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COVER PHOTO—Boating in the Punkva Cave, Moravian Karst, Czechoslovakia, ca. 1910.

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Tajemství Macochy

The World's First Speleological Documentary Film With Sound

Presented in Celebration of the Centenary of the Birth of Karel Absolon, Speleologist (1877-1960) and in Memory of Czechoslovakian Film Director Josef Lachmann (-1948)

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OTTO ONDROUŠEK

(deceased)

THE FIRST RECORD of the Macocha Abyss (Fig. 1) is that in Fr. M.A. Vigisius' (1663) theological thesis, *Valis Baptismi alias Kyrteinensis*. Included there is a story about an evil stepmother who killed her unwanted stepchild by throwing it into the Abyss. *Tajemství Macochy* (ta-yemst-vee mat-soch-y), in translation, is 'the secret of the stepmother.'

Josef Lachmann, the Director of the Czechoslovakian State Film Studios at Barrandov, near Prague, was a friend of Karel Absolon (figs. 2, 3). His specialty was scientific documentary films, and Absolon's work at Macochy fascinated him. He scripted, personally financed, and directed this film, which summarizes Absolon's work in the Moravian Karst.* It was premièred on 28 October 1934, in Brno.

The version of the film used today consists of 2 reels of 16mm black and white safety film, reduced from the 35mm original for convenience. It was edited by Hera Productions in the film studios at Barrandov and is optic-automatic.† Lachmann financed two 16mm copies; eight others were made possible by the generosity of the Jan Sigmunds, father and son, owners of the manufacturing and financial concern Sigma-Pumpy-Lutín. Lachmann's copies were never found after his death, although they had been publicly shown before World War II. Seven of the eight other copies were destroyed in the War; the surviving copy is owned by Absolon's son, Karel B. Absolon of Rockville, Maryland, and is deposited in the Absolon family archive at Brno.

*For an overview of Absolon's life and works, see Hedges and Coufalik (1977).

†Half of the original footage was edited out, but salvaged by persons unknown and shown without the consent of the producers.

The projection time of the film is 90 minutes. To the original version, taken during field work in 1932, have been added scenes staged in 1939-40 on the basis of Absolon's notebooks and publications and part of a Sigma-Pumpy-Lutin promotional film. Shooting was done on weekends, each scene usually needing several for preparation. Only one take was made of each scene.

The cameraman was O. Zíka, the narrators Průcha and Vnouček, and the language Czech (with German subtitles). The cast included Absolon and the members of his research team: mechanical engineer Vladimír Brandstätter, electrical engineer Vladimír Ondroušek, mining engineer Jan Suchánek, diver and racing car champion Tunál Divišek, and several miners. Electrical lighting was used for most scenes, magnesium flares for the others. All equipment was carried in back packs.

Other technical data on the filming are no longer known.

SUMMARY

Tajemství Macochy, the world's first educational documentary sound film, was completed in Czechoslovakia in 1934. It records the speleological studies of Prof. Dr. Karel Absolon and his associates in the Moravian Karst between 1909 and 1933, especially those focused on the Macocha Abyss and subterranean Punkva River.

This film, scripted and directed by Josef Lachmann, was the first professional-quality cave movie. It reveals Absolon's philosophy of caving, as well as depicting caves and cavers.

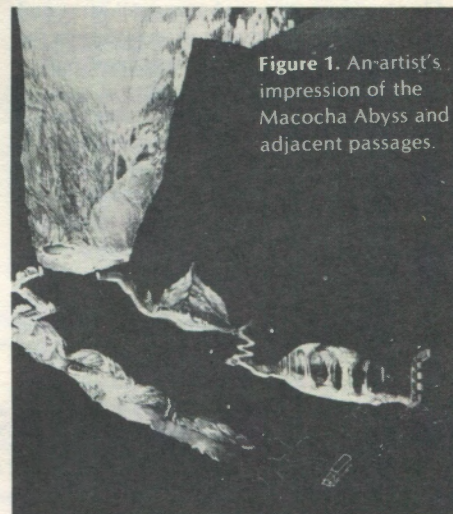


Figure 1. An artist's impression of the Macocha Abyss and adjacent passages.

ORGANIZATION

Tajemství Macochy consists of 2 parts. The first discusses the prehistory, paleo-ethnology, anthropology, paleontology, and paleozoology of the Moravian Karst, including the development of human culture in Central Europe. It also contains a history of descents into the Abyss since the Seventeenth Century and of Absolon's research between 1909 and 1913. The second part portrays explorations between 1920 and 1933.

Chapter One describes the geomorphology of the karst NE and NW of Macocha; the karst val-



Figure 2. A caving party in the Moravian Karst: (from left) Valerie Absolon, unknown, Prince Hugo, Josef Lachmann, unknown, Karel Absolon, unknown.



Figure 3. A caving party in the Moravian Karst: (from left) Otto Ondroušek, Karel B. Absolon, Bladimir Ondroušek, Karel Absolon, Bladimir Branstetter, Otto Henych.

leys of Holštejn§ and Sloup** are shown in their natural beauty and by maps. Folk music accompanies the scenes.

Chapter Two interprets the hydrology of the Punkva River system and the use of its caves by Quaternary Man.

Chapter Three concerns human prehistory and the paleontological materials excavated from the Moravian Karst. Kůlna, Pekárna, and Veštonice§§ are especially important sites.

Catherine Cave*** and its paleontology are the subject of Chapter Four. Human bones and early Aurignacian artifacts intermixed with bones of extinct animals in Býčí Skála Cave proved the antiquity of Man in Central Europe independently of Buckland's work in England.

After placing the Punkva system in scientific context, the film turns to exploration problems. Chapter Five details problems in reaching the floor of the Macocha Abyss, 137½m below the surface. Smoke experiments showed that air-filled passages existed between the Abyss and the Pustý Žleb, or Void Canyon, 600m (airline) distant. Excavations begun in the Pustý Žleb eventually provided access to the Abyss along the "Dry Way."

Chapter Six records the exploration of the rise and sink pools on the floor of the Abyss.

§Holštejn, or Höhlenstein, is a village NE of Macocha. In an old castle there in the 14th through 16th centuries dwelt a band of highwaymen who disposed of their merchant victims in a cave, Lidomorna, beneath the castle. Lidomorna Cave is an important Magdalenian locality.

**Sloup, or The Column, is a village in a karst valley NW of Macocha. Kůlna, or Shed, Cave near Sloup is famous for the discovery there of the jawbone of a Neanderthal child.

‡The term 'punkva,' in old-Czech 'ponikva,' means subterranean river.

§§Veštonice, or Wisternitz, is a village in the southern part of the Moravian Karst, where there is an important upper-Aurignacian locality.

***Catherine Cave, a place of horror for the young shepherdess Catherine in the 17th century, is a paleo-resurgence of the rivulet Bílá Voda, or White Water; it is an important paleontological site.

Chapter Seven deals with the systematic exploration of the cave system from the Dry Way.

Chapter Eight opens with a scene showing Absolon's grandfather, Heinrich Wankel, paddling upstream on a punt of logs, 60m within Punkva Cave.

Diver Tunál Divišek is featured in Chapter Nine, working in 3° water while protected only by swimming trunks and vaseline. The Punkva could rise several meters within minutes following a heavy rain. Strict safety precautions were always observed, including telephonic contact with explorers underground; nevertheless, Divišek was eventually trapped underground and nearly drowned.

The following chapter presents a 5-year intermission in exploration of the Wet Way, during which hypsometric measurements, levelling surveys, new maps, and micro-climatological observations were carried out. Absolon determined to construct a drainage system in order to eliminate sumps along the course of the Punkva.

Chapter Eleven shows the now-drained water passages and sumps.

The final sump blocking access to the Abyss along the Wet Way, Sump IV, was penetrated to a depth of 30m by Divišek, using a diving suit. Sump IV was subsequently pumped dry using Sigmund's 'Nautilus' submersible pumps (Fig. 4)† and additional pumps above water level having a combined discharge of 500 l/sec.

The struggle at Sump IV is shown in chapters 13 and 15. The final chapter, number 15, records a public ceremony on 3 February 1933.

SCIENTIFIC CONTENT

Absolon's work at Macocha between 1905 and 1933 was financed by the owners, His Serene Highness Prince Hugo Salm-Reiferscheid of Rá-

††Jan Sigmund worked for a time in the American oilfields; his pump was developed there.

jec and his wife, Princess Leopoldine. The film recreates the descents of the Prince's grandfathers, Karel Josef and Hugo, into the Abyss in 1784 and 1808.§§§ Without Prince Hugo's personal interest, Absolon would not have been able to carry out his ambitious programme.

Four speleological sub-disciplines are included in the film: The hunter-gatherers of the Old Stone Age, the mammals of the Riss-Würmien and Würmien, the hydrology of the Punkva River system, and exploration techniques. Lachmann's mastery of cinematography blends the earth and life sciences with art, music, folklore, and history

§§§The first descent was by Fr. Lazarus Schopper, later Provincial of the Minorit Order of St. Francis in Moravia, in 1723.

Figure 4. Installing one of the 'Nautilus' pumps in the Punkva Cave. Photo by Karel Absolon.



to yield a smooth performance of great spiritual charm.

Anthropology of the Moravian Karst

The anthropological part of the film describes Neanderthal Man and his cultures at Kůlna and at Šipka and Cro-Magnon Man at Predmostí. Fossil *Homo* in Moravia is represented by 4 species: Neanderthal, Cro-Magnon, Széletien, and Magdalenien; Grimaldien and Solutrien types have not been found. The earliest hunting peoples are thought to have arrived about 100,000 years BP. Their remains are found in caves and rock shelters.

Mesolithic and Neolithic sites excavated by Absolon are not discussed in the film.

Quaternary Mammals

Virtually no prehistoric paintings of animals exist in Moravian caves, the sole example known to Absolon being the scene of bison fighting found in Pekárna Cave. Fossils of Riss-Würmian and Würmian ages are plentiful, however. The film includes a discussion of the Moravian Museum and the Anthropos Museum, both founded by Absolon at Brno.

Hydrology of the Punkva

The Central Moravian Karst is an area of Devonian limestones about 10km long and 2 to 6km wide; it is a merokarst with an altitude of about 500m and a relief of 200m. The Karst is drained by 4 streams, of which the Punkva is the most important. Only the Punkva is discussed in the film. The most important landform in the Karst is the Macocha Abyss, a gigantic karst fenster across which the Punkva flows. The film dwells at length on the exploration of the Punkva caves.

