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APRIL 1965

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Papers in any discipline of speleology are considered for publication in the BULLETIN. The upper limit for length is about 10,000 words or approximately 40 pages of manuscript, typed double-spaced. At least one copy but preferably two copies of the manuscript (typed, double-spaced) should be submitted to the Editor, Jerry D. Vineyard, Missouri Geological Survey, Box 250, Rolla, Missouri 65401. Photographs and line drawings, if required, should be submitted with the manuscript. In general, prints and line drawings will be photo-reduced to the size necessary for use in the BULLETIN.

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Discussion of papers published in the Bulletin is invited. Discussions should be 2000 words or less in length with not more than 3 illustrations. Discussions of papers in this issue should be forwarded to the editor by July 15, 1965.

Development of Tower Karst of China and North Vietnam

By Jan Šilar

ABSTRACT

The present paper deals with the origin of the tower or cone karst [*Turmkarst, Kegelkarst*] in southern China and North Vietnam. Proof is given of its origin in early Tertiary times under tropical climatic conditions. Later the climate changed and some areas were uplifted so that at present the tower karst occurs not only in the tropics but also outside that climatic zone. The early Tertiary tower karst of southeastern Asia is analogous to that of other areas in Asia and Europe where tower karst is preserved below later Tertiary deposits or where it has been modified by the Pleistocene periglacial climate.

Introduction

Extensive karst regions in southern China and the adjacent areas of North Vietnam differ by their morphology and development from karst areas in temperate climates. Besides the sinkholes, solution valleys, cliffs, subterranean streams, and caves known from other karst areas, tower-like or cone-like hills occur in this part of southeastern Asia (fig. 1).

Near the south Chinese and Vietnamese areas of tower karst are similar occurrences in Cambodia, Thailand, Laos, Burma, and Indonesia (Weber, 1958). The tower karst of these regions has been studied by several authors, especially by Daneš (1915) in the area of Goenoeng Sewoe in Indonesia, Blondel (1929) in Indochina, Lehmann (1936) in Java, von Wissmann (1954) in southeastern Asia, and Šilar (1962) in southern China and North Vietnam. The geomorphology of the south Chinese karst has been studied by Cressey (1953), Chu (1953) and Lebedev (1959). The caves in the surroundings of Kweilin, China, have been described by Chen (1958) and Schworm (1958). Balázs (1961) has investigated a whole series of significant caves in southern China from the speleologic point of view and compiled a list of them.

Tower karst is further known in the West Indies (Lehmann, 1954b), and in the Congo (Barbier, 1960). Remains of fossil pre-upper Miocene tower karst have also been described from Europe (Büdel, 1951; Tyczynska, 1958; Czudek and Demek, 1960; Tyráček, 1962). It has been considerably modified, however, by the Pleistocene climate. During his expedition to the Pamirs, U.S.S.R., J. Sekyra (pers. communication) found young tower karst at the northern foot of the Alai Mountain Range in the Kirgizian Soviet Socialist Republic.

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The author worked in China from 1957 to 1960.

I am indebted with thanks to many members of the Water-power Design Institute at Kunming, China, who enabled me to visit and study the karst regions of southern China and thus made this paper possible.

Karst Cones and Towers

Generally tower karst is considered to be a form conditioned by a tropical climate (Lehmann, 1954a). During heavy rainfall a strong surface and subterranean dissolving occurred with consequent dissection of the surface into small hills and sinkholes. The

Figure 1.
Tower karst at the Li River in Yangshuo near Kweilin, China.

deep vertical solution and the deepening of the karst depressions ceased as soon as the erosion base level had been reached, and a more intense lateral corrosion began, shaping the basal parts of the hills. Their slopes became steeper, and at their feet caves were formed. The hills were transformed into cones and towers of manifold shapes, rising separately or in groups from a common base level.

According to Lebedev (1959), the karst towers in southern China are large forms of vertical fissures (grikes) developed along joints.

In different areas of southern China and North Vietnam different forms of tower karst occur, which may partly be considered as different development stages. In some places the cones rise from a flat common base. In other places we may find depressions as well as the karst-hill (fig. 2); these forms may be compared with the cockpit karst in Jamaica (Daneš, 1914; Lehmann, 1954b). Transitions between both types exist.

The kegelkarst has developed on large areas in the southern Chinese provinces of Kwangsi, Kweichow, in some parts of Kwangtung, and in eastern Yunnan (fig. 3); in Vietnam it has developed predominantly along the shoreline of the Gulf of Tongking. In the north and along the lower course of the Yangtze the karst passes, according to von Wissmann (1954), into karstified escarpments. In these areas the individual karst towers have different shapes and sizes.

In eastern Yunnan and in Kweichow, the cone-like or haystack-like karst hills (kegel-

karst) are the most frequent (fig. 2). They reach a relative height of about 300 feet and a diameter of 300-600 feet at the foot, the sides sloping about 40-60°. In places even lower and smaller hills with gentler slopes may be found. In the area at the boundary of Yunnan, Szechuan, and Kweichow, isolated low hills rise from the plain to a height of about 150 feet. They appear to be an old developmental stage of tower karst.

From central Kweichow east and southeast toward Kwangsi Province, higher karst hills become more frequent (fig. 4), passing into the form of towers (turmkarst) with a height of 300-600 feet and more, and with steeply inclined slopes (80-90°).

Figure 2.
Tower karst of the cockpit type at the junction of Kweichow, Kwangsi, and Yunnan Provinces, China. In the foreground is a polya with a winding watercourse cut into surficial deposits and disappearing into a sinkhole. The light-colored areas are irrigated rice fields.

The same types of karst cones and towers occur in North Vietnam. The tops of the highest towers attain a common level, indicating an ancient erosion surface. Lower towers occur among the higher ones. The bases of the karst towers also frequently lie at a common level, suggesting a stable period of geomorphic development.

In the differently shaped karst hills, principally at their bases, caves of various shapes and sizes occur (fig. 5). Grikes may be found on the crests of karst hills (fig. 6), and at their feet debris sometimes accumulates. The surface of the towers is frequently covered by brushy vegetation and, in the more southern areas at lower altitudes, also by abundant tropical vegetation. In densely populated areas the surface is usually deprived of vegetation or covered with sparse grass.

In Yunnan and Kweichow the karst hills occur above the upper edge of the valley slopes; they do not occur within the valleys below this margin (fig. 7). This phenomenon was found in places where the base level of the hills had been uplifted by tectonic movement, and thus the development was rejuvenated, and deep erosion was renewed. At the margin of the Yunnan-Kweichow Plateau, a deep stream valley has been cut into the base of the uplifted tower karst.

In places, where the karstified limestone is underlain by a layer of insoluble rock, the karst hills sometimes rise from this non-karstified base. In such cases the limestone hills indicate the latest stage of the karst development preceding its destruction and represent the remnants of the disintegrated, originally continuous layer of karstified limestone, which by subsequent development was dissected into isolated towers. In these places the base of the towers or hills is not always continuous and horizontal. Its shape is rather determined by the structure of the non-karstified underlying rock.

In tower karst areas of southern China and North Vietnam the karst cones with the steepest slopes and the towers occur only in places where a common base is developed from which they rise separately. Also, in groups of a large number of towers the steeper slopes occur only at the bases where they rise from a common level. Where there is no such base level (on slopes, in highlands, or at the junction

