H. H. Hobbs III

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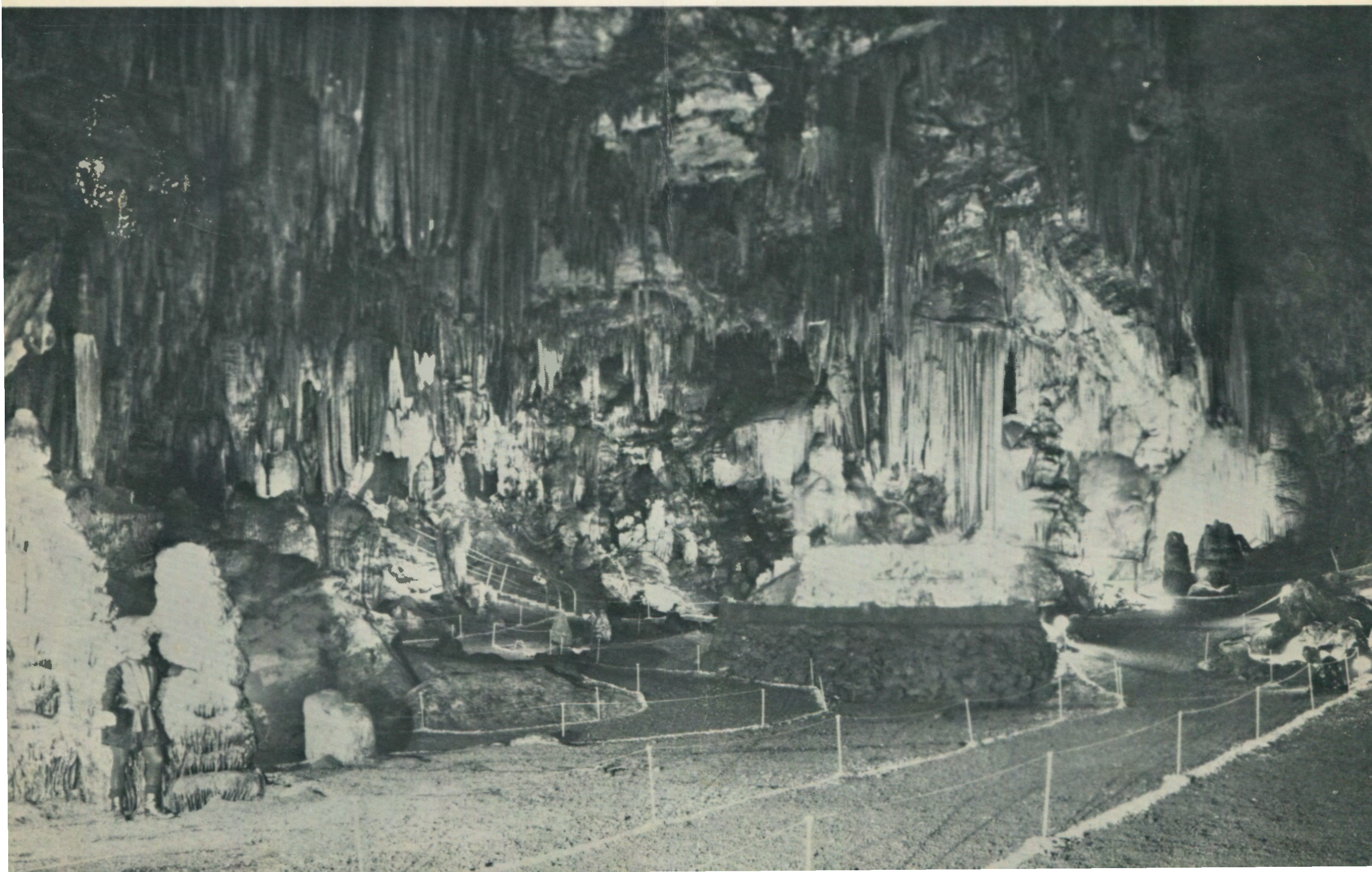

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COVER PHOTO—Carbonate speleothems, De Soto Caverns, Childersburg, Alabama. Photo courtesy of De Soto Caverns.

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A Statistical Comparison of JOINT, STRAIGHT CAVE SEGMENT, and PHOTO-LINEAMENT ORIENTATIONS

SUMMARY

A statistical comparison was made of the orientations of joints, straight cave-passage segments, low altitude photo-lineaments (1:20,000) and high altitude photo-lineaments (1:120,000 and 1:250,000) in Benton County, Arkansas. A modified version of the Kolmogorov-Smirnov (K-S) test, compensating for circular (0-360°) data, was used. The area is underlain by nearly flat-lying Mississippian carbonates (Boone and St. Joe formations) on the southwest flank of the Ozark Dome.

Eight, 2 sample K-S tests were used to compare the orientation diagrams. The null hypothesis in each case is a statement of no significant difference in orientations of the 2 distributions or populations at the chosen alpha level ($\alpha = 0.10$). The results show that for low altitude photo-lineaments and straight cave-passage segments (both 50 ft and 100 ft), the orientations are similar. This suggests that low altitude photo-lineaments may be either discrete fractures or zones of weakness that control cave passage development to a significant degree. The lack of similarity of orientation of lineaments and joints suggests that lineaments may be formed in part by larger-scale processes than those forming the regional joint patterns.

Previous testing of similar data from West Virginia showed lack of a relationship between any of the parameters (Ogden, 1974). This may be due to differences in geology and hydraulic gradient. In West Virginia, the rocks are much more deformed and the hydraulic gradient is steeper. Also, many photo-lineaments in West Virginia were defined by alignments of the abundant dolines, whereas Arkansas has few dolines. The West Virginia photo-lineaments are believed less likely to depict underlying fractures. Therefore, greater care in photo-lineament mapping must be taken, because an alignment of 3 or more dolines may not represent a zone of weakness.

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ALL TOO OFTEN, geologists and speleologists gather orientation data and make important conclusions based solely on visual comparison of the rose diagrams. This can lead to false interpretations, because a researcher's eyes are too easily biased toward looking at a few larger, similar classes of the rosettes while disregarding the many smaller classes that are not similar. The circular nature of orientation data and the lack of an absolute zero have stifled the quantitative comparison of the two types of orientation data. Therefore, the goal of this paper is to demonstrate a statistical method by which circular data can be quantitatively compared. Data collected in Arkansas is used to demonstrate the statistical technique and to draw conclusions about the orientation of cave passages. Results from similar testing of West Virginia cave passages is then compared to the Arkansas conclusions.

Several studies have been conducted throughout eastern United States testing the geologic parameters controlling cavern orientation. White (1960) found that, in the folded limestones near State College, Pennsylvania, stratigraphic dip is high and caves are largely oriented along the strike. Davies (1960) found that most cave passages in the folded Appalachians are joint-controlled. Anderson (1961) and Palmer (1962) have shown that the caves of eastern New York are mostly joint controlled. G. H. Deike (1968) noted that the mean amount of fracture-controlled cave passage for most karst regions is about 75 percent. He also found that, for the gently dipping rocks of central Kentucky, the amount of fracture control is only about 40 percent. R. G. Deike (1969) found that, near State College, Pennsylvania, most cave footage is developed along the vertical strike joints of the beds. Anderson (1961) and R. G. Deike (1969) concluded that the spacing of joints controls the arrangement of cave passages. A regional study of the relationships among joint orientations, photo-lineaments, and cave passages in the southern Edwards Plateau was made by Wermund, *et al.* (1978). Although the authors accumulated a vast amount of data, interpretations of the information was very limited, and no statistical analyses were performed.

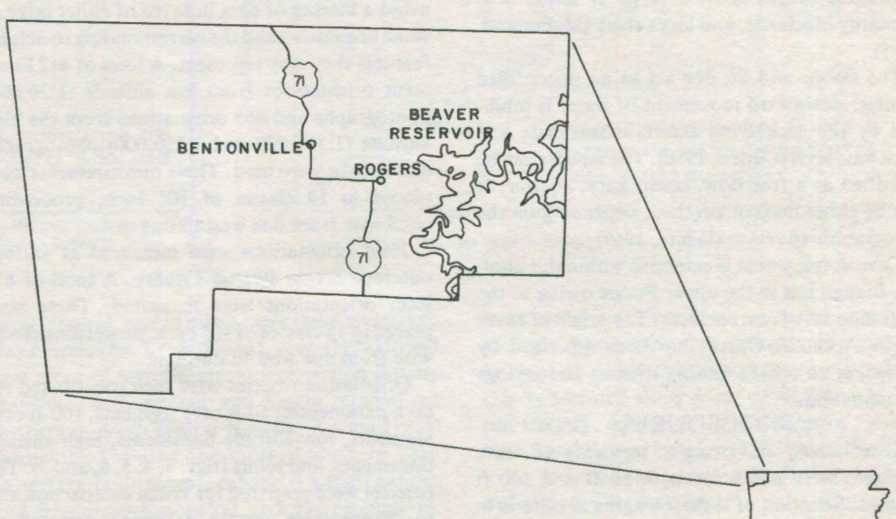

Figure 1. Location and map of Benton County, Arkansas.

Fracture control of solution features was emphasized in studies by Lattman and Parizek (1964) and by Siddiqui and Parizek (1971) in the State College area of Pennsylvania. They found water-well yields to be higher along fracture zones and along the intersections of fracture zones, as inferred by surface lineaments visible on aerial photographs. Also, a relatively large number of cavities were intersected during drilling along fracture zones. Rauch (1972) found that there are a greater number of caves along fracture zones associated with water and wind gaps near State College. In the Mississippian carbonates of the Arkansas Ozarks, Ogden, *et al.* (1981) found a strong statistical correlation between aquifer transmissivity and photo-lineament proximity. Therefore, if lineaments are indeed fracture zones and avenues of rapid water movement, then one would expect to find a significant number of cave passages oriented along them.

In order to test this hypothesis, a study was begun with 4 primary purposes:

1) Determine the orientations of straight cave segments in an area of little deformation.
2) Determine the orientations of surface joints within the same area.
3) Determine the orientations of several types of photo-lineaments within the study area.
4) Statistically compare the orientations of straight cave segments, joints, and photo-lineaments.

STUDY AREA

The study area (Fig. 1) is on the southwest margin of the Ozark Dome, on the Springfield Plateau. The Springfield Plateau is the middle of 3 Pleistocene erosional surfaces. It is developed on relatively flat-lying, but highly fractured, Boone-St. Joe limestones of lower to middle Mississippian age (Fig. 2). The Boone Limestone ranges from 100 to 483 ft thick and can contain up to 70 percent chert (Liner, 1979). The St. Joe Limestone ranges from 6 to 85 ft thick. It is primarily bioclastic, and lacks chert (McFarland, 1975).