Exploration Techniques

The methods used to explore the Moravian Karst are well shown in the film, beginning with those used by the earliest adventurers and ending with the still-modern techniques developed by Absolon. The only major advances since 1933 have been SCUBA diving gear and single-rope abseiling (which followed the recent invention of strong, lightweight synthetic rope fibers).

Initial descents of the Macocha Abyss were made by means of winches, ropes, and buckets. Rope ladders came into use about 1900, but were quickly superseded by the construction of a permanent iron ladder in 1905. The iron ladder was abandoned when the Dry Way leading from the Pustý Žleb to the Abyss was discovered in 1909. Wired aluminum ladders were introduced by Vladimír Brandstätter in 1924. Smoke- and dye-tracing were used as early as 1901. Dynamite was used during the exploration of the Wet Way, as were pumps; an adjustable dam to regulate water levels was installed in 1920. Methods of clearing breakdown and blasting rubble are also shown in the film. Telephone communication between the surface and underground parties was used regularly as a safety precaution.

PHILOSOPHY

The science of speleology was founded as a branch of geography by E.-A. Martel, Albrecht Penck, Jovan Cvijič, and Karel Absolon in the waning years of the Nineteenth Century. Absolon, though, carried it furthest. *Tajemství Macochy* shows that, to him (and, properly, to everyone), speleology can be understood only as a synthesis of all cave-related phenomena: Geologic history, hydrology, zoogeography, biology, paleontology, ecology, cultural anthropology, meteorology, even engineering and mountaineering.

Caves are not static phenomena, and speleology cannot be merely descriptive; it must interpret function and include both the events of the past and the probable events of the future.

The film emphasizes Absolon's commitment to personal safety. The possibility of injury should be minimized by advance planning, and reckless endangerment of life should result in banishment from caves. Fatigue is the greatest enemy of every expedition and must be anticipated well in advance.

A third emphasis of the film is that the speleologist should use mechanical aids freely: He should not look to the quality of the physical performance, only, but should climb as comfortably as possible and concentrate on his scientific programme.

In addition to being an artistic record of one of the world's major karst areas and its interpreter, *Tajemství Macochy* reflects a coherent philosophy of speleology. This is what enabled Absolon to achieve such brilliant results, such absolute concentration and dedication. Lachmann reveals this *leitmotiv* splendidly through his script and technical direction.

ACKNOWLEDGEMENTS

The authors thank Dr. W. S. K. Chalmers (London), Dr. Jan Jelinek (Anthropos Museum, Brno), Dr. Karel Valoch (Moravian Museum, Brno), Mme. Valerie Absolon (Brno), and Dr. Karel B. Absolon (Rockville, Maryland) for their interest during the preparation of this manuscript.

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Hedges, James and Emil Coufalik (1977)—The Karel Absolon Centenary, 1877-1977: *NSS Bulletin* 39:3-8.

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Audio-Visual Library

The NSS Audio-Visual Library has a large collection of prepared slide shows. Many include tape-recorded narrations. Slide shows and tapes are available to NSS members and internal organizations for a nominal fee (to cover postage and maintenance).

While many of these programs appeal mainly to cavers, some are suitable for presentation to groups outside the caving community. A few are especially suited for youth groups and novice cavers and, thus, can be used for training.

Slide shows and tapes (or written narrations) are made by NSS members and internal organizations and are donated to the Audio-Visual Library for the use and enjoyment of others. New programs are added regularly. To obtain a list of available programs and instructions for borrowing, write: NSS Audio-Visual Committee, Cave Avenue, Huntsville, Alabama 35810.

Photo Archives

The NSS Photo Archives Committee seeks to compile a photographic history of American caves. Its holdings are catalogued. For more information, write: NSS Photo Archives Committee, Cave Avenue, Huntsville, Alabama 35810.

Photo Salon

Any NSS member may submit photographs to the Photo Salon Committee following announcement of the annual competition in the NSS NEWS. Judging takes place 2 or 3 weeks prior to the NSS Convention, and awards are given on the basis of technical excellence, aesthetic quality, originality, and artistic merit. Usual categories are b & w prints, color prints, color slides, and movies.

Enlargements of the winning prints are hung in a gallery during Convention Week. Winning slides are presented at an assembly, toward the end of the week. Awards for all winners are presented at the assembly. This program has consistently been the most popular Convention event. For information, watch NSS NEWS issues prior to each annual convention.

KARST DENUDATION RATES for SELECTED SPRING BASINS in WEST VIRGINIA

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A topic of interest to many karst researchers is the rate at which a karst terrane is lowered by solution. The karst denudation rate has been determined in different climatic regions of the world by both direct and indirect means. The direct method generally entails measuring the lowering of an exposed limestone surface in reference to a non-erodable object. The indirect method for determining denudation ratio uses spring water hardness and discharge data to determine the amount of dissolved carbonate being removed from a spring basin. It is a better method of determining the rate of surface lowering over a large area than is the direct method.

STUDY AREA

The study area occurs in the Appalachian Mountains of West Virginia (Fig. 1) and is underlain by Greenbrier limestone of middle Mississippian age (Fig. 2). The area displays a well developed karst topography, bounded to the west by younger clastic rocks and to the east by older clastic rocks. Structural folds trend northeast-southwest, and the stratigraphic dip is rarely more than 15°. The bedding is disturbed locally by a few short thrust faults. (Reger, 1926). Figure 3 shows the axes of folds mapped by Reger (1926), Price and Heck (1939), and Ogden (1976). The range in elevation is 1710 to 3328 ft.

BASINS

Figure 4 shows the boundaries of the Monroe County, West Virginia karst basins within the study area. The 3 basins under consideration here are those of Dickson Spring, Walters' Spring, and Cold Spring. They were defined by dye traces by Jones (1981) and to a lesser extent by the author.

Dickson Spring Basin

Dickson Spring, with a basin (catchment area) of 64 km² is the largest of all the karst springs in central Monroe County. Fifty-six km² of the basin are underlain by limestone. The southern portion of the basin is underlain by highly deformed De-

SUMMARY

Karst denudation rates were calculated for 3 spring basins of the central Monroe County karst, West Virginia. Denudation rates were determined by an indirect method that utilizes water hardness, spring discharge, and basin area. The springs were sampled approximately every 2 weeks for 1 year. A variable, termed the "carbonate leaching rate" (gms CaCO₃/sec) was calculated for each sampling period from the total hardness and discharge data. The mean carbonate leaching rate is believed to reflect more accurately the amount of rock leaving the basin than the mean hardness and total discharge. The denudation rate (D, mm/1000 yrs-km²) was then calculated from the mean carbonate leaching rate (\bar{L}) multiplied by a constant (C) to convert from gms CaCO₃/sec to mm CaCO₃/1000 yrs, and divided by the bulk density (p) of the limestone and the basin area (A) in limestone.

$$D = LC/pA$$

The denudation rates for the springs are as follows: 1) Dickson Spring—22.6, Walters' Spring—22.3, and Cold Spring—19.0 mm/1000 yrs-km².

Differences among denudation rates of the basins may be related to such differences as flow type (phreatic vs vadose), flow-through time, amount of diffuse contribution to the system, climate, and/or the amount of bedrock exposed within the basin. From the work of others, these calculated values are within the expected range for a humid-temperate climate.

vonian and Silurian clastics that cap Peters Mountain, the western most ridge of the Ridge and Valley Province. Maximum flows up to 107 cfs were observed during the sampling period, but flows much higher than this probably occurred. The lowest flow observed was 6.6 cfs. Discharge values measured for this spring during the 28 sampling periods are plotted in Figure 5.

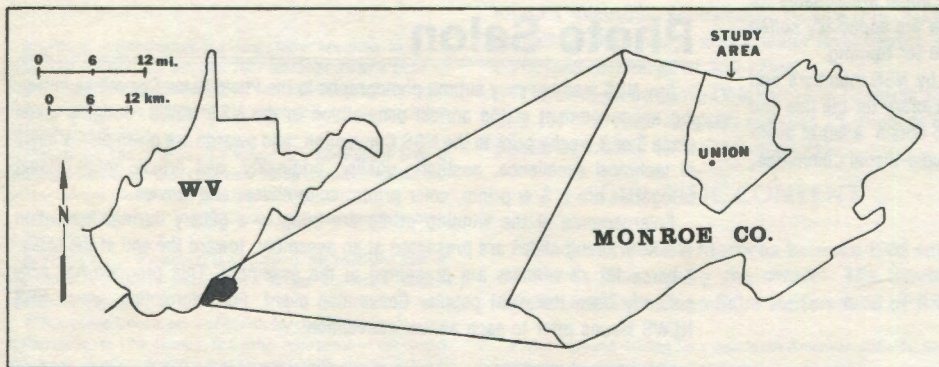
This spring discharges from a cliff into Second Creek at an elevation of 1800 ft. on the extreme northern boundary of Monroe County (Fig. 6). It emerges at the base of the Patton Limestone on the western limb of the Hurricane Ridge syncline, where the rocks are dipping 13° to the southeast. The spring emerges from a pile of rock debris, but during high flow also boils up from a pool in front of these rocks. There is no enterable cave here.

At least five sizable insurgences have been traced to Dickson Spring. Water from many other, smaller, insurgences is assumed also to emerge at this spring. The insurgence at Rehobeth Church was traced by Jones (1981) during low flow (September, 1972); water sinking here took 19 days to travel 11.7 km, assuming a straight line distance.

Walters' Spring Basin

Walters' Spring has the second-largest catchment area of the basins studied. It has an area of 27 km², at which 24 km² are underlain by limestone. The western portion of the basin is underlain by younger Mississippian clastics that cap Swoopes Knobs (Fig. 4). This basin is partially

Figure 1. Location of the study area.



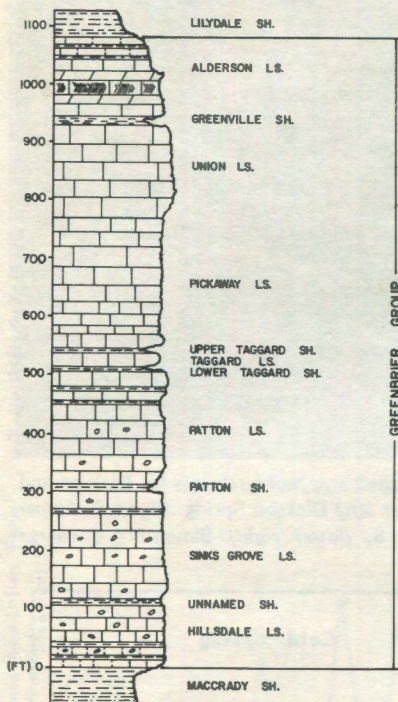


Figure 2. Generalized stratigraphic section of the Greenbrier Limestone in central Monroe County. The average thickness of each formation is illustrated.

overlain by the McPeak's Spring basin. The spring is located 5.4 km south of Union, on the north side of State Route 219, along a thrust fault within the broken beds of the Greenville Shale (Fig. 7). Four major insurgent streams sink in the Pickaway and Union limestones, and the water travels up-strata until the Greenville Shale is encountered; this shale then directs the water to Walters' Spring. The thrust fault allows the water to pass through a small portion of the Greenville Shale and emerge at an elevation of 1820 ft. There is a dry, hanging valley directly above the spring which receives runoff from Swoopes Knob during rains. Although none of this water has been traced to Walters' Spring, hydrogeologic reasoning dictates that this small drainage area must be included into the total recharge area.

