On the Definition of a Cave*

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ABSTRACT—A cave is a space rather than an object and consequently its definition involves the specification of its boundaries. This can be done in various ways for different purposes, but all definitions must involve a minimum dimension, if only to separate "cave" from such contiguous spaces as intercrystalline pores. It is proposed therefore to specify a defining dimension or *module* for a cave and for its entrances. The association of a suitable shape with the module is necessary.

Caves defined by a module of human size and shape are termed *proper caves* as they are customarily given proper names when accessible. Proper entrances may be defined similarily although proper caves may or may not have proper (and natural) entrances.

Because this concept provides a uniform basis upon which other cave properties may be studied, it is useful in applications. In addition it suggests the possibility of reasonably clearly dividing caves into groups according to their module range.

INTRODUCTION

Why be concerned about the definition of a cave? A cave is a natural cavity beneath the earth's surface. Only a few authors have found it desirable to be more specific when they wished to describe a particular class of natural subterranean cavities. Although a detailed survey of definitions which have been given is not very enlightening, the nature of the concern which exists may be illustrated by the following selection: Bretz (1956), ". . . nor is it possible that everyone will ever agree on the definition of a cave. Is a rock shelter, broad along the hillside but shallow in penetration of the hill a cave? Is a natural bridge a cave? Is a hole that can barely be crawled into for only a few feet a cave? Is it a cave if a former cavity has become completely filled with mud and broken rock? . . . In terms of human experience, we generally think of a cave as being a natural roofed cavity in rock which may be penetrated for an appreciable distance by a human."; Cullingford (ed. 1953), ". . . Frequently restricted to those openings capable of entry by man."; Davies (1960), ". . . In the present discussion a cave is defined as mature integrated solution openings. Isolated primitive tubes and pockets are excluded from the term 'cave'."; Howard (1960), "An opening is any volume surrounded by solid rock, but not filled by solid rock . . . (it) may be filled with air, water, loose rock, mineral, clay or other debris. . . . A cave is any crevice or crevice system which fortuitously conforms to a number of poorly designated and meaningless restrictions pertaining to the size, length, availability and nature of the opening. Thus the use of this term will be limited to its occurrence as a proper noun."; Curl (1960), "Caves too narrow to traverse could be included in a cave population by imagining ourselves to be smaller than we are."; Woodward (1961), "Many caves can be entered and explored but this is not a technical requirement."

The author was led to a further consideration of this question by work on statistical relations among properties of caves in a cave population (1958, 1960). There, the concept

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of a "cave" had been assumed to correspond to some physical entity which could be measured in various ways. Although striking statistical regularities were demonstrated it could fairly have been asked, exactly *what* conformed to simple statistical laws? Our concepts had proved useful; we must now clarify the nature of the measures we do use.

The questions asked by Bretz will not be answered here. Indeed it will always remain that there are in principle as many definitions as there are uses for these definitions. But it is hoped that certain elementary features of the concept of "cave" will be made clearer, and the method by which this is accomplished may be of some utility elsewhere in speleology.

The Module of a Cave

A cave is not an object. It is a space. Consequently the specification of a cave involves the specification of the boundaries of a space. Whatever specification is made, the resulting space contains, or is bounded by, a complex structure of materials which are solid, liquid, gaseous, or mixtures. It is natural, and useful for most purposes, to refer the boundary specifications to these phase boundaries between the three states of matter. However a fundamental geometrical issue becomes involved if this is attempted.

Consider the gas- or liquid-filled portion of a subterranean cavity. This occurs in many shapes and sizes but of itself has *no lower limit on its dimensions*. That is, there is a continuous class of openings including what we might call passages, tubes, crevices, fissures, cracks, and on to microscopic pores. If all of these are not to be considered, described, and explained as "cave," an arbitrary *minimum dimension* must be introduced into the definition. It is proposed, then, to specify the boundaries of a cave in terms of this minimum dimension, and it will be called the *module* of a cave.

In practice a solid shape must be associated with the module. Then a cave of a particular module becomes the *subterranean volume which may be traversed continuously by the specified shape having that characteristic dimension*. One choice for this shape is the sphere, with its diameter equal to the module. However the choice is only one of convenience or purpose. The author has referred to this imaginary object as a *standard explorer* (1961) but it will be called hereafter simply an *explorer*. Other shapes which might be assigned to the explorer are the tetrahedra, or other polyhedra, forms with extensions which permit the inclusion of adjacent crevices within the cave boundary ("hands"), etc.

A cave defined by a given spherical explorer may be imagined as a space which is in contact with the real walls (phase boundaries) of the cave at only some points. A tetrahedral explorer, or other form, would permit a closer correspondence between the actual cave space and phase boundaries. However only in the limit of the module approaching zero may a cave defined in this way be coincident with the subterranean opening. On the other hand, as the module is made larger, any given subterranean opening might well be divided into a greater number of caves.

