springs at the northern end of the valley and by discharge from limestone solution conduits within the basin. The conduits have captured the former surface tributaries. The stream flows south, sinking and rising at several points within an entrenched channel, and then makes a final submergence forming the southern end of a blind valley. It then continues in the subsurface for 3 miles and resurges into the Greenbrier River at Fort Spring.

Morphologic and hydrologic features characteristic of the basin include:

(1) Well defined tributary channels which support only ephermeral surface flow.
(2) Alternating surface and subsurface stream segments of Milligan Creek.
(3) Changes in the locations of "sinks" and "risings" with changes in the water stage of Milligan Creek.
(4) Low solution conduits in the form of cave segments rather than integrated cave "systems."

(5) Low hydraulic gradients.
(6) Water levels within the solution conduits which are generally near the surface.

The disintegration of the surface drainage is almost complete, but extensive development of the subsurface conduits has not yet progressed to the point where they can capture all levels of discharge within the valley. Therefore, the karst morphology of the Milligan Creek basin is interpreted as representing a transitional stage of development between youth and maturity.

CANDOLUMINESCENCE OF CAVE GYPSUM

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Candoluminescence is the process of luminescence activated by flames. Some dozen specimens of gypsum from widely varying cave localities have been shown to luminesce in the green when stimulated with a hydrogen diffusion flame. The color is the same for all specimens, but the intensity varies. Maximum intensity of emission is reached at temperatures of a few hundred degrees centigrade; gypsum bedrock also fluoresces. The characteristic temperature varies somewhat from specimen to specimen. Brightest emission of the cave specimens is from gypsum crusts and flowers; the weakest emission is from clear selenite crystals.

ALPINE KARST IN THE MT. CASTLEGUARD-COLUMBIA ICEFIELD AREA, CANADIAN ROCKY MOUNTAINS

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Mt. Castleguard and an adjacent valley, Castleguard Meadows, are situated at the southeastern margin of the Columbia Icefield. The mountain and meadows are underlain by massive Middle Cambrian limestones with some shales and dolomite interbeds. The rocks dip gently southeast. They are well karstified, and a close juxtaposition of karst, glacial, and periglacial erosion processes can be observed. Above 2300 m, karst features occur on surfaces recently abandoned by Neoglacial ice, and much meltwater evidently sinks underground beneath the extant glaciers. Outside of Neoglacial margins, limestone surfaces are reduced to felsenmeer devoid of karst features. In tundra below 2300 m, shaft-type sinkholes and many varieties of karren occur. Sinkholes are aligned along shale contacts, and the distal edges of terminal moraines are randomly distributed elsewhere.

Underground drainage developed in two phases. (1) Castleguard Cave drained part of the central icefield area downdip to springs at 2000 m. The cave is a single river passage, longer than 10 km, passing beneath Mt. Castleguard. It has vadose and phreatic erosional elements and is attributed to the last interglacial. (2) In Late- or Post-Glacial Times, Castleguard Cave was abandoned, and a new conduit developed beneath it that discharges at the "Big Springs" at 1740 m. Drainage of the northern Meadows and Mt. Castleguard is incorporated into this second system. Discharge of the Big Springs is comparable in magnitude to that of the meltriver of Saskatchewan Glacier, the largest valley glacier draining the icefield. The area illustrates that karst groundwater circulation may be maintained and even initiated at the soles of temperate glaciers.

APPLICATION OF STABLE CARBON ISOTOPE STUDIES TO THE INVESTIGATION OF KARST PROCESSES

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Earlier classic works established the geological relationships and distribution of the stable carbon isotopes in nature and opened a new avenue of investigation for karst researchers. In nature the stable isotopes of carbon, ^{12}C and ^{13}C, have absolute abundances of 98.9% and 1.1% respectively. The distribution of these two isotopes is such that organic material is enriched in the lighter ^{12}C with respect to atmospheric carbon dioxide, while inorganic material is enriched in the heavier ^{13}C.