The distance from the nearest known insurgence to Walters' Spring is 3.2 km., while the farthest known insurgence is 6.1 km away. Two of the insurgent streams enter caves that can be traversed for several hundred feet to sumps. These caves are generally small and are known to rapidly fill with water during storms. No known cave allows entry into the main drainage system near the spring, probably indicating that this cave system is primarily phreatic (or of closed channel flow) shortly down-gradient from the insurgence points. Walter's Spring had measured discharges ranging from 1.0 to 125.0 cfs during the study year, but generally flowed around 5.0 to 10.0 cfs (Fig. 5).

Cold Spring Basin

This small basin has its ground water resur-

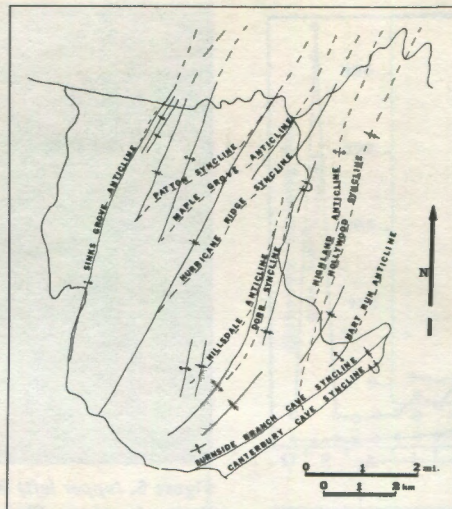


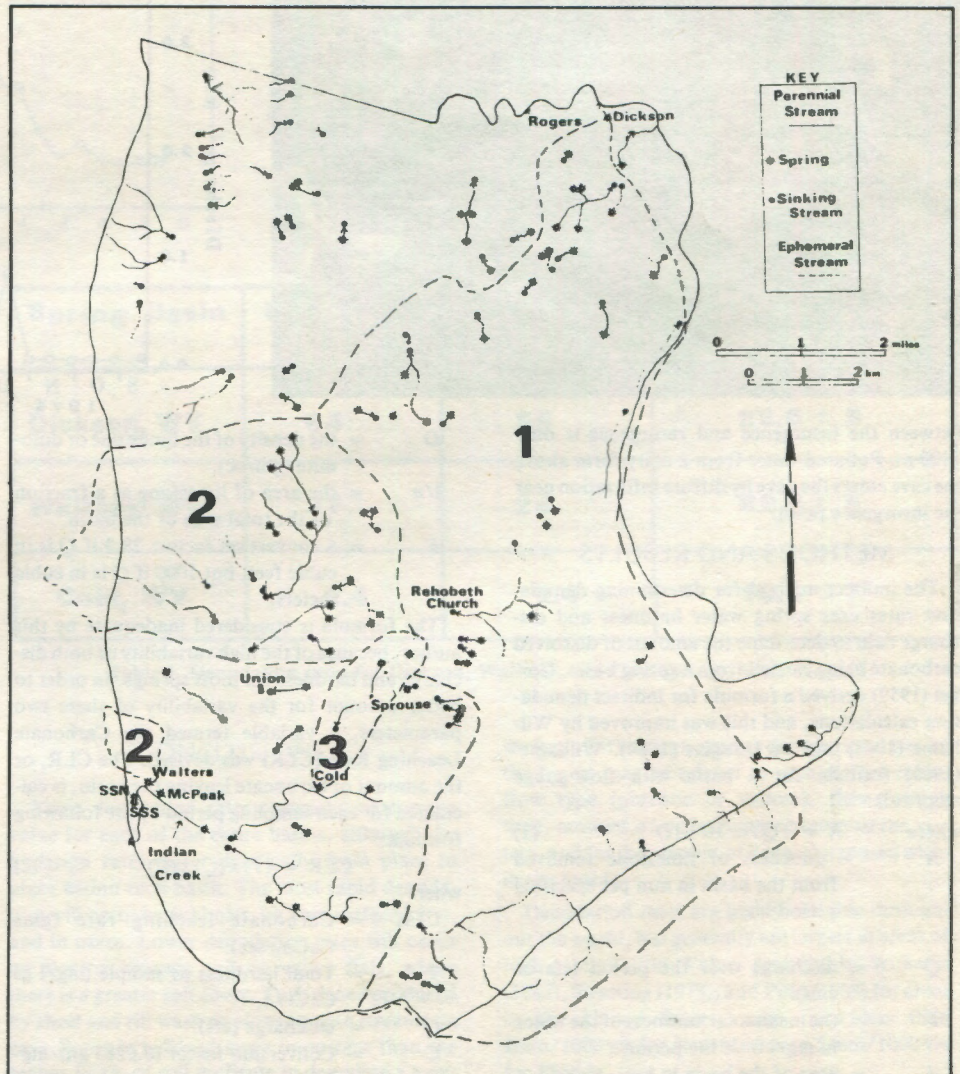
Figure 3. (above) Map of fold axes in the study area. Dashed lines show positions of axial traces mapped by Reger (1926) and by Price and Heck (1939). Solid lines represent the positions of axial traces mapped by Ogden (1976).

gence at the entrance of Cold Spring Cave (or Walker Farm Cave), which is located approximately 0.8 km east of the Willow Bend Road along the Burnside Branch Valley at an elevation of 2040 ft. The size of the basin is only 2.4 km², and it is entirely underlain by limestone. High flow is seldom more than 2.0 cfs; the average flow for the 13-month study period was 0.8 cfs (Fig. 8).

The cave at the spring (Fig. 9) can be traversed for nearly 460 m along strike-oriented passages to a sump. The cave is in nearly horizontal, arenaceous Taggard Limestone resting on the thin Lower Taggard Shale. The cave averages 3 to 5 m high and 6 m wide and contains a vadose canyon passage cut through floor sediments.

Two other small caves are known in the upper portion of the basin between the only known insurgence and the resurgence. These two caves have 150 m of explorable passage. The distance

Figure 4. (below) Outline of the three studied West Virginia spring basins: 1) Dickson Spring Basin, 2) Walters' Spring Basin, 3) Cold Spring Basin.



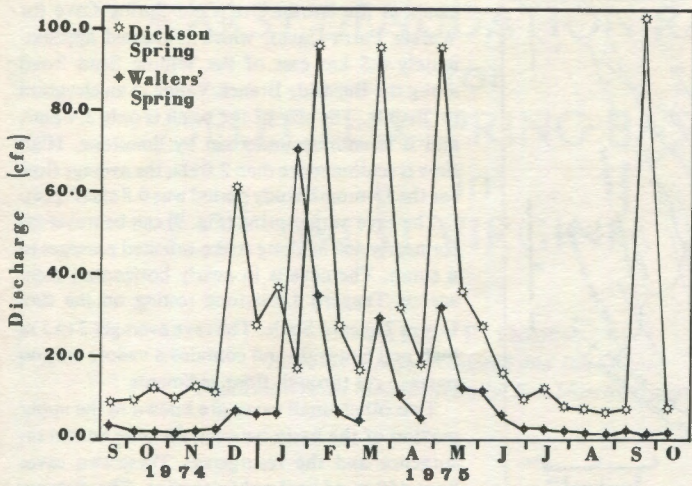
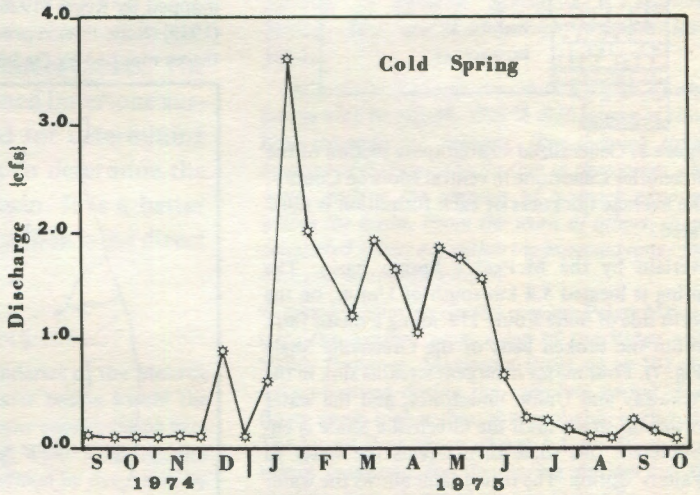


Figure 5. (upper left) Bimonthly discharge measurements for Dickson and Walters' springs. Figure 6. (lower left) Dickson Spring. Figure 7. (upper right) Walters' Spring. Figure 8. (lower right) Bimonthly discharge measurements for Cold Spring.



between the insurgence and resurgence is only 1100 m. Polluted water from a dairy farm above the cave enters the cave by diffuse infiltration near the insurgence point.

METHODS AND RESULTS

The indirect method for determining denudation rates uses spring water hardness and discharge data to determine the amount of dissolved carbonate being carried from a spring basin. Corbel (1959) derived a formula for indirect denudation calculations, and this was improved by Williams (1963) and by Douglas (1964). Williams' (1963) formula for a basin with flow-gauge records is:

where $X = \frac{FQTn}{10^{12}AD}$ (1)
 X = thickness of limestone removed from the basin in mm per specified period

- Q = discharge over the period (cfs or cms).
- T = the mean total hardness of the water in mg/l over the period.
- A = area of the basin in km².

- D = the density of the limestone or dolomite (gm/cc).
- $1/n$ = the area of limestone as a fraction of the total area of the basin.
- F = a conversion factor; 28.3 if Q is in cubic feet, but 1000 if Q is in cubic meters.

The formula is considered inadequate by this author, because of the high variability of both discharge and hardness for most springs. In order to better account for the variability of these two parameters, a variable termed the Carbonate Leaching Rate (CLR) was devised. The CLR, or the amount of carbonate leaving the basin, is calculated for each sampling period by the following formula:

$CLR = (T) \times (Q) \times (C)$ (2)

- where CLR = Carbonate leaching rate (gms CaCO₃/sec).
- T = Total hardness of sample (mg/l as CaCO₃).
- Q = Discharge (cfs).
- C = Conversion factor (0.0283 gm/mg-ft³).