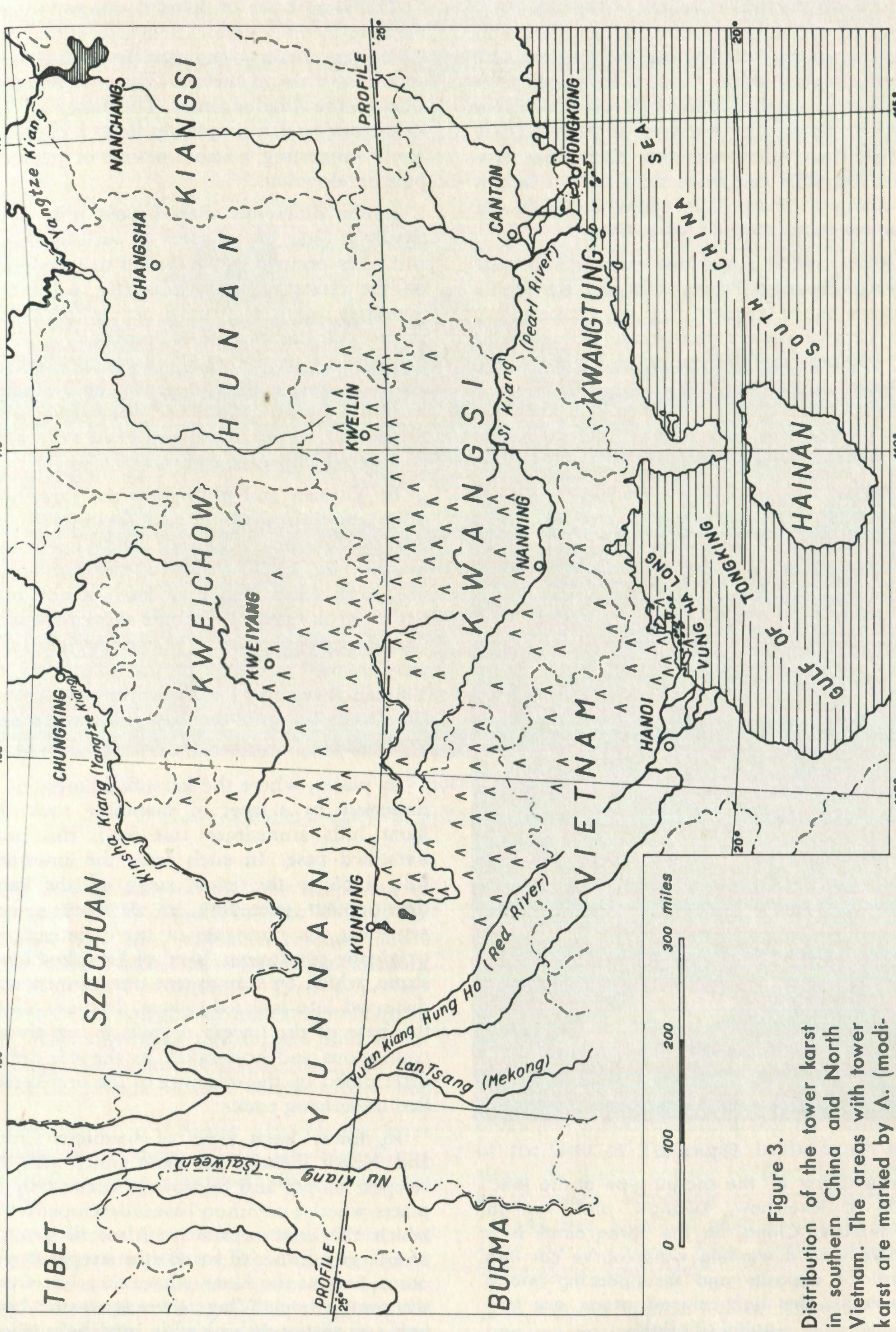

Figure 3. Distribution of the tower karst in southern China and North Vietnam. The areas with tower karst are marked by Λ. (modified from Anonymous, 1957.)

Figure 4.
Karst tower at the Li River near Kweilin, China.

between several coalescing cones), the slopes of the cones are gentler. It is obvious that the steep cones and towers lie in places where vertical corrasion and corrosion has ceased and where, after the stabilization of the erosion and karst base level, lateral cutting and dissolving grew more intense.

Sometimes, the base of karst towers was subjected to further karstification, especially if further uplift caused rejuvenation. It enabled the retrogressive erosion of streams and hence, after the subsidence of the base level, a further phase of karstification. This karstification belongs to another phase of development than the karst towers. Frequently, however, no signs of further karstification are visible at the base of the tower karst and below it. The towers rest on an erosion surface on which superficial water-courses flow. Only rarely superficial karst phenomena such as grikes occur. This was noticed either in regions which after the formation of the tower karst were not further uplifted (for example on the southeastern shore line of Kwangsi and in areas of North Vietnam) or in areas, which though tectonically uplifted have not yet sustained retrogressive erosion by rivers, for instance, in central Kweichow. Their karst development was not rejuvenated.

In some places on the surface that the towers rest on, the rock substratum crops out; in others, younger surficial formations occur. These deposits, as far as their age may be determined, date the minimum age of the tower karst.

Development of Tower Karst

Tower karst occurs in areas situated at low latitudes with prevailing tropical or subtropical climates (Indonesia, Malaya, and West

Figure 5.

Cave at the foot of a karst tower in Kweilin, China, traversed by a channel of the Li River.

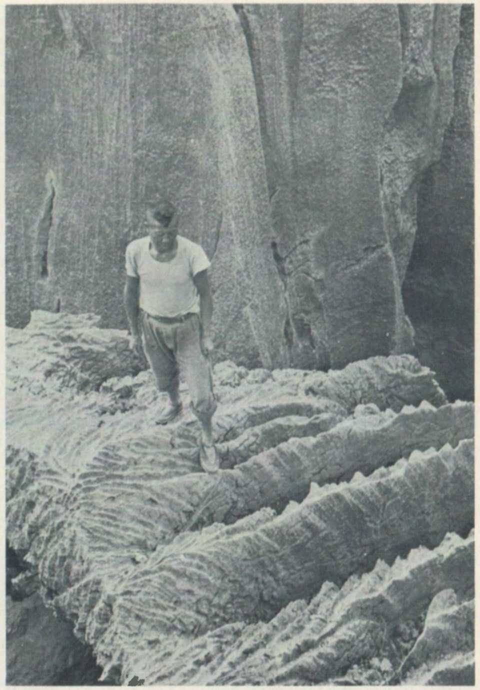

Figure 6.

Secondary rill-marked grikes on the surface of old grikes on collapsed limestone blocks in the "Stone Forest," 75 miles east of Kunming, China.

Indies). In China it reaches farther to the north, as far as 30°N lat. (von Wissmann, 1954). All these areas are distinguished by heavy rainfall (fig. 8). The dependency of the occurrence of tower karst on the latitude is striking. The climate is a decisive agent in its development. This dependency, however, cannot be deduced only from the present-day climatic conditions, as in most areas its origin dates from earlier times.

Ma (1940), studying the climatic changes which have occurred during past geologic periods in eastern Asia by the corals on marine terraces in Japan, found that in the Pleistocene the equator was situated 5° more northerly than at present. In the Tertiary, the latitude was different, too. The lateritic deposits in southern China, which de Chardin (1936-1937) assigns to the Pliocene, indicate a tropical climate during that period. If in the Tertiary the area of tropical climate extended farther to the north it is not surprising that the tower karst in southern China occurs at higher latitudes. According to Köppen and Wegener (1942), in Eocene and Cretaceous times the equator ran from southeastern Asia in a northwest direction over the Himalayan arch to western Asia and southern Europe. This corresponds with the age and distribution of the tower karst in southeastern Asia and with its buried remains in central Asia and Europe.

Besides the climate, geologic conditions also affected the development of the tower karst.

The Chinese and Vietnamese karst areas possess a great thickness of carbonate rock and a considerable territorial distribution. This can be explained by the lithologic and palaeogeographic development of the whole region, which from the Proterozoic up to the Permian and in some places up to the Triassic was

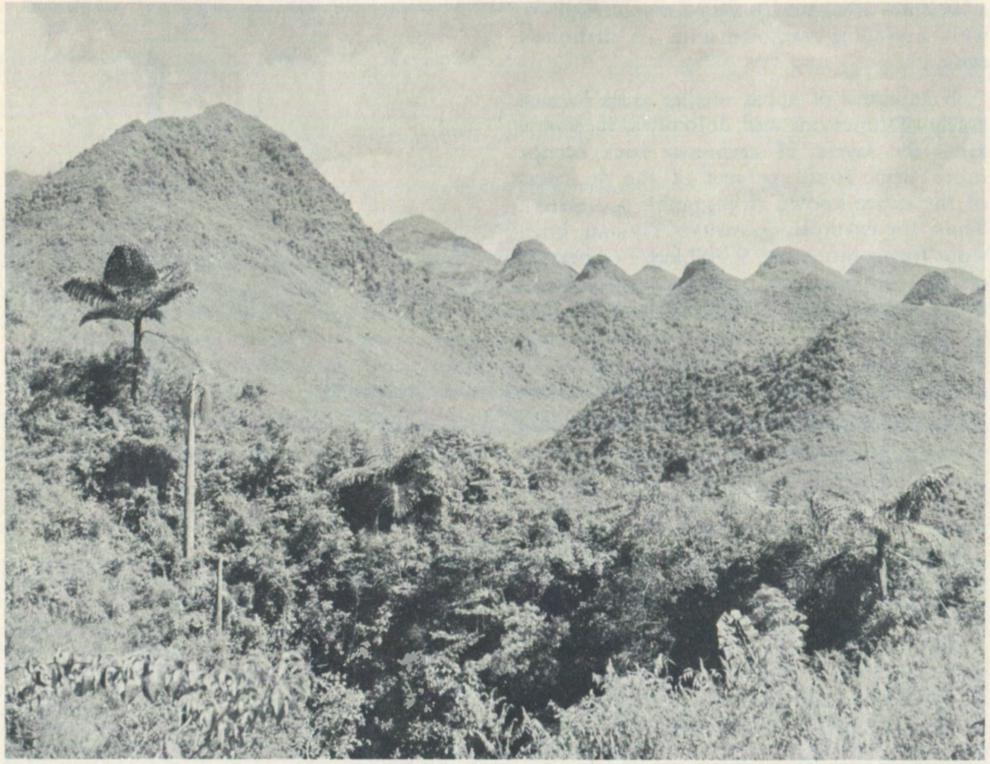

Figure 7.

Haystack-like hills of tower karst in southeast Yunnan, China, at the margin of the Red River (Hung Ho) Valley.

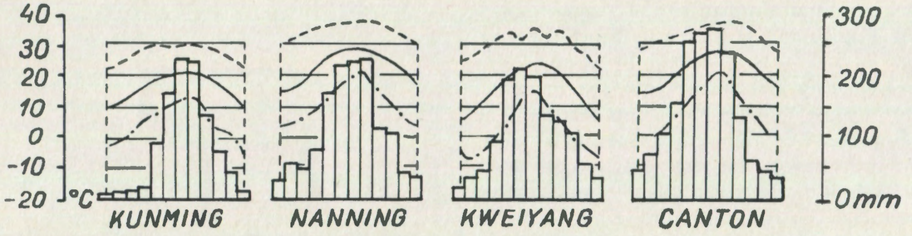

Figure 8.

Rainfall and temperature in southern China. Histograms--monthly rainfall; dashed lines--maximum monthly temperature; solid lines--mean monthly temperature; dot-dashed lines--minimum monthly temperature. (After Anonymous, 1957.)

a marine area, nearly without interruption, with prevailing sedimentation of carbonate rock.