It is not proper here to settle whether cave fill, formations, water etc., are *in* or *bound* a cave. This must be specified depending upon the purpose of the definitions. The intention here is to point out the usefulness, indeed necessity, of associating a *minimum dimension* with practically *any* definition of a cave, its entrances, or other features which are not objects but extended spaces.

The exploration and description of caves by humans is an example of the application of the above cave boundary specifications, except that now the explorer is not particularly standard. Nevertheless, such caves are selected on the basis of a human module or, since all those which are enterable are given proper names, a *proper module*. Such caves will be called *proper caves* and recognized as a very limited selection of all subterranean cavities, selected on the basis of the dimensions of humans.

A cave of a given module is always completely enclosed by a cave of a smaller module, if both explorers have the same shape. If two caves of the same or different module intersect, but with the intersection too small to allow passage of the explorer between them, the intersection will be termed a cave *connection*.

Entrances and Proper Entrances

So far it has been assumed that the explorer is not able to escape from the subterranean cavity to the surface. That is, that the cave, so specified, has no entrances. Entrances are another form of boundary to the cave space. They are, of course, a structure common to both the surface and cave morphology. It should be apparent that the same problem of specifying the boundaries of a cave in respect to its enclosing rock—the need of introducing a minimum dimension, also applies to the specification of the entrance boundary. But in this case the definitions must contain an additional arbitrariness, as an entrance boundary cannot also be a phase boundary; only "inside" and "outside" are to be distinguished.

Since all definitions of caves which have ever been offered contain the notion of "rock overhead," this suggests itself as the most natural reference for an entrance boundary. Recently the Missouri Speleological Survey has shown a "drip line" at cave entrances in their published maps (Johnson, 1960). The associated imaginary "drip surface" down along which drops fall from the most outward point possible will be adopted here to define the *entrance surface,* as it divides the space with rock above from that with sky above. This definition could also be stated more exactly in terms of the direction of the gradient of the gravitational potential.

Now if an explorer approaches an entrance surface from within a cave and is able to pass completely out through the surface, the portion of the entrance surface through which the explorer may pass will be defined as a *cave entrance* with the same module as the cave. An intermediate situation where the explorer is able to intersect the entrance surface but not completely penetrate it, will be referred to as establishing a surface *connection.* Thus a surface connection is part of a cave entrance defined for a cave of smaller module. By analogy to the terminology applied to a cave, an entrance surface through which a person is able to pass will be called a *proper cave entrance.* A proper cave may consequently have neither surface connections nor entrances, connections but no entrances, either, or both. A non-proper cave cannot have proper entrances, but may have surface connections or "ordinary" entrances. Finally, a non-proper entrance may connect to a proper cave by way of non-proper passage.

All of these relations are shown in Figure 1 where a profile of a hypothetical cave is shown being tested with spherical explorers of different module. The examples are drawn in two dimensions but the extension to three dimensions should be made in the imagination. The upper opening is meant to be only a hole in the roof of a larger chamber.

The situations depicted are as follows: (A) Cave. Subscripts indicate separate caves; (B) Connection; (C) Entrance surface; (D) Surface connection; (E) Cave entrance of same module as cave.

In this particular example it was decided to consider cave fill as a bounding surface for the cave of a given module, but to not treat stalactites as such; thus they may or may not be "within" the cave of a given module of spherical explorer. A different shaped explorer would change the details but not the principles of the definitions in this example. If the reader should care to substitute a human for a spherical explorer, he will find that the terms employed here are consistent with our ordinary experience with caves.

The situation designated (F), and the cave space so selected when the explorer may only penetrate the entrance surface for a short distance from outside is not defined above, but might be thought of as a "shelter."

Applications

Morphological: The origin of limestone caves is usually studied only in terms of air filled proper caves with proper entrances. In a few cases information about a non-proper passage may be discovered by stream or air tracing, deductions from joint patterns, etc., but these methods yield only fragmentary data. The possibility remains that many clues to cave origin reside where we cannot observe them. Not only is it possible that the volume of non-proper caves exceeds that of proper caves, but it is likely that the volume of proper caves with proper