Basically, karst processes can be divided into two categories: solutional and depositional. Stable carbon isotope studies are applicable to the study of both types of processes. In the solution of carbonate rock (e.g., limestone), the resulting carbonate, in aqueous solution as bicarbonate (HCO_3^-), has both an organic-rich and inorganic-rich component as follows:

$$Ca^{13}CO_3 + H_20 + {}^{12}CO_2 \rightarrow Ca^{2+} + H^{12}CO_3^- + H^{13}CO_3^-.$$

Thus, by determining the ratio of the two stable carbon isotopes, $\delta\,^{13}C$, where

$$\delta\,^{13}C = \left(\frac{^{13}C/^{12}C \text{ sample}}{^{13}C/^{12}C \text{ standard}} - 1\right) \times 1000,$$

karst waters in a given area can be tested for absolute amount and rate of carbonate solution. Additional sampling within specific carbonate rock units would allow an investigator to determine these two parameters for the individual rock units. The deposition of carbonate minerals from solution is the reverse of the solution process and, as a result, the precipitated carbonate has only an inorganic-rich component as follows:

$$Ca^{2+} + H^{12}CO_3^- + H^{13}CO_3 \rightarrow Ca^{13}CO_3 \downarrow + H_20 + {}^{12}CO_2 \uparrow.$$

Isotope studies of such precipitated carbonate can be used to determine the climate during deposition and, in some cases, the source of the carbonate. Thus, stable carbon isotopes can be used to study such diverse items as karst denudation rates or paleoclimates and can, therefore, be a valuable tool in any investigation of past or present karst processes.

CAVE CONDUITS AS COMPONENTS OF SURFACE STREAM CHANNELS: MEANDER BEND CUT-OFFS

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Evidence has been found that underground flow occurs across meander beds of major surface streams incised into limestone uplands. These are recognized by topographic location and by the temperature and chemistry of waters emerging from the springs on the downstream side of the meander. Caves formed by this process may bear no relationship to the local underground drainage system. Examples occur in Central Pennsylvania and in South Central Kentucky. The contrasting feature to the meander-bend cutoff, the underground oxbow, is also considered. The driving force for the formation of these features is provided by the gradient of the associated surface stream. The results illustrate again the hydraulic continuity between surface and underground stream channels.

MINIMUM DIAMETER OF STALACTITES AND STALAGMITES

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The existence of a smallest observed diameter for stalactites and stalagmites is a constraint on the morphology of these speleothems. The smallest stalagmite has previously been shown to be limited by several factors including the relaxation time for the deposition of calcite from solution. Now the smallest possible stalactite is shown to be limited by a value of the dimensionless number $\rho g r^2/\sigma$ (where ρ is liquid density; g is the acceleration of gravity; r is the stalactite radius; and σ is the surface tension of the liquid) equal to 0.874. Thus, for stalactites formed from water on the earth's surface at 10°C, the smallest will have a diameter of about 2.6 mm.

GEOLOGICAL RECONNAISSANCE OF TIMPANOGOS CAVE, UTAH

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Timpanogos Cave is the central feature of Timpanogos Cave National Monument. The cave is located at an elevation of 6700 ft on the wall of American Fork Canyon in the Wasatch Mountains of Utah. Surface karst and underground features were studied during late June, 1970. The cave was mapped and a general geological and biological reconnaissance performed.

The cave is in the Mississippian Deseret Limestone, a limestone sandwiched between mainly dolomite carbonates. The structural setting is exceedingly complex. American Fork Canyon lies close to the intersection of the main Wasatch fault system and the perpendicular Uinta fault and fold system. Rocks at the cave dip about 20° but are block-faulted on a small scale. The cave passages apparently formed along faults, and some open fractures and fractured flowstone indicate that some of these are still in motion.

The cave consists mainly of high narrow passages in a minor network arrangement. None of the usual indicators of high-velocity flow are present. The walls are intricately sculptured. Wall and ceiling pockets are common. Clastic sediments are uncommon and where exposed are composed of sand and yellow silt.

The cave contains a spectacular carbonate mineralization. The usual dripstone deposits here give way to complex helictites and other erratic forms. Aragonite is common in all areas as needles and anthoditic forms. Moonmilk occurs sparsely as tufts of material on the tips of dripstone deposits. Samples analyzed so far are composed of hydromagnesite—a surprise, for at this altitude and climate calcite moonmilk would be expected. Many of the dripstone deposits are colored. A deep yellow is common and a blue-green occurs. The yellow dripstone is calcite containing nickel at the 500 ppm level, while the green is aragonite containing nickel at about the same concentration.