By calculating the CLR for each sampling period, the effect of high carbonate removal during peak discharges is best accounted. The mean CLR is then determined from all the sampling periods and used to calculate the karst denudation rate. The more sampling periods involved in calculating the CLR, the greater will be the accuracy of the denudation rate.

In this study, each of the 3 springs was sampled 26 times over equal intervals measured over a period of one year. Discharge was determined at the time of sampling from rating curves produced earlier (Ogden, 1976). The CLR for each sampling period for Dickson, Walters', and Cold springs are plotted in figures 10 through 12. These figures clearly show that more limestone is removed in the winter and spring months when discharge is highest, even though the total hardness is lower. This is largely because the carbonate dissolution rate increases with increasing flow velocity, as verified experimentally by Wentzler (1971) and many others. Another explanation for these trends is the increased submerged area of limestone (mainly underground) with increased discharge.

The karst denudation rate was then determined

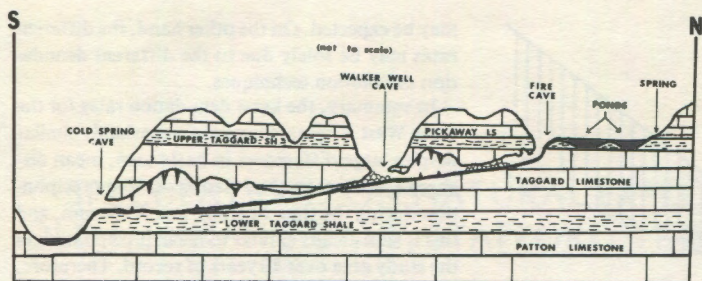
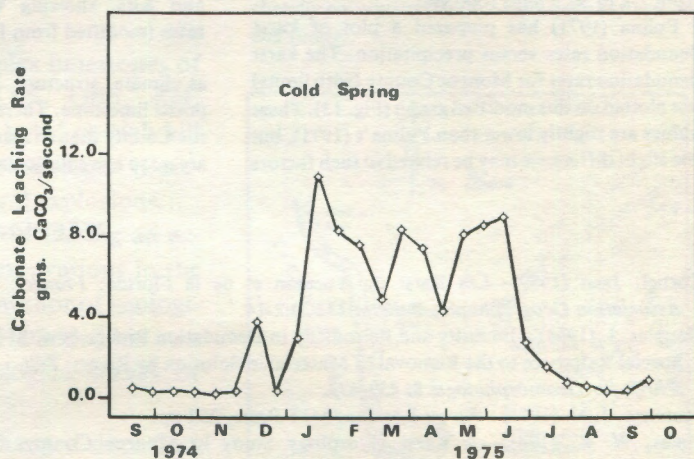
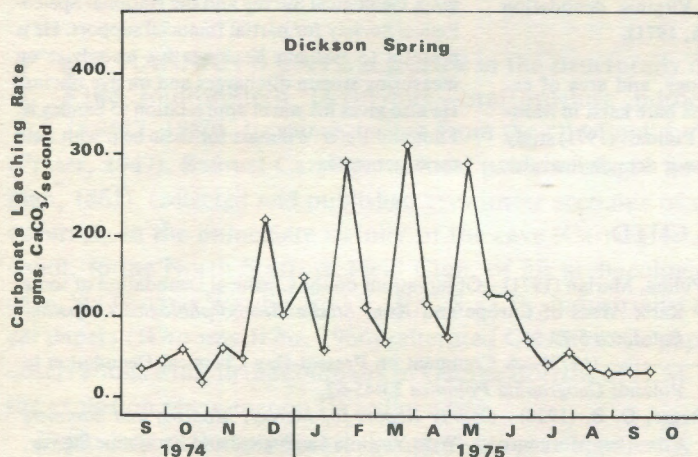
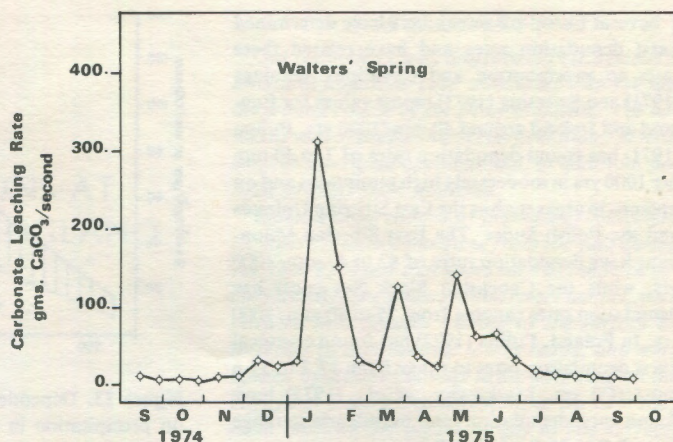


Figure 9. (upper left) Geologic cross-section of the Cold Spring-Walker Well-Fire Cave System, demonstrating the perching effect of the thin Taggard Shales. Figure 10. (lower left) Carbonate leaching rate versus time for Dickson Spring. Figure 11. (upper right) Carbonate leaching rate versus time for Walters' Spring. Figure 12. (lower right) Carbonate leaching rate versus time for Cold Spring.



for each of these spring basins from the average carbonate leaching rates by the formula:

$$D = \bar{L} C / pA \quad (3)$$

where D = the denudation rate in cc $\text{CaCO}_3 / 1000 \text{ yr} \cdot \text{km}^2$.

\bar{L} = the mean carbonate leaching rate (average for all sampling times) in grams $\text{CaCO}_3 / \text{sec}$.

p = the bulk density of the Greenbrier Limestone in gm/cc, 2.64 (West Virginia Geological Survey Subsurface File).

A = area of basin in limestone in km^2 .

C = constant to convert from seconds to a year.

Spring Basin	Basin Area (km^2)	Area in Ls. (km^2)	Denudation Rate ($\text{mm}/1000\text{yrs}$)
Dickson, WV	64	56	22.6 ± 5
Walters' WV	27	24	22.3 ± 5
Cold, WV	2.4	2.4	19.0 ± 7

Table 1. Denudation rates for Dickson, Walters', and Cold springs, West Virginia.

Table 1 presents the denudation rates, converted to $\text{mm}/1000 \text{ yrs}$, for each basin. The relatively large limits of error reflect the extremely high fluctuations in the carbonate leaching rate and take into account error associated with unknown hardness and discharge values between sampling intervals. The vadose nature and short subsurface residence time of Cold Spring water in combination with its low discharge may be responsible for its lower denudation rate. Generally, all three basins have nearly the same denudation rate. Dickson and Walters' springs have some closed channel (phreatic) flow in their drainage systems. This may allow more limestone to be dissolved, due to greater ratios of wetted exposed rock to flow volume in the cave systems.

CONCLUSIONS

These denudation rates represent an average value for each of the entire basins, although denudation rates differ drastically from place to place within each basin. The most rapid denudation will occur in sinkholes, on bare surface karst, and in caves. Lower denudation rates will occur on sloping uplands and on valley flats, where there is a greater soil cover. Turbulence produced by sheet and rill wash on slopes and in streams on cave floors is believed more important than the higher PCO_2 of soil moisture in denuding a karst

surface. Differences among denudation rates of the basins may be related to such differences as flow type (phreatic or vadose), flow-through time, amount of diffuse contribution to the system, and/or the amount of bedrock exposed within the basin.

Denudation rates are highly variable throughout the world, but generally are largest in areas of high precipitation. Values reported by Williams (1963), Sweeting (1973), and Pitty (1968) for areas in the United States range from less than $1 \text{ mm}/1000 \text{ yrs}$ for New Mexico to $5 \text{ mm}/1000 \text{ yrs}$ for Florida.

Several European researchers have determined karst denudation rates and have related these rates to precipitation and elevation. Jennings (1971) and Sweeting (1973) report values for England and Ireland around 40 mm/1000 yrs. Pulina (1971) has found denudation rates of 7 to 40 mm per 1000 yrs in moderately high mountains and on uplands in areas such as the East Siberian Uplands and the Polish Sudet. The East Siberian Mountains have denudation rates of 42 to 47 mm/1000 yrs, while the Caucasian Black Sea coast has denudation rates ranging from 75 to 80 mm/1000 yrs. In Poland, Pulina (1972) has found chemical karst denudation rates to range from 17.2 to 53.6 mm/1000 yrs. Markowicz, *et al.*, (1972) have found karst denudation rates in Bulgaria to range from 7.2 to 58.8 mm/1000 yrs.

Pulina (1971) has prepared a plot of karst denudation rates versus precipitation. The karst denudation rates for Monroe County (with limits) are plotted on this modified graph (Fig. 13). These values are slightly lower than Pulina's (1971), but the slight difference may be related to such factors

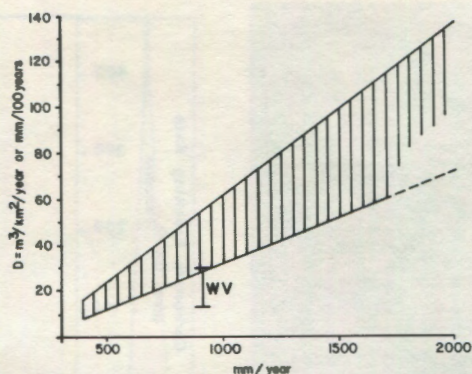


Figure 13. Dependence of chemical denudation on precipitation in some karst areas of Europe and Asia, showing West Virginia denudation rates (modified from Pulina, 1971).

as climate, structure, lithology, and area of exposed limestone. There is less bare karst in Monroe County than in many of Pulina's (1971) study areas, so less solution and lower denudation rates

may be expected. On the other hand, the different rates may be solely due to the different denudation calculation techniques.

In summary, the karst denudation rates for the three West Virginia basins are remarkably similar despite large differences in basin area, mean discharge, and mean total hardness. The precipitation during the time of study was 9,180 mm, and this is statistically similar to mean precipitation in the study area over 30 years of record. Therefore, the denudation rates calculated by the newly developed technique of this paper are considered representative for a humid-temperate climate.