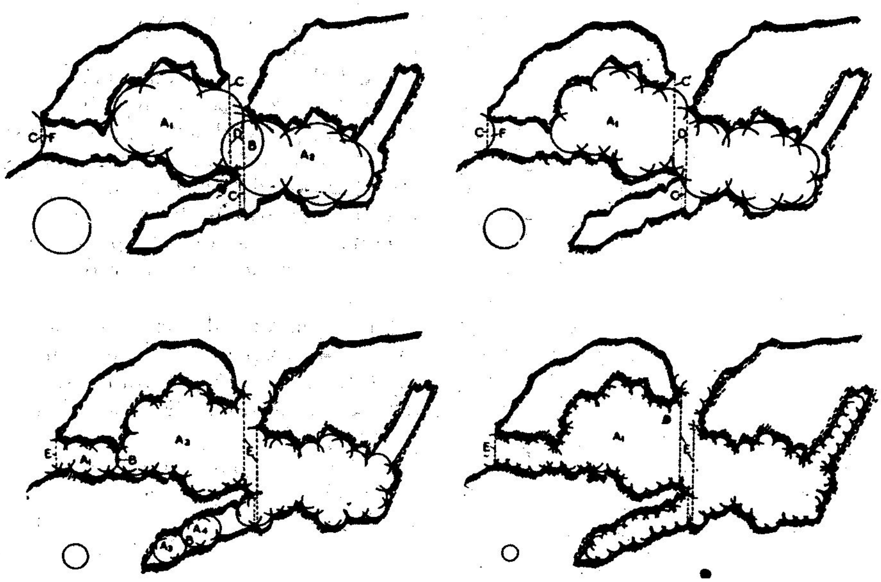

Figure 1

Examples of caves defined in a cave space by spherical explorers of different module. Also shown are the "explorer," cave and surface connections, portions of the entrance surface, cave entrances, and shelters.

entrances is only a fraction of that without. Students of cave origin may be willing to extrapolate with confidence from their observations in the available selection of caves to the remainder, but nature usually does not divulge her secrets to limited observation, and it is more likely that our present concepts are considerably biased.

As a defining module is made smaller, an explorer would be able to penetrate into an ever increasing volume of cave space. Cavities formed by the solutional enlargement of joints might be expected to exhibit features which would distinguish them from the narrow gaps in joints which have not been enlarged, and perhaps even from the primitive solutional cavities and tubes which would be explored with a different module range. Several classes of cave space might be distinguishable on this basis.

Consider the total volume of cave space under some region which is traversable by a specified spherical explorer. Include all cave space of a suitable size without regard to the existence of entrances. Imagining that this volume is measurable, plot the value of the total versus the module. If the result is the smoothly decreasing curve in Figure 2 labeled *ungrouped,* we would conclude that cave space is not naturally divided into groups by module range. But if the "stepped" result shown in Figure 2 labeled *grouped* is obtained, a classification on the basis of "caves, crevices, fissures, joints, cracks, pores, etc." might be imagined. Each of the steps represents a significant contribution to the total cave space volume over a relatively narrow module range, while the plateaus between are ranges in which there is a relative paucity of cave space.

The actual case is not now known and would be difficult to determine. Also, there are probably better measures upon which to base a division into cave types. This one is mentioned because of its possible relation to the already demonstrated order in the distribution of proper-cave lengths.

Statistical: In two earlier articles the au-

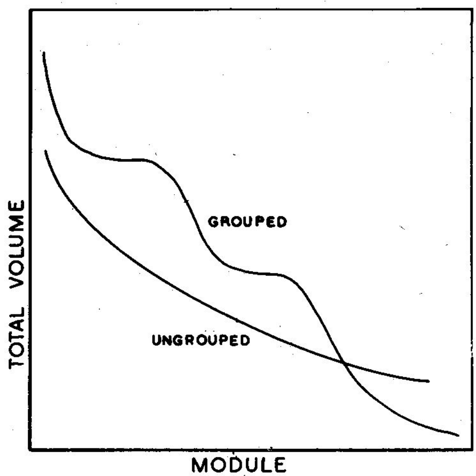

Figure 2

Possible results of measuring total cave volume as a function of the defining module.

thor considered statistical relations among properties of natural air-filled proper caves with proper entrances (although without so identifying them at the time) and deduced some properties of proper caves without proper entrances. To do this the number of proper entrances and the surveyed proper length of caves were used. Measuring length and entrances on the basis of their being proper serves to select a most consistent cave population for analysis; that is, it rejects data such as artificial entrances and connections found by digging or air or stream tracing, or by geological deductions, or entrances surmised or dug into, as not being equally well known for all caves in the population. The present considerations make clearer the reasons why proper length was a suitable variable. Entrance forming processes acting on a non-proper (though air filled) cave *cannot produce proper entrances,* and consequently this whole class of caves and entrances may be omitted from consideration without affecting the relations found in the remainder. Whether the geomorphic constants found for caves of West Virginia and Pennsylvania depend upon the module is not clear. The number of cave entrances, and cave lengths, may not vary in the same proportions as the module is changed; so for the present they should be considered as proper geomorphic constants.