The Boone and St. Joe act as an unconfined aquifer; downward movement of water is inhibited by the underlying Chattanooga shale and local base level (Ogden, 1980). The aquifer can be classified as a free-flow, open, karst aquifer. It can be either deep or perched, depending on the topographic situation (White, 1969).

Cave development is extensive within this aquifer, though less in the upper Boone owing to the large amount of chert present. The origin of caves in the Arkansas Ozarks has been described by Ogden, *et al.* (1981). Losing streams and springs are abundant.

PROCEDURES

Orientations of straight segments of cave passages were taken for both 50 ft and 100 ft lengths. Selection of these 2 lengths as criteria in the investigation was somewhat arbitrary. However, it was thought that passage segments at least 50 ft long might exhibit more structural control as opposed to fortuitous development. Straight segments longer than 100 ft were deemed unsuitable due to their rarity. One hundred seventy eight 50-ft cave segments and 48 100-ft cave segments were used in constructing the rosettes.

Passage orientations were taken from existing cave maps prepared by the Arkansas Speleological Society chapter of the National Speleological Society. The maps were drawn from Brunton compass and tape surveys. Twenty-three cave maps were utilized. Most of the mapped caves are around 1000 ft in length (range: 320 to 6510 ft), but 3 caves are approximately one mile in length. Nearly all of the caves are developed along a single plane. Their total vertical extent is generally less than 50 ft. The orientation measurements were then placed in 18 classes of 10° each, proceeding clockwise from due west to due east.

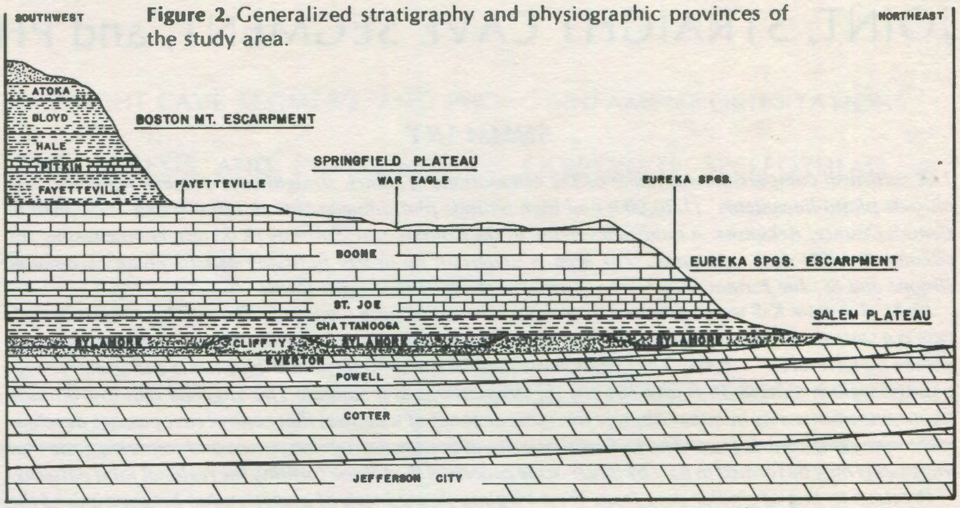

Figure 2. Generalized stratigraphy and physiographic provinces of the study area.

Photo-lineaments were defined as 'natural linear features, on aerial photographs' by Lattman (1958). Lineament orientations were taken from 1:20,000 scale, black-and-white aerial photographs; 1:120,000 scale, color, U-2 aerial photographs, and 1:250,000 scale, band 7 Landsat images. The 3 scales were used in order to avoid a biasing of data in favor of either large or small lineaments and the corresponding structural features they may represent. A total of 412 lineament orientations from low altitude (1:20,000) photographs and 465 orientations from the high altitude (1:120,000 and 1:250,000) photographs and images were used. These measurements were placed in 18 classes of 10° each, proceeding clockwise from due west to due east.

Joint orientations were measured at various outcrops across Benton County. A total of 876 joint orientations were measured. These were placed in 18 classes of 10° each, proceeding clockwise from due west to due east.

Orientation rosettes were then constructed for each paramenter: 50-ft cave segments, 100-ft cave segments, low-altitude lineaments, high-altitude lineaments, and joints (figs. 3, 4, 5, 6, and 7). The rosettes were prepared for visual comparison and to demonstrate certain preferred orientations found in each data set.

STATISTICAL METHODS

For statistical comparison, a modified (Kuiper, 1960) version of the Kolmogorov-Smirnov (K-S), 2 sample test was used. This is a sensitive test used for deciding 'whether two independent samples have been drawn from the same population or from populations with the same distribution' (Siegel, 1956). This test analyzes the amount of agreement between two cumulative distributions of data placed in classes.

Graphs of the cumulative percent data are constructed to compare the difference, 'D's,' between values in any 2 classes, *i.e.*, 0-10° to 0-10°, etc. The modified version of the test is useful for circular data, where no true base line exists. Because it is totally arbitrary to compare the 180° range clockwise from west to east, it is necessary to search for the maximum D of any 180° range.

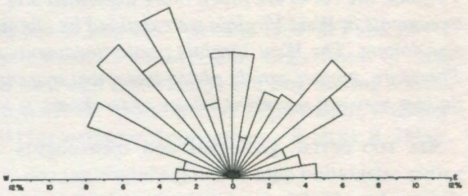

Figure 3. Orientations of 50-ft cave segments.

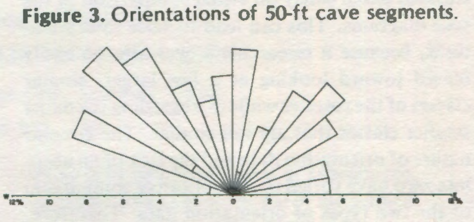

Figure 4. Orientations of 100-ft cave segments.

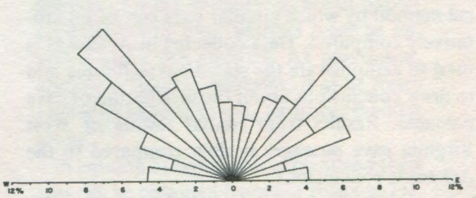

Figure 5. Orientations of low-altitude (1:20,000 b&w) photo-lineaments in the study area.

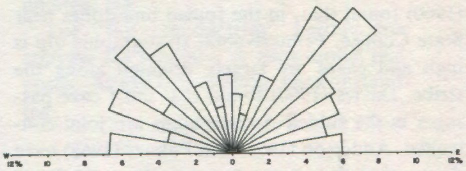

Figure 6. Orientations of high-altitude (1:120,000 and 1:250,000) photo-lineaments in the study area.

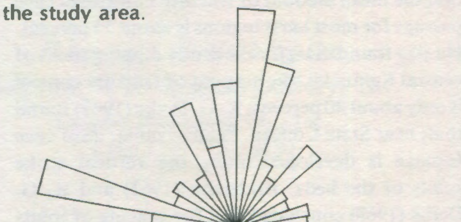

Figure 7. Orientations of joints in the study area.

This is done by repeating the 180° cumulative percent plot (Fig. 8), to include the full 360° range.

To compare the orientations, one overlaps the plot of one parameter on the plot for another parameter. This distinguishes the maximum *D* for the range clockwise from west to east. By changing the 0% base line to the values in each class, and proceeding one class to the right each time (Fig. 9), the maximum *D* for a full 360° is determined.

The maximum *D* is then compared to table values at the chosen alpha level. If the calculated *D* is greater than or equal to the table *D*, then the null hypothesis is rejected. The null hypothesis, in each case, is a statement of no significant difference in distribution between the orientations. If the null cannot be rejected, then a strong genetic relationship between the 2 parameters may be interpreted.

Table 1. Statistical Comparison of Orientation Data; the similarity of orientation is based on $\alpha = 0.1$. (?)

	JOINTS	LOW ALTITUDE LINEAMENTS	HIGH ALTITUDE LINEAMENTS
50' CAVE SEGMENTS	DISSIMILAR	SIMILAR	DISSIMILAR
100' CAVE SEGMENTS	DISSIMILAR	SIMILAR	DISSIMILAR
JOINTS		DISSIMILAR	DISSIMILAR

High altitude lineaments were compared to 50-ft cave segments and found to be dissimilar at the $\alpha = 0.1$ level. Visual comparison of high altitude lineaments to 100-ft cave segments indicates preferential orientation common to both. However, at the $\alpha = 0.1$ level they were found to have dissimilar orientations. Nevertheless, many cave passages are oriented along longer lineaments and a slightly lower (but statistically unsound) alpha level would demonstrate this. It is possible that high altitude lineaments would correlate to longer straight cave passages, such as 150-ft or 200-ft lengths. At the present, there is a paucity of mapped cave passages in excess of 100 ft in length, and this approach could not be checked.

Arkansas vs West Virginia

A study similar to this one was performed by Ogden (1974) in West Virginia. No statistical association was found between any measured geologic parameter and straight cave passage orientation. Why cave passages appear to be more closely oriented along zones of weakness in Benton County, Arkansas than in Monroe County, West Virginia may be due to structural differences in the 2 regions and to the manner in which photo-lineaments were defined.

The strata in Benton County are essentially horizontal, while those in Monroe County are folded with dips up to 45°. This leads to many caves being oriented along the strike in Monroe County, rather than along fracture zones. Of equal importance is the fact that there are few dolines in Benton County but several thousand in Monroe County. Many photo-lineaments mapped in Monroe County were defined by doline alignment. With so many dolines in such a small area, alignments may have been made solely by chance and therefore do not represent any underlying geologic feature. Most lineaments mapped in Benton County are probably more closely related to fracture or fractures zones, therefore yielding the similarity to cave passage orientation.

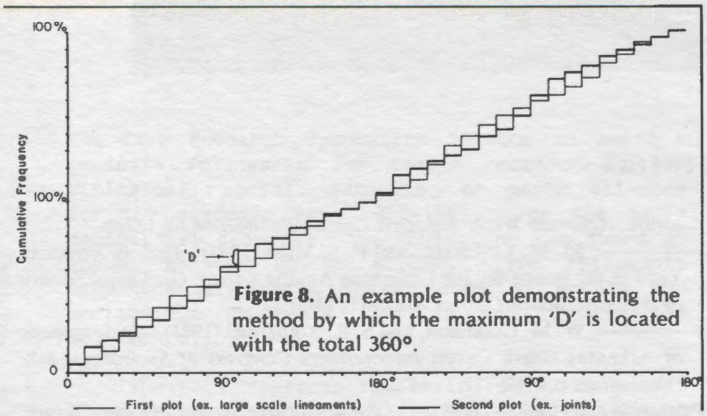

Figure 8. An example plot demonstrating the method by which the maximum 'D' is located with the total 360°.