Irrespective of some smaller areas formed solely of limestone and dolomites, in several areas the layers of carbonate rock occupy more than 50-60 percent of the thickness of the entire known stratigraphic succession. Thus, for example, in eastern Yunnan, limestone forms more than 9,000 feet – 63 percent of the entire known thickness of all strata which equals about 15,600 feet from the Proterozoic up to the Quaternary. In some parts of Kwangsi, limestone occupies up to 73 percent of the whole stratigraphic succession.

As a consequence of the Yenshan folding and the Himalayan fault tectonics whose intensity decreased from west to east, the areas occupied by limestone increase in the same direction. A further cause is the lithologic character in the eastern part of the area, with carbonate rocks developed to a greater thickness than in the west.

The existence of large continuous karst areas covering several hundred square miles in the Kwangsi and Kweichow provinces and spreading to the west as far as eastern Yunnan can also be explained by the tectonics. In central and western Yunnan the layers of limestone are broken and deformed into smaller blocks and folds.

The karst development was substantially influenced by tectonic uplift. The Yenshan folding was succeeded by a relatively quiescent period. During the Tertiary, uplift accompanied by fault tectonics, occurred in several phases, culminating in the Himalayan uplift. The height of the uplift increases from east to west (fig. 9). The present surface rises from Kwangsi to Kweichow and Yunnan to the Yunnan-Kweichow Plateau and farther into Tibet. The uplifted surface was dissected by young deep rivers, cutting headward from the marginal parts into the Yunnan-Kweichow Plateau. The development of valleys, the formation of talus, fans, and terraces, the tectonics, and the active seismicity indicate that the uplift and tectonic movement is still going on. Karst areas in different developmental stages occur both in the uplifted areas (Yunnan, Kweichow, western Kwangsi), and in the not uplifted (eastern Kwangsi) or even subsided areas (part of the shore of North Vietnam).

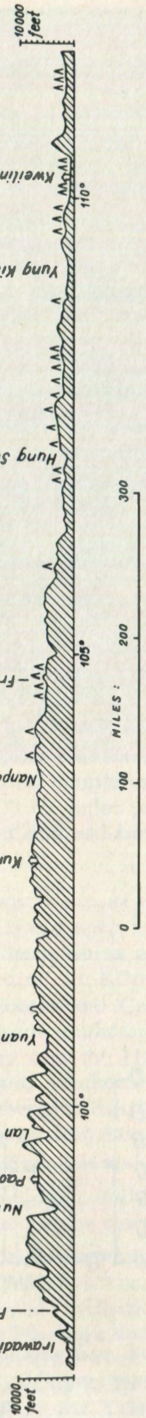

Figure 9

Section across the Yunnan-Kweichow Plateau along the 25th parallel. A–areas with tower karst.

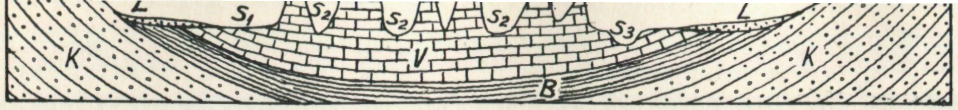

Figure 10.

Diagrammatic section through the tower karst near Kweilin in Kwangsi, China. K--Paleozoic quartzite; B--Paleozoic shale; V--Paleozoic limestone; L--lateritic sediment of late Pliocene alluvial fans; S--level of old karst surface; S --lower outer karst level, in places covered by lower Tertiary redbeds; S --lower inner karst level; S --lower level of canyon floors. (After de Chardin, and others, 1935.)

Figure 11.

Tower karst with the base submerged below sea level at an archipelago in Vung Ha Long Bay (Baie d'Halong) in North Vietnam on the shore of the Gulf of Tongking.

In connection with the repeated phases of uplift, several phases of karst formation are visible, the younger of them having been conditioned by rejuvenation. Several cave levels may be found, corresponding with the levels of river terraces. The tower karst, however, occurs only on the earliest and uppermost levels; in the uplifted areas with deep valleys it may be found only on the level above the upper margin of the valley (for example in Kweichow and Yunnan).

The tops of the higher karst towers form a crude level and indicate the level of the ancient disturbed peneplain, or of the ancient floor of the valley. South of Kweilin and in the surroundings of Liuchow, this level passes in places into the continuous surface of an old terrace. The tower karst is therefore younger than this terrace level, eventually in other areas younger than the old peneplain (fig. 10). De Chardin and others (1935) compare this level with the stage of the peneplain of Peitai in northern China. Between the karst hills, red continental sediment was laid down in places, which De Chardin considers to be "rather of Eocene and Oligocene than of Cretaceous age". According to this statement, the tower karst would be at least of lower Oligocene age.

The age of the tower karst may be established in the tectonically uplifted areas of the Yunnan-Kweichow Plateau. In central Kweichow, early Tertiary sediment was deposited between the towers. In central and southern Yunnan, the tower karst occurs on an elevated peneplain beyond the margins of the Tertiary basins, which originated in the Miocene as grabens. It is pre-tectonic, Oligocene or earlier in age. The limestone underlying the Pliocene sediment is karstified. In the environs of Lunan, the karstified limestone rises to the surface forming the base of the red continental sediment, which Bien (1940) presumes to be Eocene in age. On the Yunnan-Kweichow Plateau, stream valleys were cut deeply below the base of the karst cones. The retrogressive erosion was caused by the uplift of the Yunnan-Kweichow Plateau, which began as early as the Miocene Epoch. The tower karst is older than the downcutting of the valleys.

It may therefore be concluded that the tower karst originated in the early Tertiary, or at the boundary between the Cretaceous and Tertiary, during the tectonic rest following the Yenshan folding and before the beginning of the uplift that in southern China was a response to the Himalayan movement which began in the Miocene.

Origin of the Tower Karst

Cressey (1955) explains the evolution of the tower karst as follows: "The three provinces of Yunnan, Kweichow, and Kwangsi form an evolutionary solution sequence from west to east. Central Yunnan is a hilly plateau, fully a mile above sea level, with a few canyons and deep sinkholes. Here is the initial stage of karst development . . . In the adjoining province of Kweichow, most of the area is intricately dissected and in steep slopes, to 45° and even 60°. The plateau surface has nearly disappeared because of the enlargement of the sinks and further solution of the limestone. Original surfaces are present only as residual summits . . . Farther east, in Kwangsi, the cycle of erosion has proceeded still further and approaches old stage. Sizable areas of lowland level plain have been developed and only residual spires remain to mark the areas between the once scattered sinkholes. Some of these towering remnants are striking.

"If the solution process is 10 percent complete in Yunnan, and 50 percent complete in Kweichow, 10 percent of the original limestone has been removed in Kwangsi. Thus in Yunnan, level land is formed only at the original upper level; in Kwangsi it is present at the new lower surface; while in the intermediate Kweichow there is little flat land at any level."

Cressey (1955) thus explains the origin of the tower karst by the gradual dissection of the Yunnan-Kweichow Plateau toward the east. The level of the crests in the east corresponds to the surface of the plateau in the west. A similar explanation was given by Blondel (1929).

Actually, however, in Yunnan similar forms of tower karst were established as in Kwangsi, only with the difference that in Yunnan young deep stream valleys are cut into the ancient base level of the towers. In Kwangsi these deep valleys are missing and the erosion manifests itself only by shallow cutting of the plain. The Yunnan canyons do not correspond in age to the period of erosion and karstification during which the tower karst in Kwangsi originated, according to Cressey's explanation, but are much younger.

Figure 12.
Perforated remnants of karst towers at sea level with undercut bases, VungHa Long Bay, North Vietnam. Photo by B. Pavlickova.

In central and eastern Yunnan and in the eastern part of Kwangsi and Kweichow, the mature tower karst was uplifted between the Miocene and the Quaternary. This uplift was a response to the folding of the Himalayan geosyncline. In consequence of the uplift, river erosion began again, the erosion surface sank below the level of the existing towers, and dissolving was renewed. In some places near the shore of North Vietnam the tower karst sank below sea level (fig. 11). Between the archipelago of Vung Ha Long Bay (also known under the French name Baie d'Halong) the base of the tower karst has subsided to a depth of as much as 75 feet below the present sea level, above which only the tops of the towers emerge (fig. 12). The original subsidence was probably greater and the area was uplifted later. This is shown by shore terraces at an altitude of 45-60 feet, whose levels correspond to those of caves on several islands. Similar movements have also been known from some other places on the southern Chinese shoreline. Lin (1937) described them from the environs of Foochow, Canton, and Hongkong. Panzer (1935) reports an elevation of the shoreline of the Gulf of Tongking to a point halfway between Hong Kong and Swatow. The final development of the tower karst was therefore diverse in different parts of southeastern Asia.

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Free Living Mites (Acarina) in Caves of the Eastern United States

By John R. Holsinger

ABSTRACT

The free living, cave-associated Acarina of North America are poorly known, and the literature regarding these forms is fragmentary. To date, representatives of 13 families of mites have been collected from caves in the eastern United States but only a few species have been determined. Two families, Rhagidiidae and Parasitidae, are relatively abundant in a number of caves, and within these two groups several troglobites appear to have evolved. Taxonomically and ecologically, European and North American cave mite faunas appear to be closely related. The study of cave acarology in the United States is, at best, in its early stages. Future investigations in this field should provide a wealth of new and pertinent information on the systematics and biology of these animals.