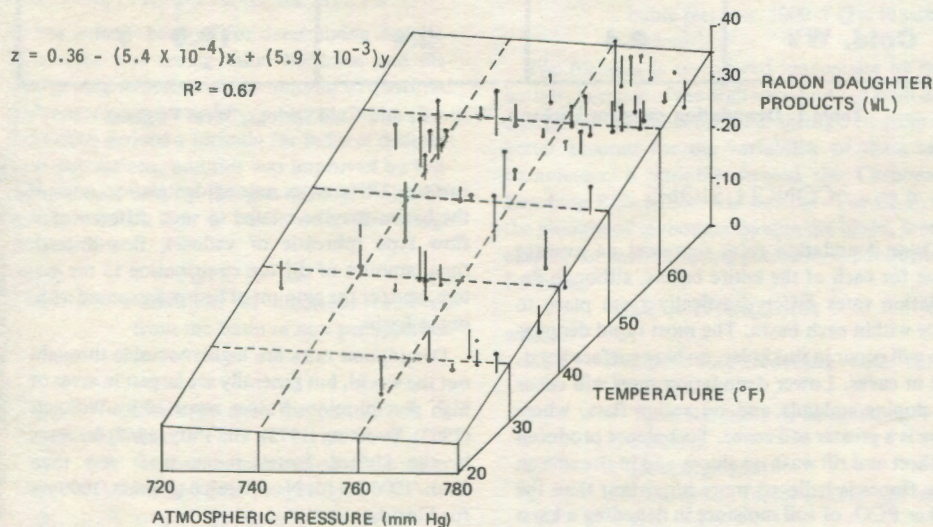
ACKNOWLEDGEMENTS

The author would like to thank the West Virginia Geological Survey and the National Speleological Society for partial financial support. He is grateful to William K. Jones for his advice on measuring stream discharges and on dye tracing. He also gives his warm appreciation to Sandra K. Flint and Peter Williams for their help with field measurements.

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erratum

G. M. Ahlstrand (1980)—Alpha Radiation Levels in Two Caves Related to External Air Temperature and Atmospheric Pressure: *NSS Bulletin* 42:39-41.

An error appears in the regression equation for Figure 3, page 41, Volume 42 of *The NSS Bulletin* (July 1980). The equation should read:

$$z = 0.36 - (5.4 \times 10^{-4})x + (5.9 \times 10^{-3})y$$

Atmospheric pressure data reported as cm Hg were used in calculating the regression coefficients. The error resulted after drafting the manuscript, when pressure data were reported as mm Hg in the figures. The correction does not affect the R² value. The regression equation for Figure 4 is correct.

SPECULATIONS ON NATURAL EXPLOSIONS AT OLD HANNAH'S CAVE, STAFFORDSHIRE, ENGLAND

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OLD HANNAH'S CAVE is located in the structurally complex limestones of the southwestern Derbyshire—Staffordshire border (O.S. Grid. Ref. 099557, 1980). Its name derives from the Old English 'hen hoh,' or high hill (Fraser, 1947). Samuel Carrington, local palaeontologist and archaeologist (Bate-man, 1861), collected and published eyewitness accounts of natural explosions... occurring in the immediate vicinity of the cave (Carrington, 1870). During an account, to the North Stafford Field Club, of his archaeological excavations in the cave, Sir Thomas Wardle, F.G.S., F.C.S., J.P., industrialist and author of geological papers (*Who was Who*, 1966) reiterated Carrington's paper. He added his own observations while in the company of George Borrow of H.M. Geological Survey, of the explosion phenomenon (Wardle, 1899).

Explosions no longer occur, though the area is apparently unchanged since Carrington and Wardle's day. This paper arises from my curiosity aroused by the explosion accounts. It is based on 6 field trips made to the area in the period 1979-81, coupled to knowledge and experience of static electrification and mining.

CHARACTERISTICS OF THE EXPLOSIONS

Carrington (1870) collected eyewitness accounts by local people. A 92-year-old lady, who had been sitting with friends on the hill above the cliff and cave, recounted her terror on hearing a crash which, she said, 'sounded as if the rocks had been rent asunder and violently knocked together again.' The ladies concluded that the event was supernatural. On January 1st 1855, George Fallows and Joseph Wint were taking cows up the track near the cave. It was a very windy day, and they heard a loud report sounding like large blocks of stone tumbling down a deep mineshaft. The roaring noise was repeated at short intervals, loud enough to be heard a mile away, 'but for the high wind which then prevailed.' 'A blue flame, edged with reddish yellow, issued from a cleft in the rock.' The cows ran up the steep Wetton road, paused for breath, but a repeat of the explosions set them off again. Fallows climbed up on to the wall to look at the site of the explosions but Wint, in terror, made him get away. Consequently they arrived in Wetton, where people commented on

their frightened appearance. They tried to persuade men to go back. Some laughed and used the 'tempestuous wind' as an excuse to stay put. However, Thomas Redfern, one of those who did go, said that the noises he heard were like blasts of gunpowder and, 'that a narrow stream of pale fire issued from the face of the rock.' In a letter to Carrington, dated May 7th 1868, Wint added that when he stood opposite the Old Hannah's cave and cliff, the reports were like the 'fall of a building, or the shooting up of stones from a cart but much louder, and at the same time a noise like the crackling of a forest on fire; and while I was in sight there came from the cleft a kind of blue blaze like the burning of sulphur, which appeared to be about 12 in. broad as it issued from the face of the rock.' In 1867, a man repairing the track opposite the explosion site heard a series of reports like sharp claps of thunder. In April 1868, Laurence Fallows was repairing the wall in the Redhurst Gorge in a gentle breeze when he heard hissing sounds repeated at intervals, 'Like a miner's fusee.' Carrington states that others were familiar with the phenomenon but that he had recounted enough accounts to record it.

SUMMARY

Old Hannah's Cave, Staffordshire (England) is a natural limestone cave associated with the underground course of the River Manifold. The adjacent wall of the Redhurst Gorge contains several smaller solutional openings and, in addition, has been strongly frost shattered.

Reliable observations of flames and coincident explosive sounds emanating from the wall during the 1800's suggest that gases such as methane accumulated in the underground river channel, were released into fissures leading to the surface by intervals of atmospheric low pressure, and were ignited by static electricity in blowing sand on the cliff face. Recent sedimentation in the cave may have blocked the access of gas to the surface, thereby preventing the occurrence of the phenomena today.

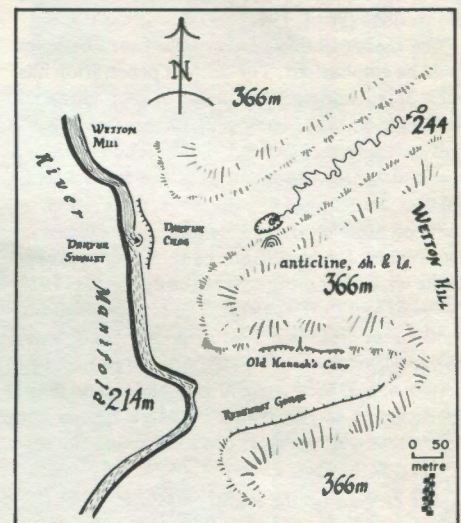


Figure 1. Field sketch of the Old Hannah's Cave area.

Wardle and Borrow's (1899) account was of Saturday, December 10th, 1899 when they heard a sound like several rifles 'being discharged simultaneously.' Realising that no one was shooting, they looked up the cliff and witnessed an explosion which emitted a flash from a hole or fissure in the upper part of the cliff. This had a bluish column 'not of steam or fire or smoke, but apparently of aqueous vapour,' which travelled with immense force across the valley (approximately 12m wide). Within minutes another discharge from higher up the cliff and then 'several ones with crackling sounds producing semitransparent wavy streaks in the air, not smokey in appearance.' Next came a very loud explosion which 'we had the good fortune to see plainly.' Wardle describes this as 'like a gun but with crackling, a series of continuous reports, cleaving the air in a zigzag or riverlike course in a narrow band about 15cm to 20cm broad, 'of bluish colour.' They waited an hour before attempting to reach the holes or fissures but could not climb the vertical

part of the cliff particularly due to the 'perfect hurricane blowing from the southwest against the cave and cliff.' The force of the wind was such at times that the 2 men lay down to avoid being blown over the edge.

THE CAVE IN THE FISSURED CLIFF

Old Hannah's Cave in the dry valley of Redhurst Gorge (Fig. 1) is about 70m above the River Manifold. Only in prolonged very wet weather does the river take its north-to-south surface course, initially over impervious Manifold-limestone-with-shales. For most of the year, it sinks into swallets in the reef limestones which begin at Wetton Mill (Ford, 1977). Of particular relevance to this paper are swallets, into the eastern bank, under Darfur Crags, which take water under Redhurst Gorge. (In passing, it may be noted that natural explosions are also mentioned as happening in Darfur Crag Cave above the swallets [Ford, 1967].)

The inaccessibility of the subterranean system must be emphasised. The deepest penetration has been 300m into the part vadose, part phreatic, Redhurst Swallet, ending at impassable cracks and unstable rocks (Ford, 1977). The hydraulic gradient (north-to-south) takes the River Manifold on its underground course 8km to resurge in the 'boil holes' at Ilam. This was demonstrated in Dr. Samuel Johnson's time by throwing corks into the water, but more reliably by dye tests in 1928 (Spencer and Porter, 1972). The cave roofs at the 'boil holes' resurgence are, in dry conditions, about 40cm above the water in the, rejoined impervious, surface course at this place. The main resurgence was penetrated by Mike Nelson for about 120m. In previous dives, he found the sys-

tem phreatic, with large submerged banks of sandy sediments (Cave Diving Group, 1977).

The steep-sided Redhurst Gorge (Fig. 2) has reef limestone outcrops which are fissured, often into large blocks. (Identical material forms the large cliffs in Lathkill Dale, about 25km away, and a winter with hard frosts sees many such blocks broken away. These, over many years of frost action, break down into large scree slopes). Old Hannah's Cliff is at the upper left in Figure 2 and projects outwards beneath the hill summit in a series of sloping steps each about 15m high. Alongside these projections, forming the covering of other, lower 'steps,' is very loose soil and scree. Hence Wardle and Borrow's fear of being blown into the gorge in high winds.

Old Hannah's Cave (Fig. 3) is a fissure, probably a swallet of an earlier river system, about 1.5m wide, 5m high at the entrance, bulging to 2m wide just inside, but then narrowing to a vertical crack about 0.3m wide. This crack is packed from floor to roof with a reddish-brown soil. Wardle found human remains 3.5m below the floor in a section beyond the crack, in what he described as a rounded room in which 4 people could easily stand side by side. This 'room' section is now filled with soil, thereby reducing the cave length from about 13m, in Wardle's time (1899), to its present 6m.