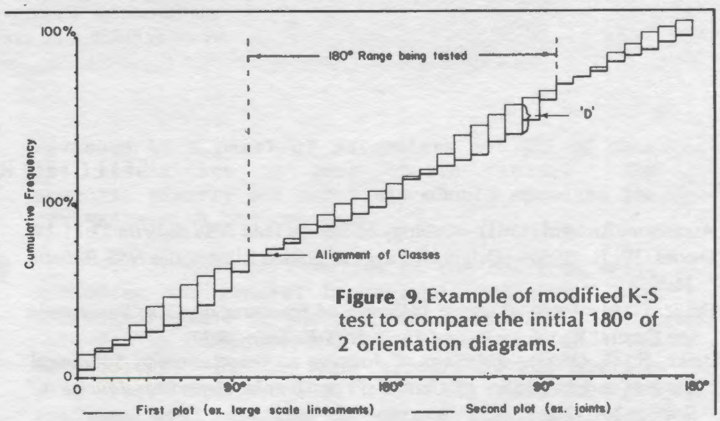

Figure 9. Example of modified K-S test to compare the initial 180° of 2 orientation diagrams.

RESULTS

Five orientation distributions were plotted, and 8 individual K-S tests were performed. The results of these tests are shown in Table 1 and will be discussed below.

Cave Segments vs Joints

The scatter of joint orientations was large, though there were several preferential orientations evident. Comparison of joints to both 50-ft and 100-ft cave segments showed dissimilarity at the $\alpha = 0.1$ level. This suggests that cave passage orientation is not related to jointing alone. Indeed, regional joint patterns may not reflect local anomalies that might control the orientation of many cave passages.

Lineaments vs Joints

Joints were compared to both low altitude and high altitude lineaments to determine if structural deformations producing the regional joint patterns might also be responsible for producing lineaments. At the $\alpha = 0.1$ level, joint orientations were found dissimilar to both low and high altitude lineament orientations. This probably indicates that many lineaments may represent zones of weakness of different structural origin than joints.

There has been a great deal of discussion on the relationship between photo-lineaments and structural features, and in many cases there appears to be a correlation. Levandowski, *et al.* (1974) found that areas of high lineament intersection density coincided with faulted and highly mineralized districts in north central Nevada. Ritzma (1974) related the Towanta lineament of northern Utah to surface fault scarps, enhanced karstification, and fracture-enhanced oil and gas production. Haman and Jurgens (1974) discovered an uplift in the subsurface by the linear patterns produced by primary fracturing and differential compaction of Mesozoic sediments draped over the uplift. However, many lineaments cannot be directly related to underlying geologic causes (Tolman, 1979). Indeed, many photo-lineaments may be wholly fortuitous or figments of the mapper's imagination.

Cave Segments vs Lineaments

Low altitude lineaments were compared to 50-ft cave segments and were found to have similar orientations at the $\alpha = 0.1$ level. The comparison of low altitude lineaments to 100 ft cave segments found similarity of orientation even at the $\alpha = 0.001$ level. This agreement of orientation strongly suggests that groundwater is moving and dissolving rock along zones of weakness that can be delineated on low altitude black-and-white photographs.

CONCLUSIONS

Simple visual comparison of orientation data often causes unsupported conclusions about similarity to be drawn. The K-S test as used here can strengthen and quantify conclusions about similarities in orientations.

Cave segment orientations being dissimilar to joint orientations does not mean that caves do not form along joints. It merely suggests that some cave passage orientations do not coincide with regional jointing. The relationship between low altitude photo-lineament and cave passage orientations suggests that caves are oriented along zones of weaknesses manifested on aerial photographs. These photo-lineaments may be of different origin and orientation than regional joints (?) and may perhaps represent en echelon joint concentrations, as shown in Figure 10.

In comparing the Arkansas area to the West Virginia area, 2 conclusions are possible: First, caves are likely to form along all zones of weakness where rocks are horizontal. Second, in areas of high doline density (Monroe County), it is important to be cautious in using dolines to define photo-lineaments. The alignment of any 3 dolines may not represent a zone of weakness in such an area.

It is not the purpose of this paper to 'prove' that structural features associated with photo-lineaments are the sole control of cave development. However, it seems certain that the longer straight passages have formed preferentially in favorable lithologies, under proper hydrologic conditions, along zones of weakness that are expressed as low altitude photo-lineaments on the surface.

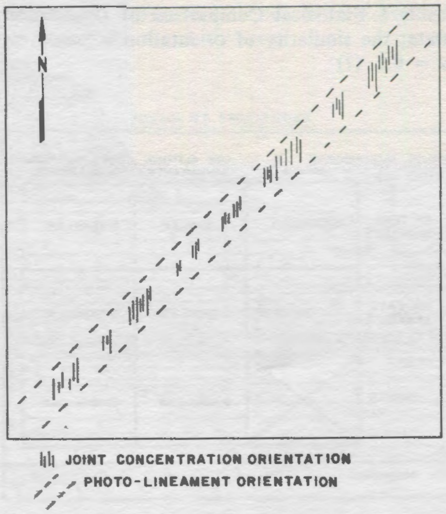

Figure 10. Diagrammatic representation of the orientation of a photo-lineament as expressed by en echelon joint concentrations.

SELECTED REFERENCES

Anderson, Richard (1961)—Geology of Barton Hill: *NSS Bulletin* **23**:11-14.

Davies, W. E. (1960)—Origin of Caves in Folded Limestone: *NSS Bulletin* **22**:5-18.

Deike, G. H. (1968)—Limited Influence of Fractures on Cave Passages in the Central Kentucky Karst (*Abs.*): *NSS Bulletin* **30**:37.

Deike, R. G. (1969)—Relations of Jointing to Orientation of Solutional Cavities in Limestones of Central Pennsylvania: *American Journal of Science* **267**:1230-1248.

Haman, P. J. and Keite Jurgens (1974)—The Discovery of the Caroline Arch, Alberta, by Lineament Analysis: Salt Lake City, Utah Geological Association, *Proceedings of the First International Conference on the New Basement Tectonics*, pp.153-162.

Kuiper, N. H. (1960)—Tests Concerning Random Points on a Circle: *Royal Netherlands Academie of Arts and Sciences, Section of Sciences, Proceedings* **A-63**:38-47.

Lattman, L. H. (1958)—Technique of Mapping Geologic Fracture Traces and Lineaments on Aerial Photographs: *Photogrammetric Engineering* **24(4)**:568-576.

——— and R. R. Parizek (1964)—Relationship between Fracture Traces and the Occurrence of Ground Water in Carbonate Rocks: *Journal of Hydrology* **2**:73-91.

Levandowski, D. W.; T. V. Jennings; and W. T. Lehman (1974)—Relations between ERTS Lineaments, Aeromagnetic Anomalies and Geologic Structures in North Central Nevada: Salt Lake City, Utah Geologic Association, *Proceedings of the First International Conference on the New Basement Tectonics*, pp.106-117.

Liner, J. L. (1979)—*Lithostratigraphy of the Boone Limestone (Lower Mississippian), NW Arkansas:* University of Arkansas Thesis, 88pp.

McFarland, J. D. (1975)—*Lithostratigraphy and Conodont Biostratigraphy of Lower Mississippian Strata, Northwest Arkansas:* University of Arkansas Thesis, 64pp.

Ogden, A. E. (1974)—The Relationship of Cave Passages to Lineaments and Stratigraphic Strike in Central Monroe County, W. Va.: Morgantown, West Virginia Geological Survey, *Proceedings of the 4th Conference on Karst Geology and Hydrology*, pp.29-32.

——— (1980)—Hydrogeologic and Geochemical Investigation of the Boone-St. Joe Limestone Aquifer in Benton County, Arkansas: Fayetteville, *Arkansas Water Research Center, Publication* **68**:133pp.

———, M. M. Chitsazan, and P. S. Muse (1981)—Factors Affecting Yield in the Boone-St. Joe Limestone Aquifer (*Abs.*): *Geological Society of America, South-Central Abstracts* **13(5)**:259.

———, W. M. Goodman, and S. R. Rothermel (1981)—Speleogenesis of Arkansas Ozark Caves: *International Congress of Speleology, 8th, Proceedings* pp.769-771.

Palmer, A. N. (1962)—*Geology of the Knox Cave System, Albany County, New York*: Williams College Thesis, 95pp.

Rauch, H. W. (1972)—*The Effects of Lithology and other Hydrogeologic Factors on the Development of Solution Porosity in the Middle Ordovician Carbonates of Central Pennsylvania:* Pennsylvania State University Thesis, 530pp.

Ritzma, H. R. (1974)—Towanta Lineament, Northern Utah: Salt Lake City, Utah Geological Association, *First International Conference on the New Basement Tectonics*, pp.118-125.

Siddiqui, S. H. and R. R. Parizek (1971)—Hydrogeologic Factors Influencing Well Yields and Aquifer Hydraulic Properties of Folded and Faulted Carbonate Rocks in Central Pennsylvania: *Water Resources Research* **7(5)**:1295-1312.

Siegel, Sidney (1956)—*Nonparametric Statistics for the Behavioral Sciences:* NYC, McGraw-Hill, 312pp.

Tolman, D. N. (1979)—*Linear Analysis from Remote Sensing Data, Arkansas Valley:* University of Arkansas Thesis, 105pp.

Wermund, E. G.; J. C. Cepeda; and P. E. Luttrell (1978)—Regional Distribution of Fractures in the Southern Edwards Plateau and Their Relationship to Tectonics and Caves: *Texas Bureau of Economic Geology, Geological Circular* **78-2**, 14pp.

White, W. B. (1960)—Termination of Passages in Appalachian Caves as Evidence for a Shallow Phreatic Origin: *NSS Bulletin* **22**:43-53.

——— (1969)—Conceptual Models for Carbonate Aquifers: *Ground Water* **7**:15-21.

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KARST RESEARCH FELLOWSHIP

The Cave Research Foundation intends to award a graduate fellowship for thesis research in the biological, social, economic, or earth sciences for the academic year 1982-1983. For the truly exceptional proposal, the Foundation can award an annual stipend up to $2,000. The fellowship committee may award lesser sums as grants for meritorious proposals that do not receive the fellowship.