INTRODUCTION

Acarina have been known from North America caves since the biospeleological investigations of A. S. Packard (1888). Though recognized early in the history of American speleology and apparently rather common in caves, subterranean inhabitants of the order Acarina are the most poorly known of all terrestrial cavernicoles. The unfortunate lack of knowledge of this group is, however, better understood when one is made aware of the corresponding dearth of information on many epigean mites, especially free living forms associated with organic litter and upper soil strata. New genera and perhaps even new families remain to be discovered among the poorly known but rich and varied edaphic acaridan fauna.

The present paucity of information on cavernicolous Acarina is perhaps attributable to the extremely small size and, in many instances, cryptic habits of these animals. Many investigators, in seeking out larger and more obvious cavernicoles, have undoubtedly overlooked or neglected a large number of these minute organisms.

It is hoped that this paper will serve a twofold purpose: (a) to bring together and present in chronological order the fragmentary published literature on the free living, North American cave Acarina, and (b) to present preliminary data on all free living mites that are now known from caves of the eastern United States.

A large percentage of the material included in this paper was collected by the writer and Thomas C. Barr, Jr. from Appalachian, Kentucky, and central Tennessee caves as part of an overall survey of the cave invertebrates of the eastern United States. Additional material, known only to the writer from the literature, has been included in order that a more complete distributional picture might be given.

With exception of the rhagidiid mites, the remainder of the acaridan material included in this paper is discussed on the generic and in some instances on the familial level. The prospect of not presenting any of these data until they could be discussed more specifically was considered, but it was finally decided that early publication would have certain advantages. If this preliminary report does no more than initiate incentive for a detailed and long needed taxonomic study of American cave mites then it has achieved a useful purpose.

Historical Review

Mites were first reported from caves in the United States by Packard (1888) in his classical treatise on North American cave fauna. Packard described 10 species from caves in Kentucky, Indiana, and Virginia, but his figures and descriptions are so inadequate that attempts to make critical comparisons with more recent material have been futile. Banks (in Call, 1897) described *Linopodes mammouthia* and *Rhagidia cavicola* from Mammoth Cave, Kentucky, but neither Banks' figures nor descriptions are diagnostic and have been of little value.

Banta (1907) reported the occurrence of three different types of Acarina from Mayfield's Cave, Monroe County, Indiana. His report mentioned *Rhagidia cavicola* Banks and two unidentified parastic forms, but no figures or analytic descriptions were included. During the same year that Banta's book appeared, Banks (1907) listed Packard's original 10 species in his *Catalogue of the Acarina or Mites of the United States* but made no comments otherwise.

Three European papers published between 1925 and 1938 included information on North American cave mites. Vitzthum (1925) in a treatment of subterranean mite fauna reassigned nine of Packard's 10 original species to different genera. The first reference to aquatic cave acarids from the United States was made by Walter (in Bolivar and Jeannel, 1931), who described two new species of the family Halacaridae and reported a third, previously known European form from Donaldson's Cave, Lawrence County, Indiana. Wolf (1934-1938) listed a total of 15 species of North American cavernicolous mites in his extensive *Animalium Cavernarum Catalogus.*

Thor and Willmann (1941), in their monograph on the family Rhagidiidae, listed *Rhagidia cavicola* Banks as a valid species but referred two of Packard's 1888 species – *Rhagidia cavernarum* (Packard) and *Rhagidia weyerensis* (Packard) – to a list entitled "Unsichere R. Arten" or uncertain species of *Rhagidia.* They did, however, present the opinion that all three of these aforementioned rhagidiid mites might represent a single species.

Muma (*in* Fowler, 1942) listed three larvae of the family Parasitidae from Mt. Etna Cave, near Cavetown, Maryland. Hubricht (1950) in a short paper on the invetebrate fauna of Ozark caves briefly mentioned but did not elaborate on the occurrence of several blind, unpigmented mites from caves in that region. In a revision of the family Veigaiaidae, Farrier (1957) briefly discussed *Laelaps wyandottensis* Packard (one of Packard's 1888 species) and followed Wolf (1934-1938) by placing it in the genus *Veigaia.* Farrier also collected nymphs of *Veigaia bakeri* Farrier from Wyandotte Cave, Crawford County, Indiana.

Baker and Wharton (1952) made cursory reference to the association of the veigaiaid and rhagidiid mites with caves and referred to the work of Willman on veigaiaids from European caves. Barr (1958) reported four genera of Acarina (*Laelaps, Gymnolaelaps, Rhagidia,* and *Linopodes*) from caves in southern Kentucky and central Tennessee but specific localities were not given.

Nicholas (1960) recognized both of Banks' 1897 species from Mammoth Cave and included them in a checklist of the troglobitic organisms of the United States. Finally, the writer (Holsinger, 1963; 1964) reported three families (Rhagidiidae, Parasitidae, and Laelaptidae) from several caves in the central Appalachians (Virginia and West Virginia).

ANNOTATED LIST

Suborder MESOSTIGMATA

Family PARASITIDAE Oudemans, 1901

In caves parasitids rank second only to rhagidiids in abundance. Parasitid mites are comparatively large and predaceous, and in caves they are usually associated with damp, decaying vegetable material or guano. In Woodard Cave, Green County, Kentucky, a population estimated to contain over 1,000 individuals was observed on the surface of wet guano under the abandoned site of a colony of the gray bat, *Myotis grisescens* (Howell). Epigean populations are characteristically

found in organic matter such as leaf litter and rotting wood (Baker and Wharton, 1952).

Parasitid mites are well known from European caves where more than 24 cave-associated species, of which the majority belong to the genera *Eugamasus* and *Pergamasus,* have been reported (Wolf, 1934-1938; Leruth, 1939; Hazelton and Glennie, 1962; Gueorguiev and Beron, 1962). Most of the European forms are apparently troglophiles and trogloxenes (Andre, 1949), although Hazelton and Glennie (1962) have referred to *Eugamasus anglocavernarum* Turk as a troglobite in the caves of Great Britian.

Whether or not any of the American parasitids are troglobitic is debatable. Life cycles as well as delimitation and distribution of species is still so poorly known that a good answer to this question is not yet possible. The occurrence of nymphs and ovigerous females, and the relative abundance and apparent successful existence of these mites in caves seems to indicate at least a troglophilic status, however.

Material from caves in the eastern United States has been worked out only to the generic level:

Eugamasus sp.

Kentucky: Woodard Cave*, Green Co. *Virginia:* Banners Corner Cave, Russell Co.; Alley Cave No. 2, Scott Co.; Cassel Farm Cave, Tazewell Co. *West Virginia:* Ludington Cave, Greenbrier Co.; Mystic Cave, Pendleton Co.

Pergamasus sp.

Kentucky: Patterson Cave, Hardin Co. *Pennsylvania:* Goss Cave, Mifflin Co. *Virginia:* Banners Corner Cave, Russell Co. *West Virginia:* Tub Cave, Pocahontas Co.

Family VEIGAIAIDAE Oudemans, 1939

A number of important papers have been written by the German acarologist Willman (see Farrier, 1957) on the cave-associated species of this family in Europe. To date the veigaiaids are known from only two caves in the eastern United States* and occur as follows:

Veigaia wyandottensis (Packard)

Indiana: Little Wyandotte Cave, Crawford Co. (known only from type locality)

Veigaia bakeri Farrier

Indiana: Wyandotte Cave, Crawford Co. (nymphs only)

Farrier (1957) discussed Packard's 1888 species in some detail and indicated that he had been unable to locate the type series. In the absence of type material and because of Packard's non-diagnostic description, a search of the type locality (Little Wyandotte Cave) was made but was unfruitful. Attempts to find this species in nearby Wyandotte Cave ended in the discovery of several nymphs of *V. bakeri* (Farrier, 1957).

Family LAELAPTIDAE Berlese, 1892

Laelaptids make up one of the largest and most widely distributed families in the suborder Mesostigmata. A large percentage of those species studied are ectoparasites, and many of them occur on mammals. A number of free living forms exist, however, but at present they are poorly known. It is in this latter group where one is most likely to find subterranean forms. Two genera have been collected from eastern caves. Packard (1888) described *Hypoaspis cavernicola* from Mammoth Cave, Kentucky, but his vague description could apply to a number of species in this genus. Additional but undetermined material referable to this genus (*Hypoaspis*) has been collected from the type of locality of *H. cavernicola* (Mammoth Cave) and from Shenandoah Wild Cave, Shenandoah County, Virginia.

One or more species of *Androlaelaps* have been taken in Mammoth Cave, and Copelin Cave, Hart County, Kentucky; and from Shenandoah Wild Cave, Virginia. In both

* Determination of this material is somewhat doubtful. It may actually be *Parasitus* rather than *Eugamasus.*

* Cave-associated veigaiaids have also been reported from the southwestern United States. T. C. Barr, Jr. (pers. comm.) collected *Veigaia* sp. from the Lower Cave in Carlsbad Caverns, New Mexico.

Mammoth Cave and Shenandoah Wild Cave, *Androlaelaps* and *Hypoaspis* were taken together from the same collecting site. Laelaptids were collected from wood under tar paper (Martha's Vineyard) in Mammoth Cave and in decaying mammal droppings in Shenandoah Wild Cave.

Evans (1957) indicated that *Androlaelaps* was parasitic on small mammals, but Tipton (1960) implied that this genus may contain free living species. Both of the above genera are known from European caves (Wolf, 1934-1938; Leruth, 1939) where they apparently exist as troglophiles.