Outside the cave, a slope of the same coloured soil mixed with scree falls, at an angle of about 30°, some 15m to the valley floor. Access to the rock outcrops, Wardle's 'cliff,' with the cave in its base may be gained by climbing loose soil and scree slopes. Figure 4 illustrates the fissured rock and a soil-scrée slope alongside it. The cave roof is about 2m under this point and runs from left to

right. The holes from which the explosions occurred are difficult to reach, for a nonclimber, but I managed this in 1979 and 1980. They are about 0.6m high (figs. 5 and 6), one the home of an ill-tempered jackdaw. Some of the holes (see Fig. 6) are connected by obvious external fissures, but others examined appeared to be interconnected by internal fissures. A camera with electronic flash inserted into one such hole obtained Figure 7, which shows an internal fissure, with fallen rocks, between holes. The edges of many fissures are sharp, like frost fractures. However the holes for the most part have the appearance of phreatic tubes dissolved in the limestone—which is the common mode of origin of Derbyshire cave systems. All the holes to which I was able to gain access had internal fissures, but how these formed I do not know.

To the north of the Redhurst Gorge is a second valley running almost parallel (see Fig. 1). A stream originating in springs about 800m up the valley runs in a very meandering course. This stream is obviously affected by rainfall and often floods into many interconnecting sections which in drier weather are overgrown with grass. Recent fieldwork by the author has revealed that the stream sinks into vertical swallets partly choked with stone blocks, soil and grass. Immediately adjacent to the swallets is a pronounced anticline, revealed where soil has been eroded away. It measures a few centimetres at its ridge and widens to about 3m before it is lost to view. The rocks of the anticline are crinoidal limestone interleaved with pyrite bearing shale beds. The layers vary from about 1cm thick near the base to a few millimetres at the ridge. Both the swallets and the anticline are in the same hill as, in direct line with, Old Hannah's Cave and its cliff (Fig. 1).

SOIL SAMPLES

Samples of the reddish-coloured soil were taken from the area above the cave as well as from the cave floor and from the floors of holes joined by fissures. These separate samples were put into glass beakers of water in order to separate out organic material, which included roots and one tiny bone, which floated, from the heavier soil constituents. Samples of the heavier material were microscopically examined in both transmitted and reflected light. The assumed soil proved in fact to be sand. The grains were sharp sided, *i.e.* not eroded, quartz typical of the Pleistocene drift found in many Derbyshire and Staffordshire caves. A few grains of mineral, possibly sphalerite, were also present. All samples were identical in structure and material. On his fatal dive into the main Ilam resurgence, Mike Nelson dug through a massive bank of this material which had been washed down through the subterranean Manifold River system (Cave Diving Group, 1977). The total sand deposits amount to many tons and were deposited by glaciers of the last Ice Age, the melt waters of which were responsible for the local cave systems (Ford, 1977).

Figure 2. View up the Redhurst Gorge, from the west bank of the River Manifold. *Author photo.*



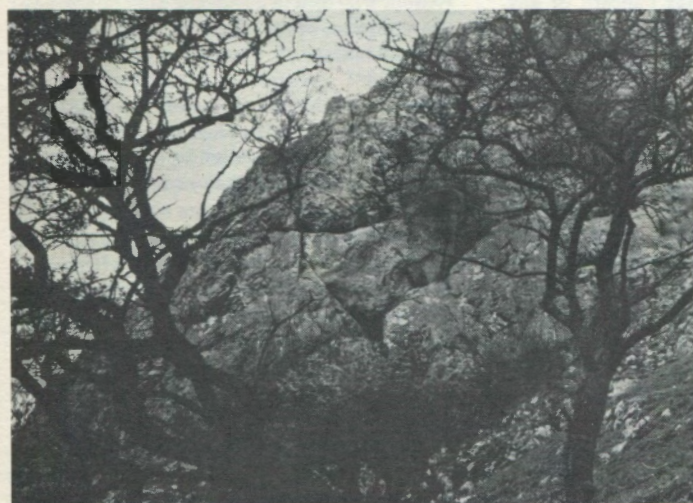


Figure 3. (left, top) Entrance of Old Hannah's Cave. *Author photo.*

Figure 4. (left, bottom) Fissured cliff above Old Hannah's Cave. *Author photo.*

Figure 5. (right, bottom) Solutional opening in cliff above Hannah's Cave. *Author photo.*

Figure 6. (right, top) Another solutional opening, with prominent fissure, in cliff above Old Hannah's Cave. *Author photo.*



NATURAL EXPLOSION HYPOTHESIS

The River Manifold takes water and organic debris under the Redhurst Gorge; as also does the spring-fed stream behind Old Hannah's Cave. I speculate that the decay of the grass and algal growth of the stream evolves methane. The degeneration of pyrites in the shales may also add hydrogen sulphide. At the times mentioned in the explosion accounts, viz. December, January, April and, one, in early May; organic material would have been taken underground by the melting snow and rain. The air would be low in humidity due to frosts. In May, 1980, I observed bubbles rising through the 20cm of water above sand on the boulders partly choking the smaller llam resurgence cave. I had no means of testing these with me. In August, there were no bubbles, which tended to rule out nearby air being entrained by the flowing water. In April, 1981, I captured the gas by the displacement of water from 2cm diameter test tubes. A match applied to these produced a loud 'Pop!' with a purplish flame. The onset of

freak snow conditions made a return impossible, but in late May, I returned with the intention of taking samples only to find that the cave entrance has been dug out, probably by cave divers, and there was an air gap of some 50cm above the water surface. It would border on the incredulous to state that inflammable gas caught 8km away from Old Hannah's Cave could be the cause of the explosions but it does offer some confirmation of the evolution of gas in the subterranean water course.

However, the speculation that inflammable gas is present under Redhurst Gorge due to the decay of organic material plus the evolution from pyrite bearing shales seems reasonable. Such accumulated gas would percolate upwards through the fissured rock and, in Wardle's time, escape to the air. Methane has been studied with respect to mine explosions (Evans and Brown 1973, Sorbie, 1978). Mason (1954) stated that the methane/air

Figure 7. (right) Open fissures within the cliff above Old Hannah's Cave. *Author photo.*



mixture is explosive between 5 and 15 percent, being most explosive at 9.5%. Recent work by Mills (1980) has demonstrably ruled out any spontaneous Will-o'-the-Wisp type of burning or explosion.

If the conditions prevailing at the times of the witnessed explosions are considered, (i) there was always a high wind blowing, and (ii) the appearance and sounds are typical of a gas explosion issuing from a tunnel mouth. The structure of the fissures and holes form a natural counterpart to the apparatus used in the investigation of the generation of static electricity by blowing dusts and sand grains (Blacktin 1928, Shaw, 1928). More recently, Kamra (1971) and Mills (1977) have investigated the large fields and electrical discharges in blowing dust clouds, particularly in sandstorms. In Mill's work, a simple experiment in which sand is whirled in a partly evacuated glass flask produced bright coronas and magnificent sparks. In my own investigation (unpublished), the earlier statements by Shaw were found to be confirmed in that unlike materials, for example sand grains blown through a tube lined with pumice, will generate very high charges. Also that identical

materials will generate very high electric fields and sparks. Laboratory tests using a few grams of material have generated high fields breaking down in sparks. How better Nature who, employing gale force winds, blows sand grains through the limestone fissures in the Old Hannah's Cave cliff!

The high winds are indicative of an atmospheric low pressure region. Such a condition results in an increased production of methane in local mines (Met. Office, 1981). Hence an increased likelihood of gas rising from the underground river system into the fissured cliff. The winds would not only generate electric sparks by triboelectrification of sand grains on limestone but would also serve to dilute the gas to its explosive concentration, resulting in the dramatic explosions which terrified local people and animals and caused one woman even into her nineties to believe that a supernatural agency was at work. These events urged Carrington (1870) to overcome his innermost feelings, that perhaps he dare not mention the phenomenon since it was unheard of anywhere else and left to posterity his exciting paper which concludes: 'The probable causes of this

phenomenon I leave for future solution, contenting myself with now simply recording the facts as they occurred.'

WHY NOT TODAY?

Why can we not witness explosions from Old Hannah's Cave cliff today? There has been a massive earth slip, which has certainly infilled the back of the cave and sealed off the ingress of gas from the subterranean river below. Until the system is explored, if ever, its actual structures remain a mystery. I predict that methane and possibly hydrogen sulphide will be found, and if it should ever become possible, if permitted, to dig out the sandy soil blocking the gas ingress fissures, the phenomenon would happen again.

ACKNOWLEDGEMENTS

My thanks to Miss E. M. White, Leek librarian for loaning me the copy of Sir Thomas Wardle's paper and to Derby, Local section, for access to Carrington's paper. To the memory of Michael Nelson, who died in advancing our knowledge of the resurgence of the River Manifold from the Ilam 'boil holes.'

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It is occasionally necessary to replace members of the Board of Editors. In order to ensure that no interested party may be overlooked at these times, and to facilitate our obtaining referees for papers submitted, everyone interested in being considered for a place on the Board of Editors is invited to forward a paragraph or two (no resumés, please, just a prose essay) describing their background and interests to the Editor. This will help us avoid making the Bulletin the exclusive domain of an 'invisible college' of

buddies; it will also help induct beginning scholars into the system.

Those who have submitted their names previously are still on record and need not re-apply.

Even if you are unable to participate in the operation of the Bulletin, we would appreciate having your suggestions and criticisms. Many of the changes made by the present staff were suggested to us by readers.

Origin of BLACK DEPOSITS IN CAVES

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ALTHOUGH the manganese oxides are the most common black substances existing in caves, they are only one of many possible coloring agents. The purpose of this paper is to describe several occurrences of black cave deposits and to instruct the reader on identifying such deposits.

MANGANESE

Manganese Minerals

A number of manganese minerals have been reported from caves. Birnessite, $\text{CaMnO}_3 \cdot 3\text{H}_2\text{O}$, is the most common manganese mineral found in limestone caves (Moore, 1981). The manganese in the birnessite is in the fully oxidized +4 state and forms from water containing abundant dissolved oxygen. Moore and Nicholas (1964) reported black layers of the mineral birnessite covering the walls and coating cobbles in Weber Cave, Iowa; also, Moore (1981) found birnessite covering the walls and ceilings of Matts Black Cave, West Virginia. An unusually coarsely crystalline occurrence of birnessite has been found in Tom Moore Cave, Missouri (George W. Moore, personal communication, 1974).