The Cave Research Foundation is a non-profit organization incorporated in the Commonwealth of Kentucky with the objectives of supporting cave- and karst-related research and interpreting and conserving karst features.

The fellowship is offered to support scientific studies related to karst areas anywhere in the world. Students engaging in or preparing to initiate thesis research related to karst are encouraged to apply for this fellowship. Proposals involving surface and/or underground research are acceptable. Although the stipend is administered directly between the investigator and the Cave Research Foundation, the study itself is to be supervised at the graduate school of the awardee's choice by the thesis advisor.

In addition to the stipend, it is possible for the Foundation to provide field support for work in central Kentucky, Guadalupe Escarpment in Texas and New Mexico, and Kings Canyon in California. These areas can provide modest housing, some field assistance, and some surface laboratory facilities. If the applicant sees the need for field facilities in these karst areas, then specific requirements should be detailed in the proposal.

Applicants should note that proposals will be reviewed by a panel of scientists not all of whom are specialists in your chosen fields. The proposal clearly and concisely should acquaint the reviewers with the research.

1. Present an overview of the research area, including the general background, the scope, and the significance of the proposed research.
2. Demonstrate a command of the methodology. Discuss your hypotheses and how you will test them. Show that the sampling and analyses will confirm or refute the hypotheses. Note any special equipment or permits needed and state how you propose to procure them.
3. Discuss the most likely alternative interpretation(s). Indicate how a totally or partly negated hypothesis may influence your conclusions.
4. Present a proposed budget.

Establish your qualifications to undertake the proposed research. Attach a personal resume and a detailed academic record (transcript). Two letters evaluating your potential as a scientist also are required; one of these should be from your thesis advisor. Inclusion of Graduate Record Examination (GRE) scores is optional.

Candidates should submit in triplicate the study proposal and those elements noted in the preceding paragraph to:

Dr. John C. Tinsley
US Geological Survey
345 Middlefield Road m/s 75
Menlo Park, CA 94025

The application should be postmarked not later than February 15, 1983. The award will be announced by April 15, 1983.

CAVE RESEARCH FOUNDATION

Cabrol, Patrick and Jean Coudray (1982)—Climatic Fluctuations Influence the Genesis and Diagenesis of Carbonate Speleothems in Southwestern France: *NSS Bulletin* **44**:112-117.

CLIMATIC FLUCTUATIONS INFLUENCE THE GENESIS AND DIAGENESIS OF CARBONATE SPELEOTHEMS IN SOUTHWESTERN FRANCE*

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SUMMARY

French caves containing aragonite are virtually all located in the south and are restricted to dolomites or dolomitic limestones. Besides speleothems containing one or several minerals as a result of diagenesis, there are occasionally found complex speleothems displaying mineralogic evolution by the successive deposition of different minerals. The spatial and temporal distribution of these speleothems with respect to their morphology and, especially, mineralogic features suggest that there exist cycles of primary deposition and diagenetic alteration associated with variations in local climate or microclimate caused by regional climatic changes. It is possible to correlate cycles of deposition from one cave to another.

CAVES DEVELOPED in the dolomites and calcareous dolomites of southwestern France (Pyrénées, Montagne Noir) contain an extremely large variety of carbonate speleothems. Stalagmites, stalactites, draperies, helictites, columns, tubes, blisters, nodules, and others may be composed of calcite, of aragonite, or of both minerals. Study of the spatial and temporal distribution of these speleothems with respect to their morphology and, especially, mineralogic features suggests that there exist cycles of primary deposition and diagenetic alteration associated with variations in local climate or microclimate caused by regional climatic changes.

CARBONATE DEPOSITION UNDERGROUND AND IN THE LABORATORY

The most common cave mineral is undoubtedly calcite, which is the most stable crystalline form of calcium carbonate under the conditions of temperature and CO^2 partial pressure typical of caves. Nevertheless, aragonite, which was first recognized underground in Iowa in 1899 (Curl, 1962) and was long thought to be very rare, is now known to be rather common and probably ranks third in importance, after calcite and gypsum (White, 1976).

That aragonite is less stable than calcite and is more soluble under ordinary conditions of temperature and pressure means that special conditions are necessary for its precipitation. These have been studied experimentally by authors such as Kitano (1962), Kitano, *et al*. (1962), and Roques (1964), who agree that relatively more aragonite is precipitated with increasing temperature, and that the Mg^{2+} ion facilitates aragonite deposition at low temperatures while inhibiting calcite deposition. More recent experiments (Cailleau, *et al*., 1977) on the precipitation of the carbonates of calcium in the presence of magnesium have confirmed this earlier work. They have also quantified the relationship between Mg^{++}/Ca^{++} and the sequential precipitation of calcite, magnesian calcite, and aragonite.

Other factors which may influence the precipitation of aragonite, such as the presence of Cu, Zn, Ni, Co, Fe, and other ions or of organic materials, have also been studied in detail, but the results are incomplete and sometimes contradictory (Dragone, 1976). Following Murray (1954), who was the first to demonstrate the role of magnesium in the origin of aragonite speleothems, Roques (1965) believed that, in addition to the presence in the depositing solution of ions inhibiting calcite, two conditions are necessary in order to obtain 'primary' aragonite (as opposed to 'secondary' aragonite, which is derived from the transformation of vaterite): (1) a level of atmospheric humidity permitting the concentration of unusual ions, and (2) an uncommon situation where quantities of weak solution evaporate with little or no concurrent replenishment. Cabrol's (1978) studies of the relationship between aragonite and the country rock confirmed the major influence of magnesium (the boundary of the region of caves containing aragonite parallels the limit of dolomitization), to which should be added those of iron (previously noted by Lacroix [1901]), of clay, and of microjoints—especially when the micro-joints are partly obstructed by clay.

DISTRIBUTION OF SPELEOTHEMS ACCORDING TO MORPHOLOGY AND MINERALOGY

Calcite occurs in all caves, forming the classical types of speleothems (stalagmites, stalactites, flowstone, draperies, columns) as well as less common and geographically restricted varieties such as helictites, tubes, shields, blisters, nodules, and cups. Many theories have been advanced to explain the origin of these. Interested readers should consult Cabrol (1978) and note, especially, that in every case the major controlling factor appears to be the nature of the water from which the speleothems were deposited.

A preliminary inventory of French caves containing aragonite, now in progress, shows that virtually all are located in the south (Fig. 1). One assumes that this is a climatic distribution. The aragonite caves are also restricted to the dolomite terranes, or to dolomitic limestones and mineralized carbonate rocks, especially those containing iron. This suggests a geochemical distribution.

Aragonite speleothems do not occur alone, but are accompanied by varying numbers of calcite speleothems. White or colored, they assume nearly all the preceding forms, and other, original ones, also, such as straws, bead chains, and twigs (Cabrol, 1978).They were first described by Lacroix (1901) and can be placed in two basic classes (Fig. 2): Acicular aragonite, well-known to speleologists, and massive aragonite, which is harder to identify.

Acicular aragonite is composed of tiny, individual needles forming clusters or 'rock flowers.' They occur preferentially in two sharply defined microclimates; (1) Protected locations with very little air movement or where there are

*Translated by the Editor and George W. Moore.

few microclimatic variations, and (2) places where, paradoxically, there is a strong air current. In the first case, the flow of water is extremely slow (the needles appear dry and only droplets of water are visible on their tips); in the second case, water flow is only moderately slow (the needles are moist), but evaporation is favored by rapid introduction of fresh air.

Massive aragonite is composed of closely packed crystals in a single mass (Fig. 2). It is found always in airy, well-ventilated caves and occurs as stalagmites, stalactites, draperies, flowstone, rimstone, and pearls. In contrast to clusters of acicular aragonite needles, from which one never sees fall a drop of water, aragonite stalactites possess a visible flow of water. This flow is not as large as is its equivalent in calcite stalactites, and it but rarely produces stalagmites (apparently, the water is very low in calcium, and its residence time on the floor is too short for mineral deposition). Usually, an aragonite stalagmite accompanies a calcite stalactite, a phenomenon which can be explained by the fact that, the proportion of calcium precipitated on the ceiling being greater than the proportion of magnesium, the Mg/Ca ratio in the remaining solution is higher, thus favoring the precipitation of aragonite on the floor.

Basically, the origin of aragonite in caves appears to be firmly controlled by the nature of the depositing solutions. It is, however, undeniably influenced by climatic and hydrologic factors, such as evaporation and replenishment, which indirectly control the concentrations of dissolved minerals in the solutions (Bakalowicz, 1976).

SPELEOTHEM DIAGENESIS

Examination of many sections cut from stalagmites (of which the manner of growth is simpler than that of other speleothems, making interpretation of its development relatively easy) leads us to conclude that there are but 2 types: Homogenous and heterogenous. The heterogenous type may very well be due to textural differences or to differences in mineralogic composition (milky white aragonite, translucent calcite). Inspection under the optical microscope after staining, by X-ray diffraction, and with the scanning electron microscope (SEM) confirms the existence of speleothems formed entirely of one mineral, which have recrystallized without mineralogic alteration, and of speleothems containing several minerals, which have been produced by the partial recrystallization of a mineral into its polymorph. Four types of evolution seem possible (Cabrol and Coudray, 1978):

Calcite to Calcite

There are many monocrystalline calcite stalagmites the development of which requires quiet conditions difficult to reconcile with dripping water. They appear to have recrystallized after deposition, a conclusion supported by the nearly complete absence of primary growth features.

Aragonite to Aragonite

Our initial approach to this phenomenon resulted from the discovery of blue aragonite stalagmites in which the color pattern follows, almost exactly, the primary growth features, which shows the coloring agent (Cu) was mobilized after deposition. Study of thin sections also demonstrated the frequent co-existence of two kinds of crystal structure: (1) Closely packed, parallel thin fibers passing more or less evenly into (2) more complex structures composed of clusters of subparallel or radiating fibers reminiscent of lepidodendron branches.

Aragonite to Calcite

The alteration of aragonite to calcite (Fig. 3), frequently described in nature and from experiments, seems to be rather common in speleothems. It can be recognized in large, crystal palisades of calcite with optical orientation of aragonite. Under the SEM, the thin fibers of aragonite appear to be undergoing solution, while the calcite crystals are sharply defined. The two minerals are separated by cavities sometimes filled with a poorly defined material. Two formative processes may be operating: (1) Homoaxial transformation across a film of water, or (2) fresh crystallization of calcite after solution of the aragonite.