FAMILY MACROCHELIDAE VITZTHUM, 1930

Macrochelids are one of the more common families in the suborder and are known from a variety of habitats including soil, humus, and in association with invertebrates and vertebrates. Packard (1888) described two species from Kentucky caves and Wolf (1934-1938) listed four species from European caves. A number of macrochelids were recently collected from Woodard Cave, Green County, Kentucky, where they were greatly outnumbered by parasitid mites (see earlier discussion) on the surface of wet bat guano. In Mammoth Cave, Kentucky, numerous specimens of *Macrocheles* sp. have been collected from rotten meat bait in the Radio Room.

One genus, *Macrocheles,* is known from American caves and is distributed as follows:

Macrocheles stygius (Packard)*

Kentucky: Bat Cave, Carter Co. (known only from type locality)

Macrocheles troglodytes (Packard)*

Kentucky: Mammoth Cave Edmonson Co. (known only from type locality)

Macrocheles sp.

Kentucky: Woodard Cave, Green Co.; Mammoth Cave, Edmonson Co.

SUBORDER IXODIDES

FAMILY IXODIDAE MURRAY, 1877

The occurrence of ticks in caves is undoubtedly through introduction by host forms such as bats, raccoons, and other trogloxenic vertebrates. In European caves *Ixodes vespertilionis* Koch is the most common and best known bat ectoparasite, and according to Jeannel (1926) this species is often collected in the free state on cave walls.

One specimen of the genus *Ixodes* but otherwise undeterminable (due to lack of a large series which is almost mandatory for determination of species in this genus) was collected from a clay bank about 300 feet inside of Copelin Cave, Hart County, Kentucky, on April 22, 1961.

SUBORDER TROMBIDIFORMES

FAMILY RHAGIDIIDAE OUDEMANS, 1922

The genus *Rhagidia** is commonly associated with caves both in the United States as well as in Europe. Wolf (1934-1938) listed eight species of this genus as being associated with caves and more recently Thor and Willmann (1941), in their monograph on the family Rhagidiidae, indicated that 13 or more species of *Rhagidia* had been reported from caves. It would appear, however, that only a small percentage of the cave associated *Rhagidia* are actually troglobites. Vandel (1964), in a brief discussion on cave Acarina, indicated that among the European rhagidiids, he considered only *Rhagidia terricola* (*gigas*) a true troglobite. In the epigean environment rhagidiids are usually found in cool, dark, moist habitats (e.g., under rocks, forest debris, moss, etc.) and because of this apparent ecological preference for such areas, it is not unusual that these animals should also occur in caves.

Two species of the genus *Rhagidia* are presently recognized from caves in the United States (Holsinger, in press) and both are probably troglobitic. These species are *R. weyerensis* (Packard) from Grand Caverns, Augusta County, Virginia and *R. cavernarum* (Packard) from a number of caves in south-central Kentucky and central Tennessee. *Rhagidia cavicola* Banks, known only from Mammoth Cave, Kentucky is considered to be a synonym of *R. cavernarum* (Holsinger, in press). A number of new species of cavernicolous rhagidiid mites have been collected from other caves in the eastern United States and currently await description.

*The validity of both of these species is questionable.

* A more detailed taxonomic study on the cavernicolous forms of this group is being published elsewhere.

The following is a preliminary list of the rhagidiid mites presently known from caves in the United States:

Rhagidia weyerensis (Packard)

Virginia: Grand Caverns (Weyers Cave), Augusta Co. (known only from type locality)

Rhagidia cavernarum (Packard)

Kentucky: Long Cave (type locality), Mammoth Cave, and White Cave (c.f., Packard, 1888), Edmonson Co.; Barnes Smith Cave, Hart Co.; Wind Cave, Pulaski Co. *Tennessee:* McElroy Cave, Van Buren Co.; Reed Creek Cave, Fentress Co.; Wanamaker Cave, Grundy Co.

Rhagidia sp.

Alabama: Guffey Cave, Marshall Co.; *Indiana:* Mayfield's Cave. Monroe Co. (cf., Banta, 1907). *Kentucky:* Water Cave, Letcher Co. *Virginia:* Ruff Caldwell Cave, Craig Co.; Starnes Cave, Giles Co.

FAMILY EUPODIDAE KOCH, 1842

This family is represented in European and North American caves by one genus, *Linopodes,* and possibly by no more than one species. *Linopodes motatorius* Linnaeus is a common European eupodid mite recorded from both hypogean and epigean habitats. Banks (Call, 1897) described *Linopodes mammouthia* from Mammoth Cave, Kentucky, and Call (in the same paper, 1897) noted that he had collected this mite from the underside of damp sticks and stones where it was associated with collembolans. Although Banks briefly described and poorly figured this species, his description could easily have applied to *Linopodes antennaepes* Banks (an epigean species) which he had described three years before. Recently, Baker and Wharton (1952) suggested the possibility that *L. antennaepes* might be synonymous with *L. motatorius,* and this suggestion in turn leads to the possibility that *L. mammouthia* may also be a synonym of the latter species.

Eight specimens of *Linopodes* were recently collected from a pile of damp wood and assorted vegetable debris on a clay bank above a stream in Slacks Cave, Scott County, Kentucky. In addition, a ninth specimen was taken from rotting wood in the bottom of the sink hole entrance to this cave on the same date. The material from Slacks Cave generally agrees with Banks' description of *L. mammouthia* and differs only in the faintness of the silvery T mark on the dorsum and by the fact that three of the nine specimens lacked eyes. The remainder of these specimens as well as the sinkhole form possessed the "shining eyes" noted by Banks in his description of the Mammoth Cave species. The Slacks Cave material appears to belong to the same species as that which occurs in Mammoth Cave. The loss of eyes in some individuals is perhaps significant only in that it indicates a certain degree of phenotypic plasticity, a situation which the writer has also observed in a number of cavernicolous spiders and opilionids.

FAMILY LABIDOSTOMMIDAE OUDEMANS, 1904

Two specimens of *Labidostomma neotropica* Stoll were collected from McElroy Cave, Van Buren County, Tennessee, by T. C. Barr, Jr. in January, 1960. According to Baker and Wharton (1952) this species is known from epigean habitats (in moss, humus, and soil) from the southern United States south to Panama. The genus *Labidostomma* has also been reported from European caves (Wolf, 1934-1938).

FAMILY TROMBIDIIDAE LEACH, 1815

Packard (1888) described "*Sejus ? sanborni*" from a cave near Dismal Creek, Kentucky, and Vitzthum (1925), but apparently with some doubt, placed it in the genus *Microtrombidium.* Trombidiid mites constitute one of the largest groups in the suborder Trombidiformes but few cave associated species appear to have been reported (cf., Wolf, 1934-1938; Leruth, 1939; Aellen and Strinati, 1962).

FAMILY HALACARIDAE MURRAY, 1876

While predominantly a marine group, a number of fresh water species of the halacarids are known, and several of these are from aquatic cave habitats. Walter (in Bolivar and Jeannel, 1931) described two species and listed a third previously known species from Donaldson's Cave, Lawrence County, Indiana. All three are apparently troglobites. They occur as follows:

Hamohalacarus subterraneus Walter (known only from Donaldson's Cave), *Soldanellonyx chapuisi* Walter (Donaldson's Cave and also from caves in Switzerland and Belgium), and *Soldanellonyx morardi* Walter (known only from Donaldson's Cave).

Suborder SARCOPTIFORMES
(Supercohort Oribatei)

Family GALUMNIDAE Grandjean, 1936

Galumna alata (Packard) was described from Dixon's Cave, Edmonson County, Kentucky, by Packard (1888). Packard's figure for this species, while not detailed, leaves little doubt that this form is a galumnid mite. The large, wing like pteromorphs, rounded anteriorly and posteriorly and figured by Packard for this species are generally diagnostic for the family Galumnidae. A recent collection of 30 oribatids from Reed Creek Cave, Fentress County, Tennessee, appear to belong to the same genus as that which occurs in Dixon's Cave. Specific determination has not been made to date.

Family BELBIDAE Willmann, 1931

This family is well represented in European caves by the genus *Belba,* and five or more species have been reported from caves in that area (Wolf, 1934-1938; Hazelton and Glennie, 1962). Andre (1949) briefly discussed the cave association of this genus and indicated that at least one species was a potential troglobite. In the United States a single cave species, *Belba bulbipedata* (Packard) is known from Dixon's Cave, Edmonson County, Kentucky.

Family CERATOZETIDAE Jacot, 1925

Wolf (1934-1938) listed six genera and six species of this family from caves in Europe and Algeria, but to date the group is poorly known from North American caves. A single ovigerous female (with ovipositor extended), belonging to the genus *Ceratozetes* and possibly close to *C. gracilis* (Michael), was collected from *Hadenoecus* guano near Fairy Grotto, Mammoth Cave, Kentucky, in September, 1961, by T. C. Barr and determined by J. A. Wallwork.

Summary and Conclusions

A historical review of the literature concerning the free living, cave associated Acarina of the eastern United States and a discussion of 13 families of mites with known cavernicole representatives have been given. Although cavernicolous Acarina have been recognized in North America since 1888 very little, if any, definitive work has ever been done on them.

Recent collecting in caves of the eastern United States indicates that several types of mites are widespread in subterranean habitats of this area and that in some caves, Acarina contribute substantially to the faunal assemblage.