Three other black manganese minerals—romanechite, rancieite, and todorokite—also occur rarely in caves where the manganese deposits are sealed from the air and thus do not exist in the fully oxidized state (Moore, 1981). Deal (1962) identified manganese minerals in the black fill of Jewel Cave, South Dakota—romanechite (psilomelane), $\text{Ba Mn}_2\text{O}_7 \cdot (\text{OH})_2$, or less likely hollandite, $\text{Ba}(\text{Mn}, \text{Fe})_2\text{O}_7$. Rancieite, a calcium-rich mineral related to psilomelane with the formula $(\text{Ca}, \text{Mn})_0.4\text{MnO}_2 \cdot 3\text{H}_2\text{O}$, has recently been identified in a number of caves: as a dark-colored crust between bauxite and underlying limestone near Itea, Greece (Bardossy and Brindley, 1978), in a black calcite flowstone in Yorkshire, England (Laverty and Crabtree, 1978) and in Mammoth Cave, Kentucky and Paxton's Cave, Virginia (Richmond, *et al.*, 1969). Fisher and White (1966) reported manganese of the todorokite (calcium-rich manganese oxide) type in the caves of Kentucky, Tennessee, and Georgia.

Another recently discovered, black, manganese caveminerals lithiophorite ($\text{LiMn}_2\text{Al}_2\text{O}_7 \cdot 3\text{H}_2\text{O}$), a lithium-rich variety of wad (Urbani, 1976). 'Wad' is the field name for an impure, unidentified group of black, manganese-oxide minerals (similar to the term "limonite" denoting a group of iron-oxide minerals.)

SUMMARY

Black deposits in caves can be composed of several different materials; manganese minerals, soot, guano, tar, and humate are some which are described in this paper.

Manganese occurs as black coatings on cave walls and stream clasts, as a stain on speleothems, or as black fill deposits. Several different manganese minerals have been identified in black deposits: birnessite, romanechite (psilomelane) rancieite, lithiophorite, and todorokite. A manganese origin can be verified by a simple chemical test.

Soot from torches and lanterns accumulates on the ceiling and upper walls of a cave. In Black Cave, Guadalupe Mountains, New Mexico, soot from a surface fire has been transported into the cave by vadose water. Evidence for guano fires is ash within floor guano deposits.

Dark brown to black guano deposits are recognizable by their smell, pelletal nature, and the presence of bones, hair, or insects; if decomposed, the guano has a high phosphate content.

Blackish organic humate and other carbonaceous matter in caves must be identified on the basis of chemical tests, X-ray diffraction techniques, and infrared absorption spectra analysis.

Unidentified manganese-dioxide minerals occur in Sullivan's Cave, Indiana (McMahon, 1958) and in Trout and Sinit caves, West Virginia (Davies, 1958, pp. 22-23).

Manganese Stain

Manganese commonly stains flowstone and dripstone speleothems black to bluish-gray. Very often this manganese alternates with reddish-orange iron staining (Hill, 1976, pl. 5) or with blue-green copper staining. In manganese-stained speleothems, the manganese occurs between individual calcite grains and is not incorporated into the calcite crystal structure.

Manganese Coatings

Manganese minerals form as dark-brown to black coatings on cave walls, ceilings, floors, and on stream pebbles and cobbles. Manganese stream deposits are generally composed of the mineral birnessite (Potter and Rossman, 1979). Manganese coatings are layered or laminar (Moore and Nicholas, 1964; Broughton, 1971), are soft and possess a sheen (McMahon, 1958), and are usually less than a few millimeters thick (Davies, 1958). Blackened stream pebbles have been reported from West Virginia caves (Bretz, 1956) and on red lava chunks in a stream channel, Dynamited Cave, Washington (Halliday, 1967). I have observed blackened stream cobbles in the Houchins River area, Flint-Mammoth Cave, Kentucky. I have also identified manganese coatings on the tips of limestone pendants in Fort Stanton Cave, New Mexico. In Carlsbad Cavern, New Mexico, a black manganese coating exists as a pool line around the edge of a small, shallow pool in the Lake of the Clouds area.

Manganese Fill

"Fill" is a geological term used to describe fine-grained deposits that fill up the spaces between larger blocks. In caves, fill occurs between break-

down blocks and in cracks so as to form smooth, even floors. Cave fill is usually composed of clastic clay and sand, but in rare cases manganese fill exists. The classic location of extensive manganese fill is Jewel Cave, South Dakota.

In Jewel Cave, pure manganese deposits completely fill floor irregularities up to 3m deep (Herb and Jan Conn, personal communication, 1979). The Jewel Cave manganese is light weight when dry, very slippery when wet, and always makes a caver grimy (Fig. 1)! Most of the manganese is soft enough to crumble or smear between the fingers; also, it sticks to the tongue when licked, drinking up drops of water like a blotter. The color of the Jewel Cave manganese deposits is dull, "dead" black, except near the very top of the cave fill where it sometimes lightens to a dark brown. The deposits are fine-grained and porous, having the consistency of dry clay. Some of the manganese fill has cracked into reticular blocks resembling desiccated mud flats. White-speckled mold has grown over the deposits where cavers have trod. The manganese in Jewel Cave is scattered throughout most parts of the cave and at all cave levels, but is especially prominent at the lowest levels of the cave and in the southern parts of the cave (Herb and Jan Conn, personal communication, 1979).

Less extensive manganese cave fill exists in Trout and Sinit caves, West Virginia, where manganese covers the floor and breakdown. In Trout Cave, boot prints made in the manganese floor fill disappeared within three years after being made, so that the passage looked virgin again (William Stevenson, personal communication, 1974). (This phenomenon is common with hydrated minerals, such as the nitrates [Hill and DePaepe, 1979]; it may be that the manganese dioxide mineral in Trout Cave [Davies, 1958] is a hydrated variety such as birnessite).

Origin of Manganese Deposits

Cave manganese may derive from circulating water or from minor amounts of manganese in the surrounding limestone bedrock. Manganese is dissolved by groundwater in the presence of CO_2 by formation of the soluble bicarbonate, $\text{Mn}(\text{HCO}_3)_2$ (Williamson and Burgin, 1959). Carbon dioxide loss, oxidation, and evaporation in the cave environment concentrates the manganese in incoming solutions, whereupon the manganese is precipitated. The black manganese pool ring in Carlsbad Cavern was probably formed in this manner—by evaporation and CO_2 loss at the pool's surface. Solutions slowly migrating down to the tips of limestone pendants in Fort Stanton Cave, New Mexico also probably deposited manganese upon evaporation and CO_2 loss.

Manganese may also form soluble organic compounds with citric, acetic, oxalic, or humic acids in

that feed the cave stream. A dissolved oxygen content of 8.6 mg/l (at 14°C) was found in the stream of Matts Black Cave. Such oxygenated water is supersaturated with respect to manganese minerals. *Leptothrix* and several other manganese-oxidizing bacteria have been cultured from the manganese collected in Matts Black Cave.

Most of the large deposits of cave manganese such as the fill in Jewel Cave probably derived from minor amounts of dendritic manganese minerals in the limestone bedrock. (Manganiferous limestones are not uncommon, because manganese-dioxide minerals form readily in shallow marine environments.) The limestone of Jewel Cave has an abundance of dendritic manganese which resembles moss that has grown within the rock. When the Jewel Cave bedrock was dissolved and its cave passages formed, the manganese within its bedrock remained as residual floor fill.



Figure 1. "Blimy it's grimy!" Jan Conin crawling through manganese fill, Jewel Cave, South Dakota. Photo by Dave Schunte.

a reducing (e.g., swamp or sinkhole) environment (Serdobol'skii and Sinyagina, 1953). Soluble, reduced manganese is transported by descending groundwater until oxidizing cave conditions are encountered: oxidation causes insoluble organic manganese compounds to reform.

Microorganisms (e.g., *Leptothrix* and *Clonothrix*) are believed to aid in the deposition of manganese. These bacteria may utilize the organic part of complex molecules, thus freeing the manganese ion (Moore and Nicholas, 1964; Nikol'skaya, 1962). Manganese on cave stream cobbles and pebbles might form by such an oxidation of organic manganese compounds—alluvial surface stream pebbles and cobbles coated with manganese are believed to have formed in this manner (Nicol'skaya, 1962; Fisher and White, 1966). Moore (1981) suggested that manganese in Matts Black Cave derived from stagnant sinkhole ponds

Tests for Manganese

Infrared spectroscopy is more useful than X-ray diffraction in identifying individual manganese minerals, because the grain size of most of these minerals is near that of the wavelength of X-rays.

In general, manganese can be detected by trying this easy chemical test: add a strong oxidizing agent such as sodium bismuthate, red lead, or lead peroxide to a concentrated nitric acid solution and a violet color will be produced in the presence of manganese.

CARBONACEOUS MATERIALS

Soot from Torches and Lanterns

Soot is a black substance consisting chiefly of carbonaceous particles formed by the incomplete combustion of burning material. Smoke from the Indians' cane torches accounts for some of the

blackened walls and ceilings of Salts and Mammoth caves, Kentucky (Hovey, 1896; Watson, 1974) (Fig. 2). The soot in these caves occurs as a dark brown, varnish-like coating which can be removed with soap and water (Benington, *et al.*, 1962). I collected a small sample of blackened ceiling (on a gypsum crust) from the Star Chamber, Mammoth Cave. A prominent graphite (C) line is present in the X-ray pattern of this black material.

In Mammoth Cave and in other caves commercialized before the turn of the century, smoke from lard-oil and kerosene lanterns deposited soot on cave walls and ceilings. Black, sooty coatings from torches and lanterns accumulate predominantly on the ceilings and upper walls of cave passages. This soot rubs off easily onto cavers' clothes.

Soot from Surface Fires

In Black Cave, Lincoln National Forest, Guadalupe Mountains, New Mexico, a black substance covers the walls, floors, and speleothems—the blackened appearance of this cave gives it its name. The coatings of Black Cave are composed of dark, chocolate-brown to black material which has collected in floor pockets in the Main Passage and which covers the upper surfaces of wall ledges, breakdown, and speleothems (Fig. 3). The undersides of the floor breakdown and flowstone are not coated. The black material gives a negative manganese test but a positive X-ray pattern for graphite. New soda-straw growth postdates the black coatings (Fig. 4), and a small amount (up to 15 cm thick) of white to yellowish flowstone on some of the speleothems also postdates the black coatings. In a side passage of Black Cave parallel to the Main Passage is a "lake" (perched water table) on which a black scum floats. The water level in this "lake" has fluctuated at least 3m within the last 20 years (Jerry Trout, personal communication, 1977).