Calcite to Aragonite

The alteration of calcite to aragonite (Fig. 4), first described by Coudray and Cabrol (1978) under conditions of ordinary temperature and pressure, seems to exist, although less commonly than the alteration of aragonite to calcite. Studies under the optical microscope and with the SEM reveal clusters of fresh aragonite filling more or less rhombohedral cavities or cutting across the calcite crystals which appear to be undergoing solution. The presence of substantial cavities at the contact of the two minerals and the 'heteroaxial transformation' (in addition to the obvious optical and crystallographic differences between aragonite and calcite) lead us to postulate mineralogic replacement after solution. A similar occurrence of aragonite which, elsewhere, was able to partly explain the origin of massive aragonite, was produced experimentally from calcite first ground and then placed in an aqueous solution of magnesium (Cabrol, *et al.*, 1978).

Such aqueous transformations usually occur

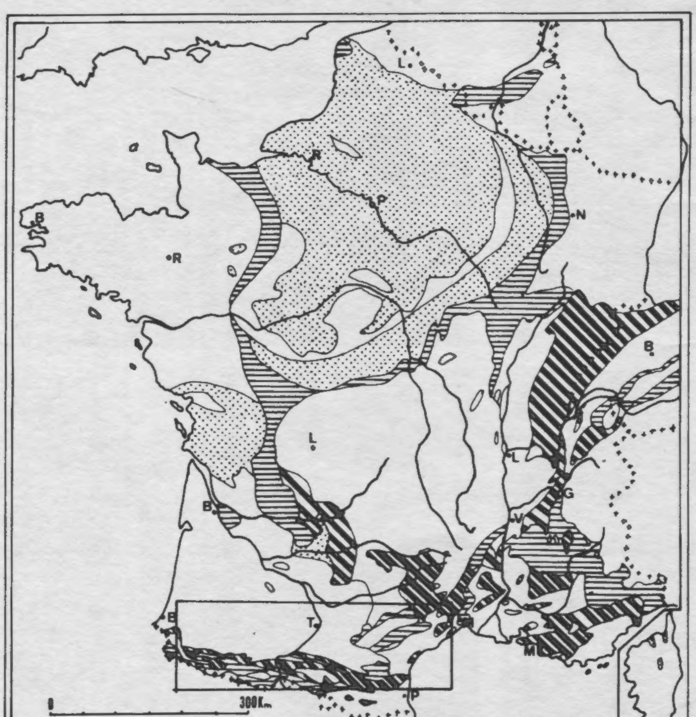
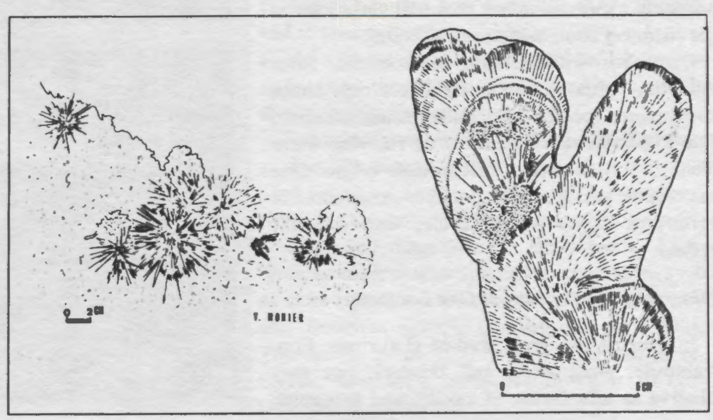


Figure 1. **(*left*) Karst regions of France, after Gèze (1973), showing the study area.** [hatched] Severely karsted region (primarily dense limestone and dolomite [lined] Moderately karsted region (carbonate rocks of moderate thickness and shaley limestone) [dotted] Lightly karsted region (chalk, thin limestone, and impure carbonate rocks)

Figure 2. **(*below*) The two basic types of aragonite found in caves. *Left,*** aragonite needles from the Grotte d'En Gorner, after Salvayre (1972). ***Right,*** massive stalagmitic aragonite with calcite inclusions from the Grotte du Pont de Ratz. (A) aragonite, (C) calcite.



soon after deposition. They appear to be able to take place in nearly all kinds of speleothems and should be attributed mainly to variations in the chemistry of the depositing waters (especially the Mg/Ca ratio).

MINERALOGIC SUCCESSION AND CLIMATE

Mineralogic Succession in One Speleothem

Without diagenesis. Besides the speleothems containing one or several minerals as a result of diagenesis, there are occasionally found complex speleothems displaying mineralogic evolution by the successive deposition of different minerals. The most typical example is that of helictites in the Grotte de La Cigalère (Pyrénées). These consist of axial calcite surrounding the central canal, a sheath of aragonite of uniform thickness, and an outer layer of gypsum crystals (Fig. 5, center and bottom). This succession corresponds to the solubility of the minerals: The least soluble form was precipitated first, the most soluble last. Likewise, 'toothbrush' speleothems (a calcite core overlain by distinctly oriented ranks of aragonite needles) partly illustrates the theoretical evolution of deposits from a solution where the Mg/Ca ratio is increasing (Fig. 5, top).

These two types of succession are linked to systematic variations in the chemical composition of the depositing solution during the growth of the speleothem. They reveal a change in the chemistry of the depositing water possibly related to reduced flow.

With diagenesis. Changes in texture or in mineralogic composition found in the centers of speleothems show that, after deposition, the speleothems were subjected to new physico-chemical environmental conditions, resulting in diagenesis. Underground, the basic parameter controlling these transformations seems to be changed water chemistry produced by altered temperature and precipitation at the surface, or perhaps by a change in the course of the water through the karst rock, or even by a change in the residence time of the water in one or another place along its course.

Diagenesis without mineralogic change (aragonite to aragonite, or calcite to calcite) can be quick (it has been observed in Roman mines) and seems to have affected virtually all of the stalagmites sampled, regardless of their location. It probably expresses minor seasonal variations in the chemical composition of the water.

Diagenesis with mineral replacement, rarer than that without, seems to affect only those speleothems located near underground streams. The dynamics and chemistry of running water seem to play the major role in their origin. One can assume that it expresses longer-range climatic variations (*e.g.*, humid cycles and drought cycles).

Mineralogic Succession at One Location

In four of the caves studied (Lauzinas, Fontrabiouse, Aragonites, and Devèze), one may observe an alternation of calcitic and aragonitic deposits in which the chronology is very clear (Fig. 6):

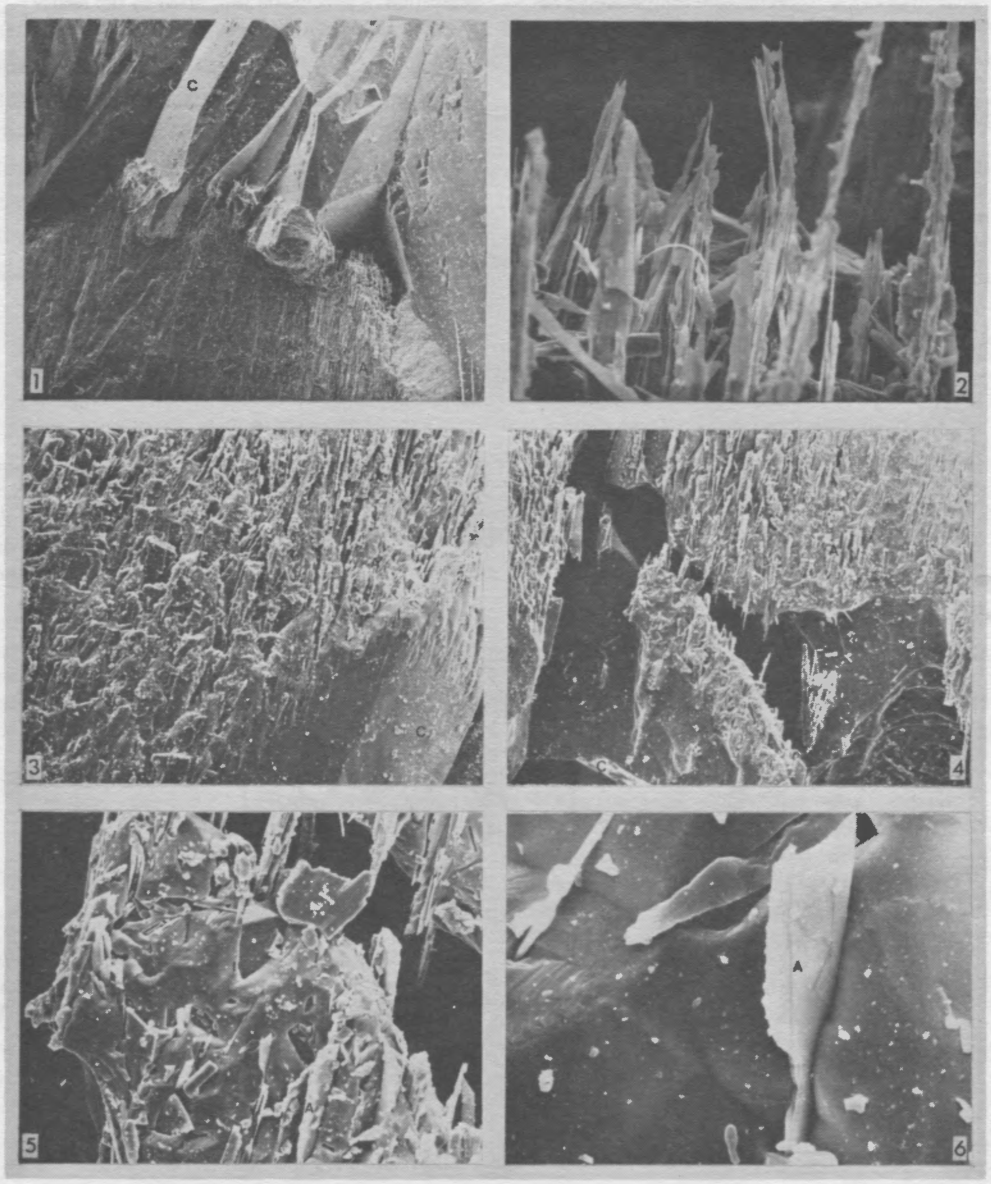
Grotte de Lauzinas. An initial deposit of acicular aragonite, now dry, dull, and brown (1) is partly covered by a calcite flow (2), while a few meters to one side, aragonite is now being precipitated (3).

Grotte de Fontrabiouse. 'Mixed' aragonites composed of massive chunks separated by radiating needles are developed on the ceiling of a small opening (4). A gour formed below the aragonite, and the lowest needles are submerged. Masses of calcite have formed below water level (5). The gour is now dry, and a second generation of aragonite needles is developing around the edge of and above the gour (6).