Of the 13 families reported in this study only two, Rhagidiidae and Parasitidae, have been found in great abundance in caves. The rhagidiids are represented in caves by the genus *Rhagidia* and several species, all of which may be obligatory cavernicoles. Parasitids are represented in caves by two and possibly three genera and a number of undertermined species. The majority of cavernicolous parasitids appear to be troglophiles although more critical taxonomic studies are needed on this group before the exact nature of their relationship with caves can be fully understood. A number of other mite families such as Macrochelidae, Laelaptidae, Galumnidae, and Eupodidae, have been reported from two or more caves and all four of these groups probably contain troglophiles.

The similarities that exist between the types of cavernicolous mites in North America and those in Europe show a striking correlation and are interpreted as reflecting more than just a casual relationship of certain groups of Acarina with caves. Rhagidiids as well as parasitids are abundant and widespread in European caves and of the remaining families thus far recorded from American caves, all have likewise been reported from caves on the European continent. Furthermore, all of the mites reported from American as well as European caves belong to groups composed essentially of animals restricted to cool, dark, moist epigean habitats such as in humus, in crevices, and under rocks and piles of organic detritus. Invasion and in some instances successful colonization of caves by members of a fauna physiologically and morphologically suited for occupying such habitats seems to be a logical assumption. A large number of the cave associated acarinids are troglophiles or habitual trogloxenes, but others such as certain rhagidiids have apparently become so well adapted to caves that they can occur nowhere else.

The study of cave acarology in this country is in its early stages. Additional biological exploration of caves with emphasis on the more minute invertebrates should reveal a rich and varied mite fauna. Moreover, studies on ecological associations and physiological adaptations are certain to provide a wealth of heretofore unknown information.

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A Method of Contouring Cave Maps

By Derek C. Ford

ABSTRACT

Gradients and topographic relationships in a cave may be displayed by linking ceiling or floor points of equal elevation in different passages or rooms, with contours. Where drawn through the intervening rock the contours are inflected to show the passages as valleys or spurs, whichever is appropriate. The method is intended to give the viewer who is not familiar with a particular cave a better impression of its topography than is provided by the conventional cave map.

Introduction

It is difficult to show the simple geographical organization of caves. Standard plans and sections can be used, but they are not wholly satisfactory. Spot ceiling heights in cave passages do not show at a glance the height relationship between one part of a cavern and another, nor do they suggest gradients of ascent or descent, or changes of gradient. Such information may be gained by reference to the section, but where there is any complexity of plan form it is often necessary to project on a fixed bearing, thus distorting the gradient, or to offset or omit different passages which share the same elevation. The reader's attention must shift back and forth from plan to section. Contour maps show the interrelationships of three dimensions in one picture. The following discussion illustrates a method of contouring maps of caves to bring the dimensional interrelationships into a similar, single picture for the purpose of giving a "first impression." The method has its limitations: it is not without ambiguity, but it is not intended to be a tool for careful analysis. It is proposed as a supplement to the standard plan and section, not as a substitution.

The Cave Contour Method

The method is demonstrated by completed contour plans. Figures 1 and 2 show contours drawn for the cave roof and floor levels of G.B. Cave, England. Approximately 4,000 feet of passages appear in each figure and the depth of the cave, entrance to lowest point, is 440 feet. The contour interval is 20 feet (this interval is appropriate to the size of the cave), and refers to elevation above mean sea level. The novelty of the method consists of extending contour lines on roof or floor to join places of equal elevation in adjacent rooms or passages* Between these places the lines pass through presumed solid rock. It will be appreciated that the contours are not indicating any measurable characteristic of the solid parting, *e.g.*, they are not an isobase plot of the dip or strike of a particular bedding plane nor do they indicate any surface along which water moves. Contour position and shape upon the blank areas of the map may therefore be manipulated to indicate relationships between passages, which do exist.

The writer's method is to make a preliminary frame of straight lines joining all points in the cave having the same elevation. The aim is to soften this angular frame, producing the flowing contour of the surficial topographic maps and highlighting interrelationships, while avoiding any great deviation from the

*So far as this writer is aware, this method has not been illustrated before.

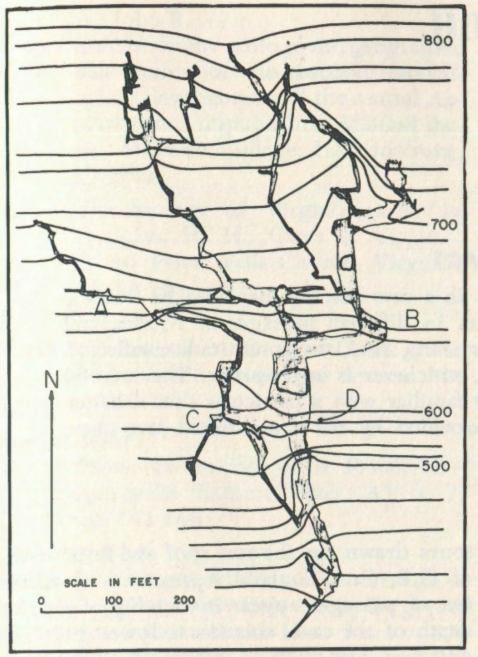

Figure 1.

Roof contour plan of G. B. Cave, Mendip Hills, England.

straight lines. The product can be read by anyone familiar with surface contour maps.

As a first modification, contours are extended from the cave toward the edges of the map sheet on bearings normal to any general descending trends in the course of the cave. This stresses such trends, as in the case of the G. B. Cave, which descends in a southerly direction.

Any cave passage will tend to collect part of the drainage from the rock about it, at and above its elevation. It may thus be thought of as of a valley within the rock. This is indicated by inflecting the contour in toward the passage, as in a shallow surficial valley.

In certain circumstances, however, passages may stand in relation to one another as alternating hillside spurs and valleys do at the headwaters of a surface system. Here, the inter-passage relationship is stressed rather than that between the individual passage and the rock that encloses it (fig. 2). The four passages, E, F, G and H (fig. 2) are inlets descending to the principal passage of the cave (the "Gorge"). Inlets E and G have been deeply entrenched by past vadose streams. F and H have not been entrenched and their floors hang above the floor of the Gorge at the junction, or drop into it exceptionally steeply. This relationship is indicated by curving the contours to suggest the sequence valley-spur-valley-spur (E-F-G-H).

Where part of a passage approaches very close to, but does not attain, a particular contour elevation the appropriate contour is displaced toward it. No other rules are needed. The rest of this section illustrates the finished cave contour map in use.

The higher, or roof parts of cave passages are often the earliest formed. In figure 1, the general regularity of the roof contouring suggests a simple origin. But along lines between points A-B and C-D, it will be noted that gradients steepen abruptly in adjacent passages. Steepening here is the product of two vertical, east-west faults. Preliminary study of a contour plan would draw the researcher's attention to the need to determine the cause underground.

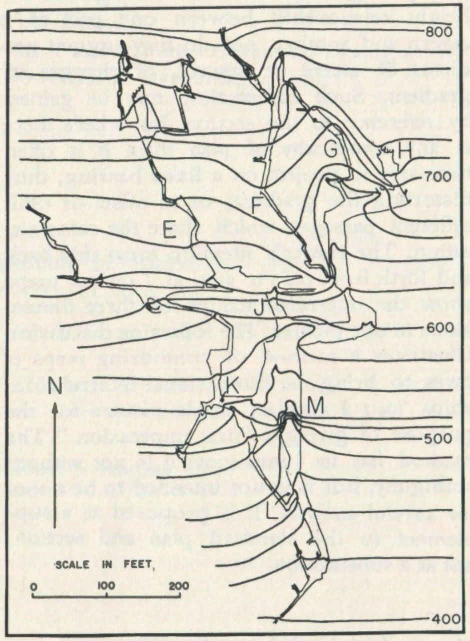

Figure 2.

Floor contour plan of G. B. Cave.

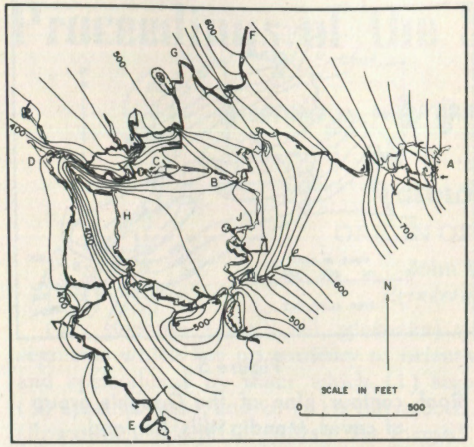

Figure 3.

Floor contour plan of Swildon's Hole, Mendip Hills, England. The arrows indicate the course of the main stream.

In figure 2, in addition to relationships already outlined, the contouring shows the very steep entry of tributaries to larger passages at J, K, and L. These may suggest a sequence of vadose captures. At M, the very steep drop-off may be related to the southerly of the east-west faults mentioned or it may be a nick point which, from changes in gradient indicated by contour distribution to the south, has retreated from some starting place close to point L. The latter explanation is the correct one.

Swildon's Hole (fig. 3), is 450 feet deep and some 14,000 feet of passages are shown. The geological position is similar to that of G. B. Cave, which is five miles away. But the contouring emphasizes that the pattern of development has been different and suggests that the cave can be divided into three physiographic type-areas: 1. Areas A-B and F-G, which are inlets of steep and irregular gradient. 2. Area C-D-E, a much flatter passage lying downstream and descending steadily. It defines the local water table and can be thought of as a Swinnertonian cave. 3. Area H-J, south and east of B-C-D-E. Trends are irregular here; the passages rise and fall and are poised steeply above the active water table cave. This is an abandoned system, developed at and below two past water tables and captured by the C-D-E passage.