System specification: The module concept leads naturally to defining a cave-space volume or *system* for a number of other applications. For example, in cave meteorology it is necessary to consider the heat balance on a cave. That is, a volume of cave space is selected and all the thermal fluxes are measured at the boundaries of the system, while the thermal accumulations are measured within the system. The boundaries for such a thermal system may be placed arbitrarily, although the use of a specified module provides a consistent selection. Similar considerations might apply to ecologic studies where it is necessary to account for biogenic energy which is passing through or accumulating within the cave boundaries.

The "father of modern biospeleology," E. G. Racovitza (1907) was concerned with the module question. He referred to the habitat of cave fauna as the "domaine souterrain" which he divided into *"Les grottes accessible à l'homme,"* and *"Les fentes étroites inaccessibles à l'homme,"* concluding that the *real* domain of cave fauna is to be found in the latter.

Discussion

Selecting specific, or arbitrary, definitions may at first thought seem to allow an investigator to reach any conclusion he wishes. But this is not true. Such apparent arbitrariness of definitions is in fact basic to the scientific method. People are weighed minus their shoes and their height measured excluding their hair; the yield of wheat from a farm is measured per acre, but excludes the roots, stalks and chaff; the positions of the planets are discussed sometimes with respect to their centers and sometimes with respect to their surfaces. In essence, we make our definitions and then attempt to determine whether they are useful; that is, functionally or statistically related. Considerable "pruning" or rearrangement of the definitions may be necessary before a significant conclusion can be reached, which then only applies to the defined variables. So it is with caves.

There has been a need for unique definitions of cave and cave entrance for purposes of both description and for quantitative manipulations. It has been proposed here to define these in terms of a *module* assigned to a *standard explorer,* the shape of which is in turn selected for convenience or purpose. Likewise the materials which are to be considered as boundaries to the explorer (rock, breakdown, fill, water, speleothems . . . ?) must be separately selected. This then leads to definitions of *cave space, cave entrance,* and *connection* on the basis of a given module, which have the virtue of being consistently selected or measured and hence usable in precise statements. To designate caves or entrances traversable by humans the word "proper" has been suggested, which makes the surveyed lengths used in previous work, *proper lengths.* The distinctions "natural" or "artificial" may be applied separately.

Returning to the examples of definitions given in the introduction, we may tabulate what each author specified in each of the above categories in his definition of a cave. They are given in the order *a.* Bounds, *b.* Explorer, *c.* Module, *d.* Entrances, and *e.* Purpose:

Bretz (1956) and Cullingford (1953), a. Rock and fill, b. human, c. proper, d. unspecified, e. descriptive; Davies (1960), a. Solution surfaces, b. unspecified, c. larger than "primitive tubes," d. unspec., e. theory of origin; Howard (1960), a. Solid (original) rock, b. unspec. c. not stated but apparently small, d. not required, e. descriptive; Curl (1960), a. Rock, fill, and water, b. human, c. proper (and possibly smaller), d. proper, e. statistical theory of evolution; Woodward (1961), a. Rock and fill, b. water, c. "freely flowing water," d. not required, e. theory of origin.

All append the word *natural.* These authors have selected their definitions according to the purpose they had in mind. This is acceptable so long as such purposes and definitions are clearly stated, and the existence of alternate definitions for other purposes is recognized.

References

Bretz, J Harlen, 1956, Caves of Missouri: Mo. Geol. Survey, v. 39, p. 1.

Cullingford, C. H. D. (ed.), 1953, British caving: p. 438 (London).

Curl, R. L., 1958, A statistical theory of cave entrance evolution: Bulletin of Nat. Speleological Soc., n. 20, pp. 9-22.

———, 1960, Stochastic models of cavern development: Bulletin of the Nat. Speleological Soc., n. 22, Part 1, pp. 66-76.

———, 1961, On the definition of a cave: Paper presented 20 September 1961 at the 3rd Int. Cong. Speleo., Vienna, Austria.

Davies, W. E., 1960, Origin of caves in folded limestones: Bulletin of the Nat. Speleological Soc., n. 22, Part 1, p. 5.

Howard, A. D., 1960, Geology and origin of the crevice caves of the Iowa, Illinois and Wisconsin lead-zinc district: Jour. Yale Speleo. Soc., v. 2, n. 4, Part 1, p. 63.

Johnson, Paul A., 1960, Map of Sallee Cave: Mo. Speleology, v. 2, n. 3, p. 69.

Racovitza, E. G., 1907, Essai sur les problèmes biospéologiques: Biospeleologica, v. 1, *in* Arch. Zool., Expér. et Générale, IVe Sér., VI, pp. 371-488.

Woodward, H. P., 1961, A stream piracy theory of cave formation: Bulletin of the Nat. Speleological Soc., n. 23, Part 2, p. 39.

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