Grotte des Aragonites. Aragonite needles now dry, dull, and reddish-brown have formed on older calcite columns (7). A gour filled with water and submerged the tips of the lowest needles; calcite masses formed on these needles (8). The gour is now dry, and new, white needles, moistened with water, today are developing on the dull needles (9).

Grotte de La Devèze. One can see white aragonite and brown aragonite in many ceiling domes; some of the aragonite is white at the base and brown at the tips. The boundary between the

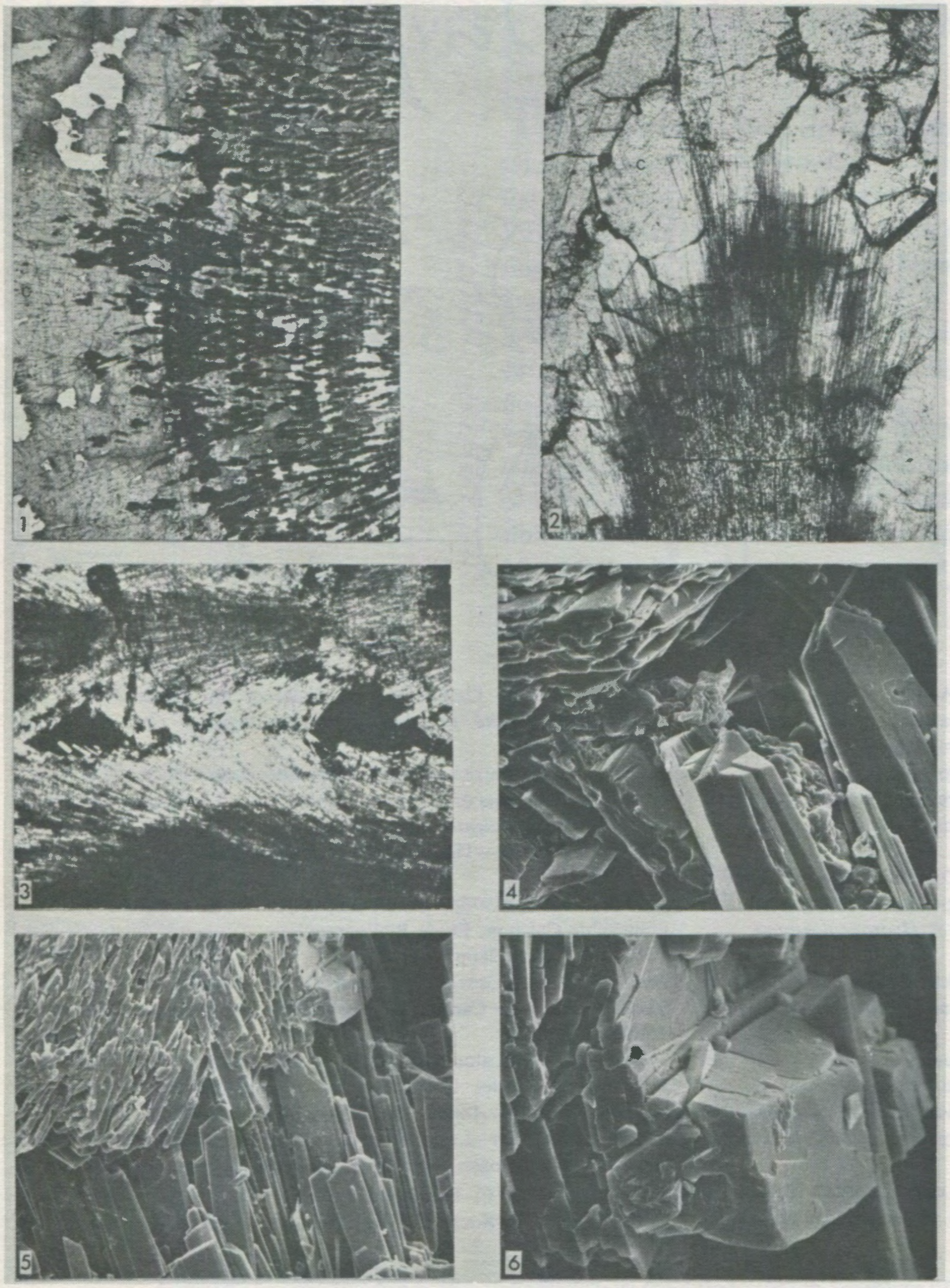
Figure 3. **Diagenesis of speleothems:** calcite replacing aragonite (SEM images courtesy of the Laboratoire Paléobotanique, Montpellier). ***1.*** Contact of calcite (above) on aragonite (below), 16x. ***2.*** Detail of aragonite needles undergoing solution (?), 500x. ***3.*** Contact between altered aragonite and fresh calcite (lower right); between the two are poorly defined intermediate products, 150x. ***4.*** Altered aragonite and fresh calcite, 60x. ***5.*** Enlargement of a portion of #4, showing the transition zone, 220x. ***6.*** Enlargement of a portion of #5, showing altered aragonite partly engulfed in calcite (?), 1800x.



two colors is located at the same elevation on all the crystals and corresponds to a former water level, as indicated elsewhere by traces of clay on the walls. There was first of all the development of aragonite needles, now inactive (10), after which water rose in the cave but submerged only part of the needles, making a water level (11); finally, new needles formed and are still growing (12).

These 4 examples show: (1) That in one location there can be cycles of deposition; (2) that the deposition of aragonite indicates drier conditions than does that of calcite; (3) that the growth of aragonite is possible and commonly occurs today in many caves; and (4) that it is possible to correlate cycles of deposition from one cave to another.

Figure 4. **Diagenesis of speleothems:** aragonite replacing calcite (?) *1.* Thin section containing the transition front between aragonite (on right) and calcite (on left); calcite is light gray, voids are black, aragonite is darker gray; 2.6x. *2.* Another example of aragonitization; dark needles below are aragonite, lighter surrounding areas are calcite; 1.0x. *3.* Optical microscope view of black voids preserving the rhombohedral forms of calcite crystals now dissolved, partly invaded by aragonite needles, 34x. *4.* Border of the aragonitization zone, showing an aragonite needle piercing a calcite rhomb, SEM image 1000x. *5.* Limit of the aragonitization front, showing altered calcite above and fresh aragonite below, SEM image 500x. *6.* Greatly enlarged portion of #5, showing a calcite rhomb crossed by an aragonite needle, SEM image 2000x.



Mineralogic and Morphologic Succession in One Cave

Study of the classification of the suites of speleothems within many different caves leads to the following general conclusions:

1) Some speleothems are still being deposited ('alive') and others are dry ('fossil'),

2) The largest speleothems are usually the oldest; these are most often dry, and

3) Helictites and tubes almost always appear to be the youngest; they are active, white, and never engulfed within flowstone.

Generally, delicate speleothems such as helictites, tubes, small draperies, and small stalactites are alive and white and post-date dry, relatively massive, reddish-brown speleothems. Black speleothems are the oldest of all. (Caves where the country rock and the speleothems are colored, such as old mines or caves associated with mineralized zones, are not included because of the danger of confusing causes and effects.)

Color probably being controlled by water chemistry (dissolved ions or other optically active particles) and by temperature (at the surface), it is proper to conclude that changes in color reflect variations in mean annual precipitation and temperature. The body of observations on speleothems classified by color, morphology, size, and mineralogy, suggests the existence of a 'mega-sequence' of deposition beginning with large, colored, calcite speleothems and moving toward smaller, white, aragonite speleothems as the flow of water lessens.

CONCLUSIONS

Moore, (1956) had previously proposed that the kinds of minerals in carbonate speleothems are indicative of former temperatures, and that aragonite is deposited where the temperature at the surface is higher than 16°C. Actually, it is the temperature at the site of deposition which controls this, and that is not directly linked with temperature at the surface. If, following the recent work of Andrieux (1978), one agrees that caves experience a net loss of heat as the result of infiltrating water, and that, in the absence of water, they should be subject only to the flux of geothermal heat, then one should conclude that the presence of aragonite could be not only an indication of dry climate but also an indicator of cold climate. It is not impossible that some types of aragonite, such as the 'hoarfrost' which is uniformly distributed over the walls of some caves and is always fossil, could be related to a former glacial climate during which the percolation of water from the surface would have been greatly diminished by frozen ground.

This hypothesis obviously requires verification, as does the descriptive approach which we have used in regard to the relationship between percolation rate and color, size, morphology, mineralogy, and diagenesis of speleothems. Additional isotopic studies and radiometric dates, such as those already made in several caves by Duplessy and Delibrias (1970), Duplessy, *et al.* (1972), Thompson, *et al.* (1974), and Harmon, *et al.* (1977), now seem necessary in order to corroborate our work.