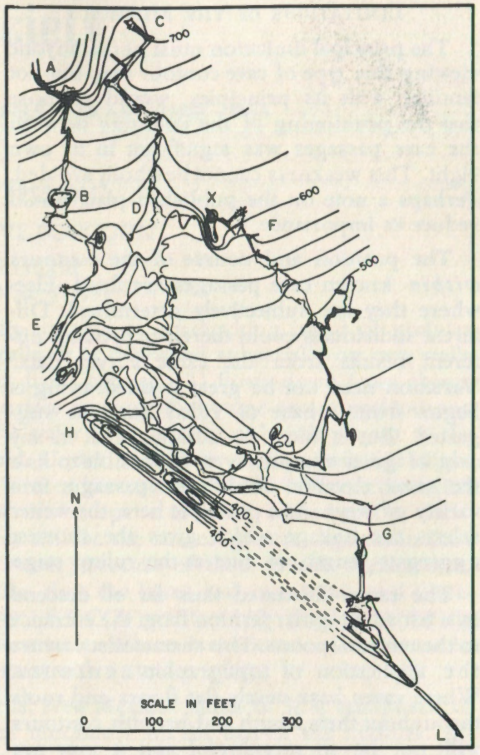

Figure 4.

Roof contour plan of St. Cuthbert's Swallet, Mendip Hills, England.

Figure 4 shows St. Cuthbert's Swallet, with 5,000 feet of passages and a total depth of 400 feet. The cave is within one mile of Swildon's Hole but the contours indicate a different form. A-B, C-D and X are steep vadose inlets that break into a much earlier phreatic complex, E-F-G. Between E and G, only the larger members of a warren of crawlways are shown. The regularity of contour distribution suggests that there may be uniform geological control. The passages follow two bedding planes across an anticline.

H-J, K-L is a great rift passage following a vertical fault. It is blocked by breakdown and stream fill between J and K but its continuity has been suggested by extending dashed contours between the two points. The contouring emphasizes its hydrological role as a single reservoir catching all drainage through the complex to the north and turning it south-east.

Limitations of the Method

The principal limitation must be that anyone viewing this type of cave contour map but not familiar with its principles, would suppose that the positioning of the contours between the cave passages was significant in its own right. This weakness cannot be wholly avoided. Perhaps a note on the published plan would reduce its importance.

The position and course of the contours *within* known cave passages are fixed. Elsewhere they are subjectively determined. Different individuals could therefore produce different results from the same survey data. Variation need not be great if the drawing is begun from a base of ruled lines, as suggested. But it must be admitted that in any area of great complexity it is possible to link the same elevation in different passages in a variety of ways. As a principle here, the writer selects the linkage which gives the shortest aggregate length of line at the ruling stage.

The caves illustrated thus far all descend in a broadly regular fashion from the entrance to the terminal points. This characteristic favors the application of topographic contours. Where caves have nearly flat floors and roofs throughout their length and breadth, contours will not be so meaningful and it may not be worth drawing them. Where there are many superimposed levels of cave passage the method may be unworkable. In all of the above examples, some short sections of cave have been omitted to avoid producing an unreadable tangle of lines. In other cases the writer has had some success by using different colors for contouring different cave levels. If the superimposition is not too complex, higher or lower

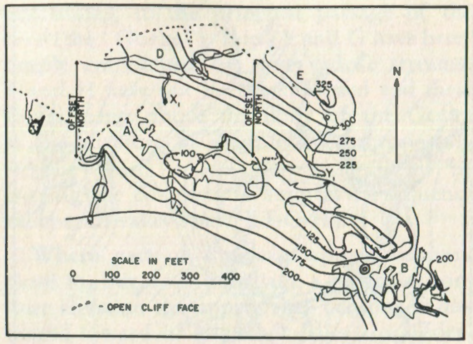

Figure 5.
Roof contour plan of the Gough's group of caves, Mendip Hills, England.

passages can be offset and contoured in the same color. Figure 5 is an example: The Gough's group of caves are an abandoned spring-head system that has been intercepted by entrenchment in a surficial river gorge. At low level, the contouring between A-B indicates the nearly flat profile of a large discharge conduit. Tall passages climb away steeply to the south (points X and Y). D and E are the remains of an overlying system, here offset to the north, which drew its water by long ascents through X-X_1 and Y-Y_1.

In conclusion, it is re-emphasized that this cave contour method is intended for general display purposes rather than careful analysis. Within the noted limitations, it can be quite illuminating. It is hoped that other workers will try the method and judge its value for themselves.

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GEOLOGY SESSION

ORIGIN OF CAVE POPCORN

John V. Thrailkill
Princeton, New Jersey

Cave popcorn (cave coral, globulite) typically consists of a branching frond of nodular segments which has no tendency to orient vertically. It is deposited subaerially on cave walls and speleothems by water which (1) seeps out from behind, (2) flows down from above, (3) splashes onto, and/or (4) is introduced by surface tension. Flowstone-group speleothems (flowstone, stalactites, gours) are formed if the water is supersaturated with respect to the carbonate being deposited or where flow is rapid. Under conditions of low flow and slight or no supersaturation, however, cave popcorn is formed because deposition is here controlled principally by the escape of CO_2. The velocity of this escape is inversely related to the thickness of the water layer, hence irregular surfaces will be the site of greater deposition than smooth surfaces (assuming equal volumes of water) because of their greater surface area. Also, the ends of nodules will have a thinner film than the bases and re-entrants and therefore grow more rapidly. If ventilation is poor, a P-CO_2 gradient may develop in the air near the wall and longer fronds will grow preferentially. Where evaporation is important in inducing supersaturation, a P-H_2O gradient may exist with a similar effect.

Cave popcorn is abundant in Carlsbad Caverns, New Mexico. Much of it is composed of hydromagnesite, which was initially deposited as moonmilk on the tips of the nodules. Although moonmilk (and cave popcorn?) is often associated with primitive plants (fungi, bacteria, algae), the above explanation probably also applies to aspects of its growth.

SOME FEATURES OF VULCANOSPELEOGENESIS

William R. Halliday,
Seattle, Washington

As has been previously outlined, lava tube caverns are far from the simple tubular conduits of popular concept. As in solutional caverns, speleogen-speleothem sequences can be deciphered. Common and some unusual speleogenetic features of these caverns were presented.

A SUMMARY OF VERTEBRATE PALEONTOLOGY IN THE CAVES OF TEXAS

Ruben M. Frank
Austin, Texas

In 1920, O. P. Hay described the first vertebrate fossils from a Texas cave; Freisenhahn Cave in Bexar County. No further work of any importance was done until 1949 when the Texas Memorial Museum excavated in the same cave and recovered over 3,000 specimens of Late Pleistocene vertebrates. In 1957 Dr. E. L. Lundelius came to the University of Texas as professor of Pleistocene vertebrate paleontology. Under his direction, vertebrate paleontology in Texas caves has gained a strong foothold. Two of his students are preparing theses on cave vertebrate paleontology, and Dr. Lundelius is currently studying the fossil bones from a number of caves throughout the state. In addition, a number of archeologically investigated shelter caves have yielded vertebrate remains of recent and subrecent age. At present there are 34 caves in the state from which vertebrate fossils of any significance have been recovered. Twelve of these have proven to be important sites and many more will undoubtedly be found in the future.

SOME OBSERVATIONS ON THE RATE OF LIMESTONE SOLUTION AND THEIR APPLICATION TO CAVES

Marjorie M. Sweeting
Albuquerque, New Mexico

As a result of the development of modern chemical techniques, we now know much more about the rates of solution of limestones in differing physiographic and climatic environments. These rates have much bearing upon the modes and rates of cave formation in different areas. Corbel is insistent that temperature is the over-riding factor responsible for the widely varying rates of solution, these being according to him much greater in cooler temperate lands than they are in the warmer tropical areas. Preliminary observations on caves have tended to support Corbel's hypothesis; temperate caves tend in general to be deeper and longer than the caves in more tropical areas. But we are now acquiring much more knowledge of caves, particularly in the Tropics such as in areas like Puerto Rico and Maylaya, and are finding large caves in those areas. Moreover, recent analyses of limestone waters, both on the surface and underground, seem to indicate that there is much less variation in the values obtained in similar limestone environments in different parts of the world than Corbel would have us believe. It is becoming clear that temperature is only one factor affecting the rates of solution of limestones; we must also take into account the nature and type of vegetation in the area, and also the physical properties of the limestones themselves (water absorbing capacity, pore space, etc.). In dealing with the rates of limestone solution, much geological work is needed.

GEOLOGY AND MINERALOGY OF THE BUTLER CAVE - SINKING CREEK SYSTEM, VIRGINIA

William B. White
University Park, Pennsylvania

The Butler Cave-Sinking Creek System, Bath County, Virginia has been partially mapped and studied. This paper is a reconnaisance report on the general geology and mineralogy. The cave pattern is that of a main trunk channel following the axis of a syncline with network pattern side caves on the flanks. The trunk channel contains several free surface streams which have been underdrained by a third free surface stream. This is ascribed to the self-perching action of the sediments in the upper streams. Butler Cave contains an excellent natural bridge, the origin of which can be ascribed to free-surface stream action. The clastic sediments of Butler Cave consist of a complex sequence of cobble fills topped with a veneer of laminated silts and manganese oxides. The chemical sediments include in one area a complex suite of calcite overgrowths on aragonite, gypsum, and hydromagnesite.