The fauna of the cave are extremely sparse. Other than a few bats, no animals were seen. The pools in the cave appear to be barren of aquatic animals.

The landforms of the Wasatch Mountains provide interesting examples of alpine karst. At high altitudes on Mount Timpanogos, rinnenkarren and pinnacle karren are forming under snow melt conditions on the Bridal Veil Falls Limestone. The Deseret Limestone supports a pinnacle karst with a relief of tens of feet along the canyon walls. There is some evidence that this more extreme relief karst is a relic from Pleistocene climatic conditions and that it is being destroyed by present-day weathering conditions.

GEOGRAPHY/EXPLORATION SESSION

CAVES OF OKINAWA

Douglas W. Rhodes
Washington, D. C.
Edward Arters
Milwaukee, Wisconsin

A slide description of the caves on the island is presented with narration concerning the history, concentration of caves, and fauna.

CANADIAN CAVING

Derek C. Ford
Hamilton, Ontario

A spectacular slide description is presented which tells the story of the caves, cavers, and caving in general throughout Canada.

GILLEY CAVE, LEE COUNTY, VIRGINIA

Roger Baroody
Charlottesville, Virginia

Located in Pennington Gap, Virginia, Gilley Cave has been well known since 1870. In 1962 the University of Virginia Grotto explored and surveyed the cave. Five years of work have yielded 4 miles of passage, mystery in hydrology, and confusion in geology. Gilley Cave, in the Copper Ridge Dolomite, lies within an overturned anticline divided by three major active faults. In the past few years the activity of these faults has caused one large section of wall to separate and expose a stream channel. During the same period, another passage became 300 ft longer, mostly through breakdown, and one area of the cave has been closed due to a collapse. Two drainage systems have been observed within the cave. One system drains the upper levels and discharges into the North Fork of the Powell River three-fourths of a mile distant. The lower level drainage has been traced to Echo Lake, 450 ft below the entrance and 90 ft below the North Fork of the Powell River. Although the stream feeding Echo Lake often floods, the lake itself changes very little in depth, with a maximum change of 3 inches noted during exploration. A few of the features displayed in the cave are faults with up to 13 inches of slippage, a complex of folds with passages lying along their axes, and a peculiar hoop-like formation whose origin is still unknown.

ANDROS BLUE HOLES

George J. Benjamin

Andros Island is the largest island in the Bahamas. The whole area consists of the tops of a large mass of limestone which has been traced down to 27,000 ft. This area is subsiding. The loss is replaced by sedimentation and coral growth at an equal rate. During the Ice Age, the ocean level was several hundred feet lower than now. During this low water period caves were formed in a manner well known in cave science. After the ice melted, the rising waters flooded the caves, which are now known as the Blue Holes. Most of them are located on the east shore of Andros.

A systematic search from the air pinpointed the locations of many possible caves, and by now 54 openings have been entered. Submarine springs have been known since ancient times, but the Blue Holes differ with their strong reversing currents. The water is believed to flow inland in the form of underground rivers and is distributed in porous rock beneath the freshwater lens. Inland sinkholes were explored to a depth of 200 ft. The top is usually clear, fresh water; underneath there is salt water. The interzone is sometimes less than 1 ft.

For years, stalagmites have been searched for. In 1970 the dramatic discovery of a grotto was made with hundreds of stalactites and stalagmites at an underwater depth of 140 to 180 ft and at a distance of 1,000 ft from the surface. White crystalline cores were found and analysed, which is the first such recorded case. Diving in the Blue Holes since 1960 has led to the development of special equipment and specialized methods. The dives may be considered difficult and dangerous and have no margin of error.

MAJOR NEW CAVE DISCOVERY NEAR MAXWELTON, GREENBRIER COUNTY, WEST VIRGINIA

J. C. Hempel
Bethel Park, Pa.

On December 6, 1970, a major new cave was discovered in the extensive limestone country of Greenbrier County, West Virginia. The first entry revealed little except that the cave was big. Two mapping parties entered the cave the following Saturday, December 12, and surveyed a total of 13,000 ft of passage—quite a distance to cover, not to mention to map, in one day. The discovery was the result of sporadic digging and blasting attempts by various groups over a 2-year period. The cave is developed along the contact of the Greenbrier Limestone Series and the MacCrady Shale. Similar contact caves have developed some of the most extensive drainage patterns in West Virginia.