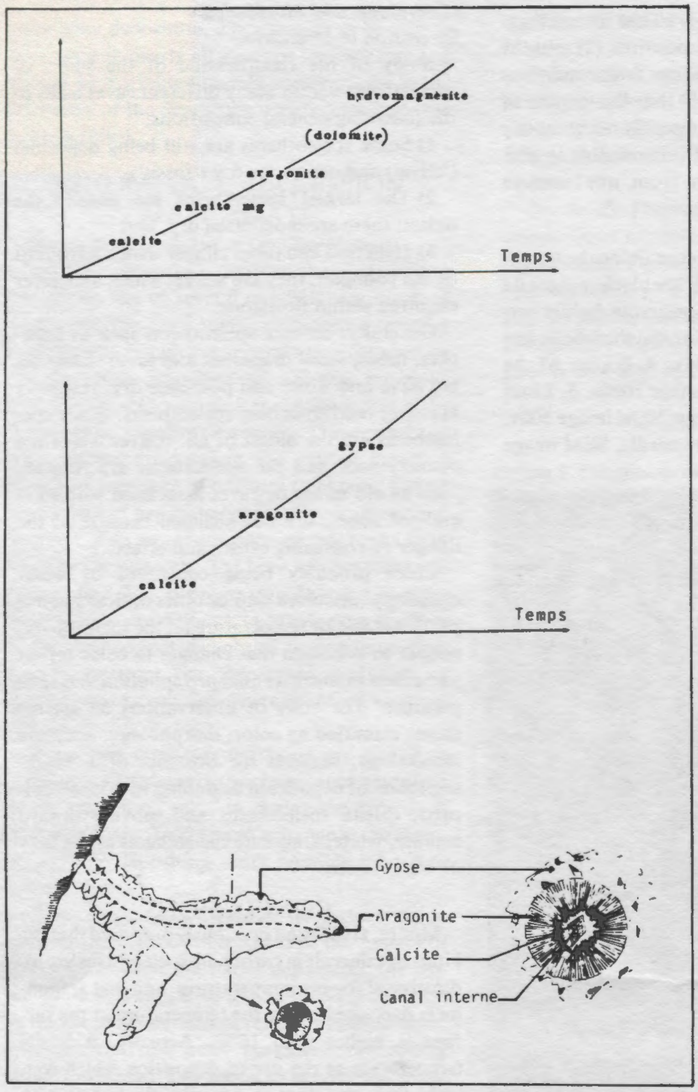
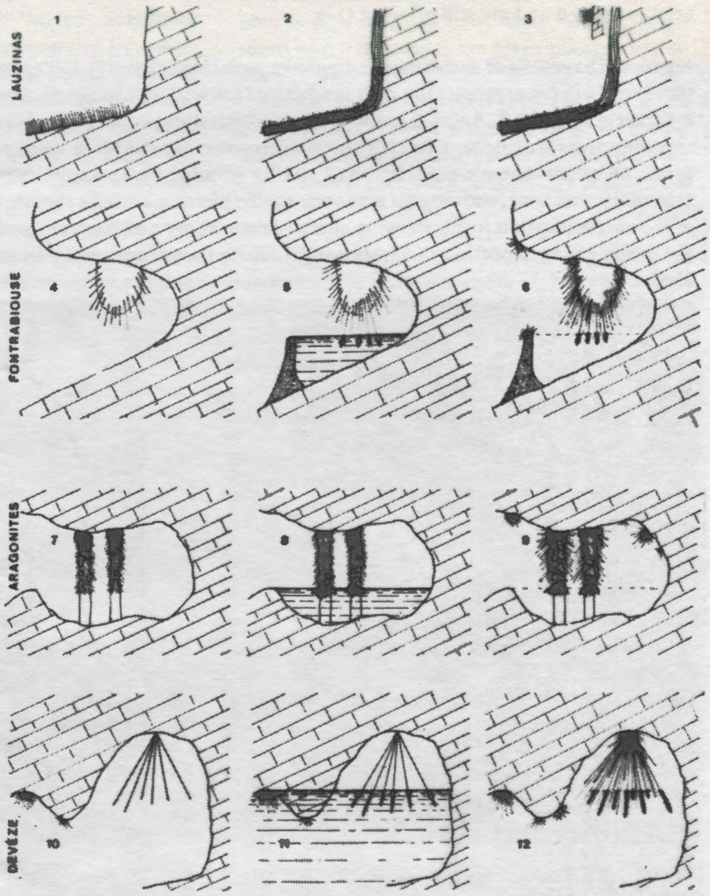


Figure 5. (*left*) **Sequence of deposition over time with changes in the depositing solution.** ***Top***, with increasing ratio of Mg to Ca. ***Center***, with increasing solubility. ***Bottom***, an example from the Grotte de la Cigalère. ***Figure 6.*** (*below*) **Sequence of deposition with climatic variation dry-moist-dry**, as observed in four caves.



REFERENCES CITED

Andrieux, Claude (1979)—Problèmes Soulevés par l'Action des Circulations d'Eau et d'Air sur le Climat des Cavités Souterraines dans les Massifs Karstiques: Centre National de la Recherche Scientifique, *Colloques Internationaux: La Fin des Temps Glaciaires en Europe.*

Bakalowicz, Michel (1976)—L'Evolution Saisonnière de la Minéralisation des Eaux Karstiques: Origine et Significations (*Abs.*): Toulouse, *Séminaire Carbonates I.N.S.A.*, 1p.

Cabrol, Patrick (1978)—Contribution à l'Étude du Concrétionnement Carbonaté des Grottes du Sud de la France: Morphologie, Genèse, Diagenèse: *Centre d'Études et de Recherches Géologiques et Hydrogéologiques, Mémoires* **12**, 275pp.

——— and Jean Coudray (1978)—Les Phénomènes de Diagenèse dans les Concrétions Carbonatées des Grottes: Orsay, *6th Réunion Annuelle des Sciences de la Terre*, p.82.

———, ———, J. L. Dandurand, and Jaques Schott (1978)—Sur la Possibilité de Transformation Naturelle Calcite Aragonite dans les Conditions Ordinaires de Température et de Pression; Reproduction Expérimentale du Phénomène: *Académie des Sciences de Paris, Comptes Rendus* ser. D, **287**:411-414.

Cailleau, Patrick; Daniel Dragonne; André Girou; Louis Humbert; Christian Jacquier; and Henri Roques (1977)—Étude Expérimentale de la Précipitation des Carbonates de Calcium en Présence de l'Ion Magnésium: *Société Française de Minéralogie et Cristallographie, Bulletin* **100**:81-88.

Coudray, Jean and Patrick Cabrol (1978)—Some new Aspects of Diagenesis in Cave Speleothems of Southern France (*Abs.*): Liverpool, *6th Meeting of Carbonate Sedimentologists*, 2pp.

Curl, R. L. (1962)—The Aragonite—Calcite Problem: *NSS Bulletin* **24**:57-73.

Dragonne, Daniel (1976)—Genèse Expérimentale et Naturelle des Carbonates de Calcium, Étude Bibliographique: Toulouse, *Séminaire Carbonates I.N.S.A.*, 28pp.

Duplessy, J. C. and Georgette Delibrias (1970)—Datation des Concrétions des Cavernes par le Carbone 14: *Association Spéléologique Est, Bulletin* **7**:38-41.

———, Claude Lalou, Georgette Delibrias, and A. V. Nguyen (1972)—Datations et Études Isotopiques des Stalagmites. Applications aux Paléotempératures: *Annales de Spéléologie* **27**:445-464.

Gèze, Bernard (1973)—Lexique des Termes Français de Spéléologie Physique et de Karstologie: *Annales de Spéléolgie* **28**:1-10.

Harmon, R. S.; D. C. Ford; and H. P. Schwarcz (1977)—Interglacial Chronology of the Rocky and Mackenzie Mountains, based upon ^{230}Th-

^{234}U Dating of Calcite Speleothems: *Canadian Journal of Earth Sciences* **14**:2543-2552.
Kitano, Y. (1962)—The Behaviour of Various Inorganic Ions in the Separation of Calcium Carbonate from a Bicarbonate Solution: *Japan, Chemical Society, Bulletin* **35**:1973-1979.
————, K. Park, and D. W. Hood (1962)—Pure Aragonite Synthesis: *Journal of Geophysical Research* **67**:4873-4874.
Lacroix, Alfred (1901-1909)—*Minéralogie de la France et de ses Colonies:* Paris, Librarie Polytechnique, vol. 3, 815pp.
Moore, G. W. (1956)—Aragonite Speleothems as Indicators of Paleotemperature: *American Journal of Science* **254**:746-753.
Murray, J. W. (1954)—The Deposition of Calcite and Aragonite in Caves: *Journal of Geology* **62**:481-492.
Roques, Henri (1964)—*Contribution à l'Étude Statique et Cinétique des Systèmes CO_2-H_2O-$CaCO_3$*: Toulouse University Thesis, vol. 19, Part 2, pp.255-484.
———— (1965)—Sur la Genèse des Formations Aragonitiques Naturelles: *Annales de Spéléologie* **20**:47-54.
Salvayre, Henri (1972)—Les Cristallisations Excentriques de la Grotte d'En Gorner (Pyrénées Orientales) - France: *Conflent* (Prades) **58**:171-190. .
Thompson, Peter; H. P. Schwarcz; and D. C. Ford (1974)—Continental Pleistocene Climate Variations from Speleothem Age and Isotopic Data: *Science,* **ns 184**:893-895.
White, W. B. (1976)—Cave Minerals and Speleothems, IN: D. C. Ford and C. H. D. Cullingford (Eds.)—*The Science of Speleology:* NYC, Academic Press, pp.267-327.

Manuscript received by the editors and accepted 20 February 1979.

Hill, C. A. (1982)—Saltpeter Caves of the United States—Updated List: *NSS Bulletin* **44**:117-120.

SALTPETER CAVES OF THE UNITED STATES—Updated List

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THE LIST of saltpeter caves published a year ago as part of a symposium on saltpeter caves (*NSS Bulletin* 43, No. 4) has been supplemented with additions by Bill Balfour (West Virginia), Robert Custard (Virginia), Bill Douty (Tennessee, Virginia), Mike Dyas (Kentucky, West Virginia, Alabama, Virginia), John R. Holsinger (Virginia), Tom Meador (Arkansas, Texas), Ira Sasowsky (Illinois), Marion Smith (Alabama, Tennessee), and W. W. Varnedoe, Jr. (Alabama). Cave names followed by question marks (??) refer to either unverified or to questionable saltpeter caves; these caves have been reported in the literature, but evidence of mining may no longer exist in them.

Some of the Texas 'saltpeter caves' may be bat caves, where nitrate was leached from guano, rather than saltpeter caves in the sense used in the symposium (caves containing nitrous, inorganic clastic sediments). However, it is oftentimes impossible to distinguish between these two types of nitrate origins without detailed study. Many times, both processes are present. The Texas caves are, therefore, listed for completeness' sake.