THE DEVELOPMENT OF CAVES IN GYPSUM

William H. Russell
Austin, Texas

From the study of about 40 gypsum caves in west and northwest Texas it was found that the development of caves in gypsum was quite similar to that in limestone, except that there is, in general, continued enlargement during the vadose period. Speleogenesis in gypsum begins with the formation of small water-filled tubes, varying in diameter from one to four feet; these are then drained as the area is dissected. Over 80% of the caves visited were developed where a surface stream invaded and enlarged the previously-formed tubes. This type of development has caused most large gypsum caves to be near surface streams where gradients are steep enough to enable the invading stream to clear and enlarge the underground channel. Many of these channels have loops and divergences and some are even mazes. In general, enlargement of the cave by the surface stream continues until the cave collapses, with many of the caves opening into narrow canyons probably formed by the collapse of caves. In some areas extensive gypsum karst has developed, especially in West Texas where the gypsum is very thick. The largest cave visited was River Styx Cave with more than 7,000 feet of passage, and several other caves were over a half mile in length.

THE HISTORY OF THE EVOLUTION OF THE MAP OF MAMMOTH CAVE KENTUCKY

James F. Quinlan
Austin, Texas

The first published map of Mammoth Cave was made in 1815 by Bogert. Nearly 70 other maps have been made since 1815, the most important of which are maps by Ward (1816), Lee (1835), Wood (1841), Bishop (1845), Blackall (1871), Hovey (1882 and 1907), Call (1897), Kaemper (1908), Walker (1936), and Nelson (1959). Nearly every map has its own fascinating story. The most accurate and remarkable map is that of Kaemper (1908). It shows 35 miles of passage, all that were known at that date. Nelson's map (1959) shows 32.5 miles of passage, 11 miles of which were discovered and mapped subsequent to the Kaemper survey. By comparing the Kaemper and Nelson maps the author has obtained a total of about 46 miles of surveyed passage, which probably represents 85 to 90% of the known cave. Accurate copies of the Kaemper and Nelson maps have been made by the author and will be made available at a later date.

A HYPOTHESIS FOR THE FORMATION OF RIMROCK DAMS AND GOURS

William W. Varnedoe, Jr.
Huntsville, Alabama

A process involving local pressure reduction as a precipitation causative is presented to explain the flowstone dams that often develop across cave streams and those from hot springs. The hypothesis must account for the upward growth of these formations narrowly and evenly along their top edges at right angles to the stream flow.

HELICTITE "RIBBONS": A NEW SPELEOTHEM?

Richard J. Reardon and D. N. Rimbach,
Arcadia, California

Helictites with a ribbon-like appearance, apparently formed of aragonite, occur in Lost Soldiers Cave, Sequoia-Kings Canyon National Park, California. It is believed these speleothems may be unique to this cave.

HYDROMAGNESITE SPELEOTHEMS FROM JEWEL CAVE

Dwight E. Deal
Albuquerque, New Mexico

Hydromagnesite "balloons", several centimeters long with extremely thin walls, occur in one section of Jewel Cave. They hang from the ceiling and walls of the cave and have an overlapping opening which cannot be seen until they are removed from their point of attachment. They are very fragile and are associated with hydromagnesite moonmilk deposits.

BIOLOGY SESSION

PROGRESS REPORT OF A BIOLOGICAL SURVEY OF TEXAS CAVES

James R. Reddell
Austin, Texas

In 1962 the Texas Speleological Survey began a study of the interesting and unique cave fauna of Texas. To date over 60 troglobites have been reported and while the distributions of many are fairly well outlined at least half are yet undescribed. Collecting is still incomplete and further collections are necessary for the description and study of interrelationships of some of the populations. New cave records of troglophilic and accidentally occurring species appear in almost every collection and over 300 species, including the troglobites, are presently reported from Texas caves. Of the three principal biospeleological regions in the state (the Edwards Plateau, Northwest Texas, and the Gypsum Plain of Culberson County) the Edwards Plateau is by far the most important. Only two troglobites are known from the Gypsum Plain and only one from Northwest Texas.

TEXAS CAVE BEETLES OF THE GENUS *RHADINE* (COLOEPTERA: CARABIDAE)

Thomas C. Barr, Jr.
Lexington, Kentucky

The troglophilic *Rhadine* in Texas caves include *R. araizai howdeni* Barr and Lawrence, *R. a. babcocki* Barr, *R. rubra* Barr, *R. longiceps* Van Dyke, and *R. longicollis* Benedict. The troglobitic species are smaller (average 8 mm) and have restricted distributions. They occur in caves along the Balcones Fault Zone and in caves in drainage systems running eastward from the Edwards Plateau into the fault zone. Two main groups of troglobitic species occur, represented by *R. subterranea* Van Dyke and *R. infernalis* Barr and Lawrence. In the *subterranea* group the body is extremely narrow and the terminal segments of the maxillary and libial palpi are swollen into (presumed) specialized sense organs. The *infernalis* group is more generalized. Despite this convenient subdivision, however, both groups are closely related, and all the troglobitic species are believed to be monophyletic.

SOME ECOLOGICAL STUDIES OF THE TROGLOBITIC CARABID BEETLE, *AGONUM* (*RHADINE*) *SUBTERRANEUM*

Robert W. Mitchell
Austin, Texas

A population of *Agonum* (*Rhadine*) *subterraneum* located in the Beck's Ranch Cave, Round Rock, Texas was studied. Distribution within the cave and dispersion within the areas of occurrence were determined, and factors potentially responsible were investigated. Responses of the beetles to environmental factors which might possibly influence their dispersal were also examined.

THE MILLIPEDS IN THE CAVES OF TEXAS AND ADJACENT STATES

Nell B. Causey
Baton Rouge, Louisiana

The cave millipeds of this area differ from those of the eastern United States in that there are fewer species and most of them are relics. Eleven species and subspecies representing three orders, three families, and five genera have been collected. With the exception of one troglophile in Culberson County, Texas, all are probably troglobites. They are distributed as follows: one in northern Chihuahua; one in Eddy County, New Mexico; two in Murray County, Oklahoma; one in Childress and Wheeler Counties, Texas; and five in 22 contiguous counties in central and southwestern Texas. The most abundant and widespread is *Cambala speobia* (Chamberlin), commonly known as the blind Texas milliped, with one subspecies in northern Chihuahua and another in central and southwest Texas. The four species of *Speodesmus* occupy much the same area as the latter.

EXTENSION OF THE KNOWN RANGE OF THE CRUSTACEAN ORDER THERMOSBENACEA TO THE WESTERN HEMISPHERE

Bassett Maguire, Jr.
Austin, Texas

Six specimens of a new species of *Monodella* have been collected in Ezell's Cave, San Marcos, Hays County, Texas. All previously known members of the Thermosbenacea live very near the Mediterranean Sea. *Thermosbaena mirabilis* lives in hot, saline springs in Tunisia about 25 km from the coast; *Monodella stygicola* and *M. argentarii* come from slightly brackish and fresh water respectively in caves very near the Mediterranean, and *M. halophila* is found in the salty interstitial water a few meters from the sea and in slightly brackish water in a cave near the shore of Yugoslavia. The zoogeographic implications of the discovery of the new species of Monodella in fresh waters of a cave in North America about 200 km from the Gulf of Mexico and at an altitude of about 177 meters was discussed.

A PRELIMINARY STUDY ON THE EFFECTS OF ORGANIC POLLUTION OF A CAVE ECOSYSTEM IN RUSSELL COUNTY, VIRGINIA

John R. Holsinger
Lexington, Kentucky

Four pools were observed in Banners Corner Cave, Russell County, Virginia, over a 28 month period from November 1961 to February 1964. Three of these pools were visibly polluted with sewage which had seeped into the cave from septic tanks on the hill above. All four of these pools, at one time or another during the study, contained large populations of planarians, *Phagocata subterranea* Hyman and isopods, *Asellus recurvatus* Steeves. Physiochemical and microbiological analysis of the pool water indicated that oxygen tension is as low as 2.8 ppm in one pool and coliforms as well as other bacteria (apparently saprophytic) are abundant in the contaminated waters of the cave. Further examination of the pool waters revealed a rich and varied microfauna, especially protozoans and rotifers. In addition, the polluted pools contain large amounts of colloidal materials which are believed to be rich in organic content. The influx of organic wastes is undoubtedly responsible for the basic trophic input in the aquatic environment of this cave and it is further suggested that this material serves as a rich food source for saprophytic bacteria as well as for much of the aquatic fauna, including micro- and macroforms. Precise trophic relationships between the larger aquatic organisms have not been worked out, but several significant feeding responses have been observed.

NATIONAL SPELEOLOGICAL SOCIETY

The National Speleological Society is a non-profit organization devoted to the study of caves, karst and allied phenomena. It was founded in 1940 and is chartered under the law of the District of Columbia. The Society is associated with the American Association for the Advancement of Science.

The Society serves as a central agency for the collection, preservation, and publication of information relating to speleology. It also seeks the preservation of the fauna, minerals, and natural beauty of caverns through proper conservation practices.

The Affairs of the Society are controlled by an elected Board of Governors. The Board appoints National Officers. Technical affairs of the Society are administered by a Research Committee of specialists in the fields that relate to speleology.

Publications of the Society include the Bulletin published quarterly, the News appearing monthly, and the Occasional Papers. All members receive the Bulletin and News.

A Library on speleological subjects is maintained by the Society. Material is available to Society members at a nominal charge to defray the cost of handling and to others through inter-library loan.

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