THE CURRENT STATUS OF "THE HOLE," GREENBRIER COUNTY, WEST VIRGINIA

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The Hole was the first major system discovered and explored by WVACS in their Great Savannah Project. The cave was discovered in 1960 east of Frankford in the northeastern corner of the Great Savannah, a heavily karsted outcrop of Mississippian limestone near Lewisburg in Greenbrier County, West Virginia. Since that time, exploration and mapping have been conducted intermittently, and they are continuing today. As of March, 1971, The Hole had three known entrances and 16.4 miles of surveyed passage. The passages are developed mainly in the Hillsdale Limestone (Greenbrier Formation), although parts probably reach upward into the Sinks Grove Limestone. Significant portions of the cave are also found in beds of reworked MacCrady material along the unconformable contact between the Hillsdale and the underlying MacCrady Shale. Passages in the reworked MacCrady gravels are predominantly vadose and carry drainage from the surface contact down dip (N60°W) to the originally phreatic passages in the Hillsdale. These then carry the streams northward along the strike (N30°E) for ultimate delivery to Spring Creek. Dye traces have been conducted from the southern regions of the cave to Shale River in the northern section and thence to two resurgences of Spring Creek about 0.4 miles apart. Biological collecting has revealed mites, collembola, spiders, bristletails, amphipods, isopods, planaria, beetles, crickets, pseudoscorpions, and a variety of salamanders. Fish have been observed, while crayfish are notably lacking. Abundant fossils are present which are frequently silicified and sometimes transformed into banded agates, especially Lithostration.

THE SLOAN'S VALLEY CAVE SYSTEM, KENTUCKY

Louis Simpson
Circleville, Ohio

The Central Ohio Grotto, following through with the considerable efforts of David P. Beiter, is currently surveying Sloan's Valley Cave System, Pulaski County, Kentucky. Previous surveys were begun by the USGS and Albert Geiser, the latter having mapped more than 15 miles, but as yet no adequately detailed map of the system has been published or made available for study. Total passage length may exceed 20 miles, since the current map already contains more than that of Geiser. Silva compasses, Abney levels, and plastic tapes made from TV lead-in wire are used for surveying. Use of real-time plotted sketching has improved detail.

While multiplicity of entrances (11) facilitates access, problems have been flash flooding and seasonal inundation of about 5 miles of the cave by man-made Lake Cumberland. Parts of the cave have been siphoned by this lake since the dam's construction. Although several entrances are located in a national forest, recent surface vandalism and heavy traffic at privately-owned entrances has resulted in some unfortunate closings.

Sloan's Valley Cave drains a well-known karst valley and exists primarily along the edge of the surrounding hills. One underground river apparently flows up one side of a surface valley and down the other. The survey has stimulated activity and interest in speleology. Rick Day has prepared a program for the NSS Slide Series. New sections of the system are still being found. Qualified analysis of the cave's hydrology and genesis needs to be done.

TWO TYPES OF GLACIER CAVES

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The term glacier cave refers to a cave within or at the base of a glacier. The term 'ice cave', which is sometimes used for such caves, refers to a subterranean cave in which ice forms and persists for some time. Glacier caves may be divided into two types: ablation and obstruction; these two types of glacier caves show differences in their mode of formation, size, position in the glacier, and speleothems.

A NEW EXPLANATION OF LIMESTONE CAVERN GENESIS

Derek C. Ford
McMaster University
Hamilton, Ontario

Principal theories of limestone cavern genesis have contended that the locus of major cave development is a) above a defined watertable; b) at random depth below; or c) along it.

Observations of some 500 caverns in intermediate to massively-bedded limestones in Europe and North America result in the following contentions:

1. There are three common cases of limestone cavern development: the predominantly vadose cave, the deep-phreatic cave, and the watertable-type cave. There is one special case: the true artesian cave.

2. The type or types of common cave that will develop in a system are governed by the frequency of fissures significantly penetrated by groundwater and the geometric proportionality, (bedding plane: joint/ fault ratio) of the fissure network. The higher the fissure frequency, the more likely it is that watertable-type caves will develop rather than the deep-phreatic type.