ALABAMA

Bibb County
- Saltpeter
- Saltpeter Sink

Blount County
- Adcock
- Bangor
- Blowing Saltpeter
- Crump
- French's Saltpeter
- Horse
- Saltpeter
- Second

Calhoun County
- Lady
- Little Weaver
- Meadows
- Oxford
- Weaver

Cherokee County
- Daniel
- McKinney
- Wolf Den

Colbert County
- Keefon

Cullman County
- Saltpeter

DeKalb County
- Manitou

Jackson County
- Blue River
- Coon Creek Saltpeter
- Crossings
- Devers Cove Saltpeter
- Fabius
- Horse Skull
- Long Island Saltpetre
- Saltpeter
- Sauta
- Steele Saltpeter
- Tumbling Rock
- William's Saltpeter

Jefferson County
- McClunney

Lauderdale County
- Collier
- Watkins Saltpeter

Lawrence County
- Melsom
- Saltpeter
- Saltpeter

Limestone County
- Indian
- Kendall Saltpeter

Marshall County
- Cave Mountain (Long Hollow)
- Eudy
- Fort Deposit
- Guntersville
- Hambrick
- Hampton
- Honeycomb
- Ledbetter Saltpeter
- Reeves

Morgan County
- Brown
- Cave Springs
- Hughes
- J. F. Roberts
- Newsome Saltpeter
- Talucah
- Trinity
- Wolf

Talladega County
- DeSoto
- Hawley
- Kymulga

ARKANSAS

Carroll County
- Cane Creek

Independence County
- Saltpetre

Marion County
- Nitre

Saltpetre
Newton County
Saltpeter (Bat, Cisle)
Saltpetre

GEORGIA

Bartow County
Kingston Saltpetre
Yarbrough
Dade County
Hooker
Howard's Waterfall
Floyd County
Cave Springs

ILLINOIS

Jackson County
Cave Creek
Monroe County
Fults

INDIANA

Crawford County
Saltpetre
Saltpetre (near Corydon)
Saltpetre (near Wyandotte)
Sumnerville Saltpetre
Wyandotte
Harrison County
Big Mouth (Rat)
Lawrence County
Salts
Monroe County
Buckner's
Coon's
Saltpetre
Orange County
Saltpetre (near Valeene)
Washington County
Saltpetre
Saltpetre

KENTUCKY

Adair County
Breedings Saltpeter (??)
Allen County
Goodrum's
Bath County
Daniel Boone Hut
Carter County
Saltpetre
Saltpetre (in Carter Caves State Park)
Caldwell County
Lisanby (Saltpeter)
Clinton County
Buffalo Saltpeter
Copperas Saltpeter
Edmonson County
Cedar Springs
Dixon
Hundred Dome
James
Longs
Mammoth
Pigg (Beckner)
Short
Hart County
Forestville Saltpetre
Hatcher Valley Saltpetre
Lone Star Saltpeter
Saltpetre (east of Horse Cave)
Saltpetre (west of Horse Cave)
Logan County
Collier (Saltpeter)
Potato
Jackson County
John Rogers
Pulaski County
Petre (Saltpeter)
Saltpeter Pit
Rockcastle County
Great Saltpetre (Crooked Creek)
Owens Saltpetre
Teamer's Saltpeter
Trigg County
Kanady
Warren County
Plano Saltpeter
Pruett Saltpeter
Wayne County
Saltpetre
Triple Saltpetre (Triple S)
Wind

MARYLAND

Allegany County
Saltpetre (near headwaters of the Youghiogheny)
Garrett County
John Friend Saltpetre
Washington County
Hughes (near Hagerstown)
Saltpetre (near Hancock)
Saltpetre (foot of South Mountain)

MISSOURI

Callaway County
Saltpetre
Dent County
Saltpetre
Laclede County
Saltpetre
Maries County
Saltpetre
McDonald County
Saltpetre
Ozark County
Saltpetre
Phelps County
Saltpetre
Pulaski County
Saltpetre
Saltpetre
Saltpetre
Ste. Geneviève County
Saltpetre
Stone County
Saltpetre
Texas County
Saltpetre

PENNSYLVANIA

Bedford County
Saltpetre

TENNESSEE

Anderson County
Fritz's Saltpeter (??)
Springhill Saltpetre
Bedford County
Harrison Saltpetre
Meadows Hill Saltpetre
Blount County
Whiteoak Blowhole
Campbell County
Meredith (Saltpetre)
New Mammoth (Cumberland Mammoth)
Cannon County
Robinson Ridge Saltpetre (Window)
Carter County
Carter Saltpetre
Gap Creek Saltpetre
Renfro
Cheatham County
Neptune Saltpetre
Claiborne County
Arthur Saltpetre
Buis Saltpetre
Chadwells (John Greer)
Cox Creek Saltpetre
Cumberland Mountain Saltpetre
King's Saltpetre
Tazewell Saltpetre
Whitaker Saltpetre
Clay County
Brown Saltpetre
Tom Dailey
Coffee County
Riley Creek (Duke)
Saltpetre
Cumberland County
Grassy Cove Saltpetre
Dekalb County
Avant
Gracey
Indian Grave Point
Overall
Snow Hill
Temperance
Fentress County
Buffalo
Campbell Saltpetre
Cobb Creek Saltpetre
Copely Saltpetre
East Fork Saltpetre
Manson Saltpetre
Yogdrasil
York
Zarathustra
Franklin County
Crownover Saltpetre
Lost Cove
Williams Saltpetre
Grainger County
Dunville Gap Saltpetre
Jarnigan Saltpetre Pit
Grundy County
A. Smartt

Fultz
Hubbard Saltpetre
Laurel Creek Saltpetre
Payne Saltpetre
R. C. (Ira) Winton No. 1
Woodlee

Hamblen County
Saltpetre
Saltpetre

Hamilton County
Lookout

Hawkins County
Sensabaugh Saltpetre

Hickman County
Only Saltpetre

Jackson County
Peter

Jefferson County
Animal Hill Saltpetre
Nance Ferry
Saltpetre
Tater

Knox County
Saltpetre Bluff

Lincoln County
Kelso Saltpetre

Macon County
Saltpetre (Lick Branch)
Whiteoak Saltpetre

Marion County
Gillams Saltpetre
Marion Saltpetre
Martin Saltpetre (??)
Monteagle
Nickajack
Speegle Saltpetre

Maury County
Hobbs
Southport Saltpetre

Monroe County
Craighead (Lost Sea)

Montgomery County
Bellamy

Overton County
Allred Saltpetre
Cooper Saltpetre
Copeland Saltpetre
Great Saltpetre Chasm

Perry County
Sheppard Saltpetre

Pickett County
Abbott Saltpetre
Eastport Saltpetre

Putnam County
Calfkiller Saltpetre
Johnson Saltpetre
Milligan
Nash Saltpetre
Petre

Roane County
Eblen

Robertson County
Robertson Saltpetre

Smith County
Bridgewater
Piper

Stewart County
Tobaccoport Saltpetre

Sullivan County
Buzzard
Caudill Saltpetre
Fordtown Bridge Saltpetre
Morrill

Union County
Jolley Saltpetre Pit
Oaks
Wolf

Van Buren County
Big Bone
Cagel Saltpetre
Camps Gulf
Cane Creek Saltpetre
Dig (Hitchcock's Peter Pile Pit)
McElroy
Rice
W. R. Johnson Saltpetre

Warren County
Henshaw
Hubbards
Rodgers
Solomon Saltpetre Pit

Washington County
Keplinger
Solomon Saltpetre

Wayne County
Ross Creek
Skinner (Yieser)

White County
Big Lost Creek Saltpetre
Cassville Saltpetre Pit
Cave Hill Saltpetre Pit
Cherry Saltpetre (Petre)
Lost Creek
Pollard Saltpetre
Walker Mountain Saltpetre

Wilson County
A. H. Buchanan Saltpeter
Anderson
Valley

TEXAS

Bexar County
Cibolo
Henry Weir's

Burnett County
Beaver Creek
Longhorn (Sherrard)

Comal County
Brehmmer (Brehmmer-Heldrich, Heldrich)
Bracken Bat (Bracken, Bat, Cibolo, Cibolo Creek)

Coryell County
Saltpeter

Gillespie County
Saltpeter

Travis County
Saltpeter

Uvalde County
Frio (Verdi, Frio Bat, Annandele Ranch, Florea, Uvalde)
Ney (Bandera Bat, Bat, Ney Bat)

Williams County
Beck Bat

VIRGINIA

Allegheny County
Manns Saltpetre

Augusta County
Madisons Saltpeter

Bath County
Breathing
Clarks
Millboro #1, #2
Mountain Grove Saltpeter
Starr Chapel Saltpeter
Williams
Witheros

Bland County
Hamilton
Repass Saltpeter (Barger, Bland)

Botetourt County
Peery Saltpeter

Craig County
Shires (Saltpeter) (??)

Giles County
Bluff City Saltpeter #1, #2
Canoe
Curve Saltpeter
Klotz Quarry
Saltpeter
Tawneys

Highland County
Arbegast Saltpeter
Hupmans Saltpeter
Varners
Woods-Terry

Lee County
Cattle
Cumberland Mountain Saltpeter
Gilley Saltpeter
Jasper (Mudslick)
Jones
Little Saltpeter
Minoc Saltpetre
Minors Saltpeter
Molley Wagle
Neals Saltpeter
Reasor
Skull

Page County
Saltpeter

Pulaski County
Melbane Saltpetre

Rockbridge County
Saltpetre (at Natural Bridge)

Scott County
Bucket
Burrie Saltpeter (Berry)
Kerns
Lawsons
Natural Tunnel
Parsons
Sinking Spring Saltpetre

Shenandoah County
Saltpeter

Smyth County
- Buchanan Saltpeter
- Little Saltpeter
- Tilson's Saltpeter
- Ward Saltpeter

Washington County
- Walker Mountain Saltpeter

Wise County
- Big Kennedy
- Crackers Neck
- Faust Saltpetre
- Kelly
- Little Kelly
- Little Kennedy
- Parsons
- Powell Mountain Saltpetre
- Ridge
- Rocky Hollow
- Wildcat Saltpetre

Wythe County
- Sutherland Saltpeter

WEST VIRGINIA

Grant County
- Kline Gap
- Peacock
- Spring Run Saltpetre

Greenbrier County
- Alta Vista Saltpetre
- Bob Gee
- Carlisle
- Hanna
- Higgenbotham #2, #3
- Knights Saltpetre
- Lost
- McFerrin (Saltpetre)
- Organ
- Pollock
- Seldomridge

Hardy County
- Dyer's

Mineral County
- Saltpetre

Monroe County
- Dicksons Saltpetre
- Doane Ballard
- Greenville Saltpetre
- Haynes

Pendleton County
- Cove Knob
- Cave Mountain #1, #2
- Hoffman School
- Mill Run
- New Trout
- Peter Run
- Schoolhouse
- Sinnett
- Tory's
- Trout

Pocahontas County
- Lobelia Saltpetre
- Overholt Saltpetre
- Snedegar's

Randolph County
- Crawford (Wymer's)
- Fortlick

Thrun, Robert (1982)—Saltpeter Symposium: Discussion: *NSS Bulletin* 44:120.

Saltpeter Symposium: Discussion. Robert Thrun, *8123 14th Avenue, Adelphi, Maryland 20783.*

I am skeptical of the twice-quoted (pages 95 and 103) claim that it is possible to test for saltpeter dirt by making a mark in the dirt and seeing if it disappears. I have seen footprints and scuff marks in the dirt of saltpeter caves. Many of the caves still have mattock marks in the dirt left from the Civil War. Have the authors tested this claim?

The correlation of saltpeter caves with hardwood forests, shown on page 123, is striking, but it may be coincidental. The distribution of caves, settlement patterns, and boundaries during the Civil War explains the distribution of saltpeter caves perfectly well. Also, the map on page 85 showing the distribution of saltpeter caves does not agree with the map on page 123. In particular, there are caves in Alabama that would make the correlation not as good.

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