3. In a given limestone mass, fissure frequency and proportionality may vary from place to place, will normally increase with passage of time after onset of karstification, and may differ radically from region to region.

4. Predominantly vadose caves of large size can develop wherever sufficient streams collect above sink points and where there is sufficient relief above the spring positions. Deep-phreatic caves attain their optimum development in steeply dipping rocks because bedding planes may guide water to great depths. Water table caves are more probable in flat-lying rocks because deep penetration is inhibited by the presence of shallow bedding planes that are continuous to spring positions. Lithologic perching of conduits is most effective in flat-lying rocks.

5. Before any caves have begun to develop, the watertable is at the surface in most limestone regions. Where it is at depth in the rock before cave development occurs, fissure frequency is so high that the watertable-type cave will develop rather than the deep phreatic type.

6. Where the ratio of penetrable bedding plane : joint length is large, the fundamental building blocks of cave systems are linear anastomotic bands in gently dipping rocks and dip tubes in steeply dipping rocks, linked by short ascents or descents in joints. Strike-oriented passages may develop subsequently. Caves that are guided predominantly by joints are associated with high values of fissure frequency.

7. Different climates do not appear to create fundamentally different types of caverns. The paper is illustrated with empirical case studies and some random-walk models.

AIR TRACING IN THE GARRISON CHAPEL RIDGE, INDIANA

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Indiana University
Bloomington, Indiana

Two air-tracing experiments have been conducted in the Garrison Chapel Ridge within the past three years. The first test, headed by R. Sperka in 1968, outlined the extent of the 14,000-ft King Blair System, which was later discovered and mapped. The second test, by D. Des Marais in 1971, suggests conditions present beyond the accessible reaches of Queen Blair Cave.

The method is discussed, and data from these experiments are presented. Not only positive (and negative) tracing connections, but also the relative flow times of positive connections, appear to lend value to this technique.

CAVING/CLIMBING ROPES AND ROPE TESTING

Dave Mischke and Bob Vocke
Mountain Safety Research, Inc., Seattle, Washington

A compilation of rope testing results and techniques is presented.

SPELEAN HISTORY SESSION

THE EVOLUTION OF "JIM WHITE'S OWN STORY"

Dr. William R. Halliday
Seattle, Washington

Following the collapse of his New York Times expedition to Carlsbad Caverns, the controversial Frank Ernest Nicholson wrote "Jim White's Own Story; the Discovery and History of Carlsbad Caverns". The first edition cover contained an inset picture of "Twin Domes and Giant Stalagmites in Big Room"; in the second edition this was replaced by "Rock of Ages, Carlsbad Caverns". In the 1940's, a third edition appeared; the front cover no longer bore the motto "As told to Frank Ernest Nicholson" and several of the illustrations were colored. Major changes insisted upon by the National Park Service marked the fourth edition, with the title changed to "Jim White's Story of Carlsbad Caverns". A still later version, which may be described either as a Fifth Edition or a second printing of the Fourth Edition, includes on page 3 the text of the Jim White plaque in the Visitor Center at the cavern.

Ernst H. Kastning

BALL'S CAVE, NEW YORK: ONE HUNDRED FORTY YEARS OF EXPLORATION

Pound Ridge, New York

Situated in the wooded hills near Schoharie, New York, Ball's Cave has had numerous visitors for nearly a century and a half. Many of these visitors have left accounts of their observations and impressions. Some have been inspired to write exaggerated, although moving, accounts of their exploits. Ball's Cave has been mentioned over and over again in gazeteers, Victorian "wonder" books, and countless writings of 20th Century cave explorers. It has been described in at least one novel and was almost developed commercially in the mid-19th century. Bibliographic research has yielded dozens of references, and the preliminary history presented here forms the basis for continuing studies.

PENNSYLVANIA'S ONLY SALTPETRE CAVE: A BACKGROUND STUDY

Peter M. Hauer
Lebanon, Pennsylvania

Saltpetre Cave, Bedford County, Pennsylvania, is a small sandstone fissure which was mined for saltpetre dirt during the 18th Century. One of the very few natural sources of the material in the state, Saltpetre Cave illustrates the needs and remoteness of the western

counties in the state which became the leading gunpowder producer during the American Revolution.

NAMES OF CAVES AND CAVE FEATURES ON FLINT RIDGE, MAMMOTH CAVE NATIONAL PARK, KENTUCKY

Dr. John F. Bridge
Columbus, Ohio

No abstract submitted.

THE AMERICAN ANTIQUARIAN SOCIETY'S VERSION OF THE HISTORY OF FAWN HOOF

Dr. William R. Halliday
Seattle, Washington

Recent inquiry through the American Antiquarian Society revealed the existence of a diary published in 1909 that confirms that Charles Wilkins had intended "Fawn Hoof", the famous Mammoth Cave mummy, for that institution, but Nahum Ward "appropriated it for himself, and exhibited it in all the large cities of the country". That Society took determined action and obtained the mummy in the Spring of 1817. A footnote gives details of the subsequent history of the mummy through its transfer to the Smithsonian Institution.

EARLY EXPLORATIONS OF MAMMOTH CAVE, KENTUCKY

Harold Meloy
Shelbyville, Indiana

An outline summary of the discoveries and explorations of the passages in Mammoth Cave during the first half of the 19th century, given in chronological order. From these discoveries and the literature reporting them, the cave—which began as just another unnamed hole in the ground—became by mid-19th century the largest and the most celebrated cave in the world.

THE EVOLUTION OF THE MAMMOTH CAVE POSTCARD

Ernst H. Kastning
Pound Ridge, New York

Postal viewcards, which first gained popularity in the 1890's, have provided travelers with a media with which to send greetings to friends and relatives back home. The Mammoth Cave in Kentucky has been the most popular cave visited by the public and the wide range of postcards published during the 1900's has proven this to be so. The history of Mammoth Cave postcards is traced from the Ben Hains—Henry Ganter cards of the turn of the century to the modern chrome cards.

Information for Contributors To The Bulletin

Papers in any discipline of speleology or any cave-related topic are considered for publication in the BULLETIN. Papers may be a technical article on some cave-oriented geological or biological research, a review paper on a speleological topic, or a speculative discussion of theory. We particularly welcome descriptive or geographical articles about significant caves or cave areas, especially if comments on speleogenesis, biological surveys, historical significance, etc. are included. Articles on other topics such as cave conservation, history, etc. are also invited.

Articles in the biological sciences should be sent to the Biology Editor, David C. Culver, Dept. of Biological Sciences, Northwestern University, Evanston, Illinois 60201. Articles in the line of geology or geography should be sent to the Earth Sciences Editor, William B. White, Materials Research Laboratory, the Pennsylvania State Univ., University Park, Pa. 16802. Articles not falling in either of these categories may be sent to the Managing Editor, David Irving, 102 Olean Road, Oak Ridge, Tennessee 37830.

At least one copy of the manuscript, typed and doublespaced, should be submitted to the appropriate Editor. The upper limit for length is about 10,000 words or approximately 40 pages of manuscript. This limit may be waived where a paper has unusual merit. Photographs and line drawings should be submitted with the manuscript. Because of cost, only illustrations essential to the presentation should be included. Photographs must be sharp, with high contrast. All line drawings should be done with lettering instruments or other satisfactory means. Typed lettering is not ordinarily satisfactory. Captions will be set in type and added. All drawings must be inked, with India Ink or a satisfactory substitute. In case of doubt regarding length or illustrations, consult the Editor.

For general style, see papers in this BULLETIN. Abstracts, which should be brief and informative, are required for all papers. Captions are required for all illustrations, and all unusual symbols used should be explained. References to the literature should be by author and date, with specific pages where desirable. Literature cited should be listed in an end bibliography with entries alphabetically by author's last name. Consult bibliographies in this BULLETIN for general format.

Before publication, all papers will be reviewed by one or more authorities in the appropriate fields. After review, papers will be returned to the authors for approval and action if required.

Interested contributors, especially those who are not professional scientists or writers, are invited to consult with the editorial staff or the NSS Research Advisory Committee for guidance or aid in the presentation of their material.

Reprints may be ordered at the time galleys are returned by the authors to the Editor. These reprints will be furnished at cost.

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