Based on the above evidence, I propose the following origin for the Black Cave deposits: The vegetation on the ridge above Black Cave was burned by a local, naturally caused (lightning) fire. A subsequent heavy rain transported the charred surface vegetation into the cave, which flooded to its ceiling. The suspended carbonaceous matter then slowly settled out, coating the floors and the upper surfaces of wall ledges, breakdown, and speleothems. Some of this same black material still remains suspended in the "lake" today as a black scum. The hypothetical fire on the ridge

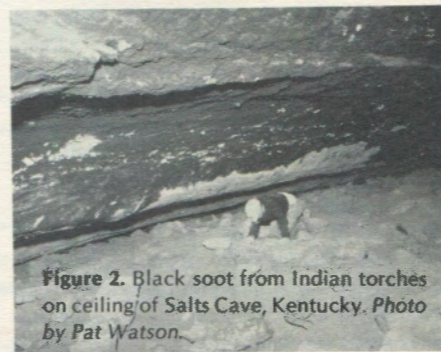


Figure 2. Black soot from Indian torches on ceiling of Salts Cave, Kentucky. Photo by Pat Watson.

overlying Black Cave and the subsequent flooding of Black Cave was a fairly recent event (probably more than two thousand and less than ten thousand years ago) based on the amount of new carbonate speleothem growth overlying the black coatings and the absence of charred trees on the surface above the cave.

Soot from Guano Fires

Another possible source of smoke and black soot in caves is guano fires. Highly nitrogenous bat guano deposits can ignite spontaneously. One attempt to smoke a bear out of a guano cave generated a great explosion, after which the guano continued to burn for two years (Hutchinson, 1950). Guano ash has been found in many southwestern caves; in extreme cases, compacted ash up to 5m deep occurs (Adriance, *et al.*, 1895). The smoking bat caves are referred to by ranchers as "smoke holes." "A cave on fire in the mountains at night is indeed a rare sight, as the reflection coming from that seething furnace is no larger than the opening . . . (giving) it the weird appearance of a cyclopean eye" (Campbell, 1925).

Rat guano in caves has also been known to ignite. Burning deposits in Defense Cave, California, produced gray ash and black clinker on the floor and a dark-brown, tarry substance on the ceiling (Moore, 1964).

Humate

Humate is an organic derivative of humus-rich vegetation. Varnish-like brown to black organic humate coatings have been identified from the ceilings and walls of Mammoth and Salts caves, Mammoth Cave National Park, Kentucky (Quinlan, 1966). The humate contains minor amounts of wood fragments and late Pleistocene pollen and spores. In some areas, rivulets of humate have flowed down the wall and have dripped and splattered onto the cave floor where they have desiccated, cracked, and curled into fragments. The humate in the caves is possibly derived from water seeping down through humus-rich debris in surface sinkholes (an alkaline environment) and into the caves, where the thin films composed of solutions of humic acid are concentrated by evaporation.

Tar

In Tumbling Rock Cave, Jackson County, Alabama (AL 171), a black sticky tar deposit occurs on the floor. The tar is oozing from the flat-bedded Gasper (Mississippian) limestone, from bedding planes, joints, and small cracks in the ceiling (W. W. Varnedoe, Jr., personal communication, 1981). Multiple small seeps of tar exist over an area of about 25 x 7m, but tar infiltration primarily covers a ceiling area of about 3 x 3m. The black tar drips from the ceiling and then flows plastically as many rivulets over breakdown and over the sandy floor fill (Fig. 5). It covers a floor area of about 7 x 7m.

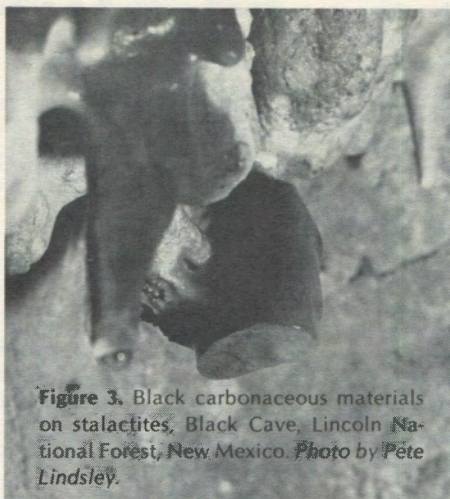


Figure 3. Black carbonaceous materials on stalactites, Black Cave, Lincoln National Forest, New Mexico. Photo by Pete Lindsley.

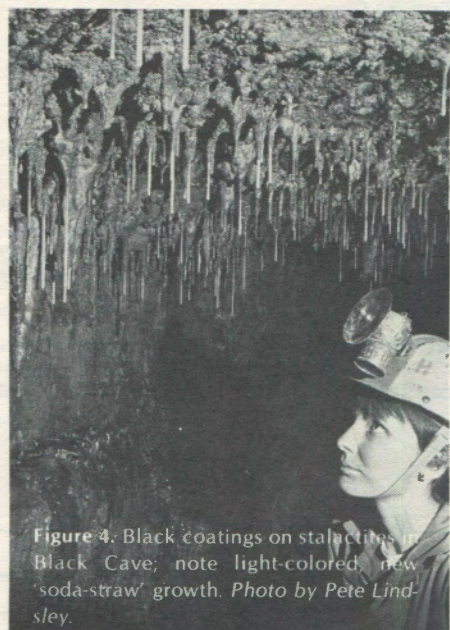


Figure 4. Black coatings on stalactites in Black Cave; note light-colored, new 'soda-straw' growth. Photo by Pete Lindsley.

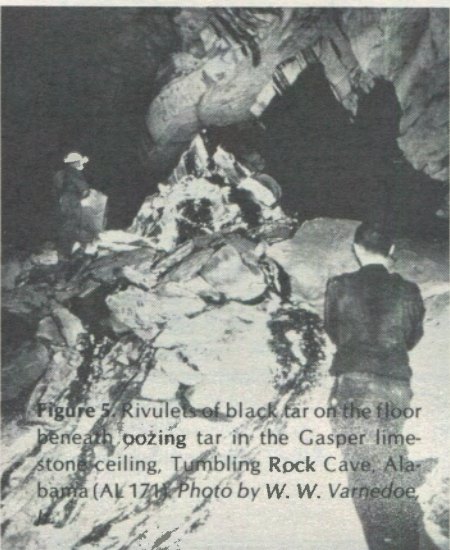


Figure 5. Rivulets of black tar on the floor beneath oozing tar in the Gasper limestone ceiling, Tumbling Rock Cave, Alabama (AL 171). Photo by W. W. Varnedoe.

The tar is probably a local, natural seep which derives from the Gasper limestone itself. Small amounts of tar in the Gasper have been exposed by road cuts and foundation blasting, and a few small natural seeps exist some 300 km to the west of Tumbling Rock Cave (W. W. Varnedoe, Jr., personal communication, 1981).

Coal-Derived Organic Material

In Ellison's Cave, Georgia, there is a small (approximately a few square meters), nearly black area in a passage which is aligned along a major fault (Bill Deane, personal communication, 1976). The black material is organic and coats the mud and rock of the passage. A possible explanation is that black material derived from overlying, coal-bearing Pennsylvanian shales was brought down as suspended particulate matter by descending groundwater via the fault zone.

Surface Vegetation-Derived Material

Black stringers of material sometimes occur in clastic cave sediments. These appear to be derived from plant material—wood or leaves carried into the cave, buried in the sediments, and then decomposed so as to leave residual carbon behind (William B. White, personal communication, 1980).

Tests for Carbonaceous Material

Carbonaceous deposits can be identified by chemical tests, X-ray diffraction techniques and infrared absorption spectral analysis. Since soot contains carbonaceous matter, an X-ray diffraction pattern will sometimes exhibit a graphite (C) line. A simple chemical test for carbonaceous material is: add HCl and HNO₃ to the unknown (to dissolve any carbonate). Since carbonaceous matter is insoluble in acid, it will remain as a black residue. If this residue is heated in air to incandescence, it will turn white. Also, a sooty and tarry residue will form on the inner surface of the top of the test tube when carbonaceous material is heated at the bottom of the tube.

GUANO

Bat Guano

When bat guano drops to the floor it forms dark-brown to black deposits. Fresh bat guano can be recognized by its smell, pelletal nature, and by the bat bones and hair within the guano. Decomposed bat guano is harder to identify; it must be analyzed for phosphate (Hill, 1981a). When bat guano is leached, the dark, soluble, nitrate-rich portion is removed and the lighter-colored insoluble phosphates remain. Leached, decomposed guano is usually somewhat compacted, orangish to brownish in color, and may contain light nodules or stringers of phosphate minerals.

Black deposits exist in side galleries off of Sand Passage, Carlsbad Cavern, directly underlying Bat Cave (Fig. 6). Where these side galleries pass beneath Bat Cave, they contain either black flowstone or a black dusty material covering the top surfaces (but not the undersides) of breakdown. The black flowstone of Sand Passage probably originated from solutions that leached through



Figure 7. Black flowstone, Sand Passage, Carlsbad Cavern, New Mexico. Photo by Wayne Burks.



Figure 8. Bat bones embedded in black flowstone, Sand Passage, Carlsbad Cavern. Photo by Wayne Burks.

above-lying guano in Bat Cave. The black flowstone issues from vertical joints in the back walls of the side galleries; bat bones are embedded in the black flowstone of one such gallery (figs. 7 and 8). The dark, dusty material covering the breakdown in these galleries is most likely dry guano dust which has filtered down the same vertical joints; upon settling out of the air, this fine dust has covered the top surfaces of floor breakdown.

Rat Guano

Amberat (dehydrated rat urine plus feces) associated with rat middens is found on the ceilings and walls of many western caves. Dark brown to blackish beads of amberat have been found in Flower Cave, Big Bend National Park, Texas, closely associated with the rare nitrate mineral, darapskite, $\text{Na}_3(\text{NO}_2)(\text{SO}_4) \cdot \text{H}_2\text{O}$ (Hill, 1981b).

Tests for Guano

Fresh guano is rich in both phosphate and nitrate; decomposed guano is rich in phosphate and often contains phosphate minerals such as

brushite ($\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$) which can be X-ray or optically identified (Hutchinson, 1950; Hill, 1981a). Chemical tests must be used to determine relative amounts of nitrogen and phosphorus.

CONCLUSIONS

Black deposits in caves originate in a variety of ways. Before deciding what a black deposit is, one must examine the field evidence very carefully and then identify the deposit by chemical, X-ray diffraction, or other techniques. The distinctive criteria by which black deposits can be identified are listed in Table 1. Other black deposits in caves probably exist that are unknown to the author and which are not included in this list.

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Figure 6. Black flowstone deposits in Sand Passage, Carlsbad Cavern, New Mexico. Map adapted from a survey furnished by The Cave Research Foundation.

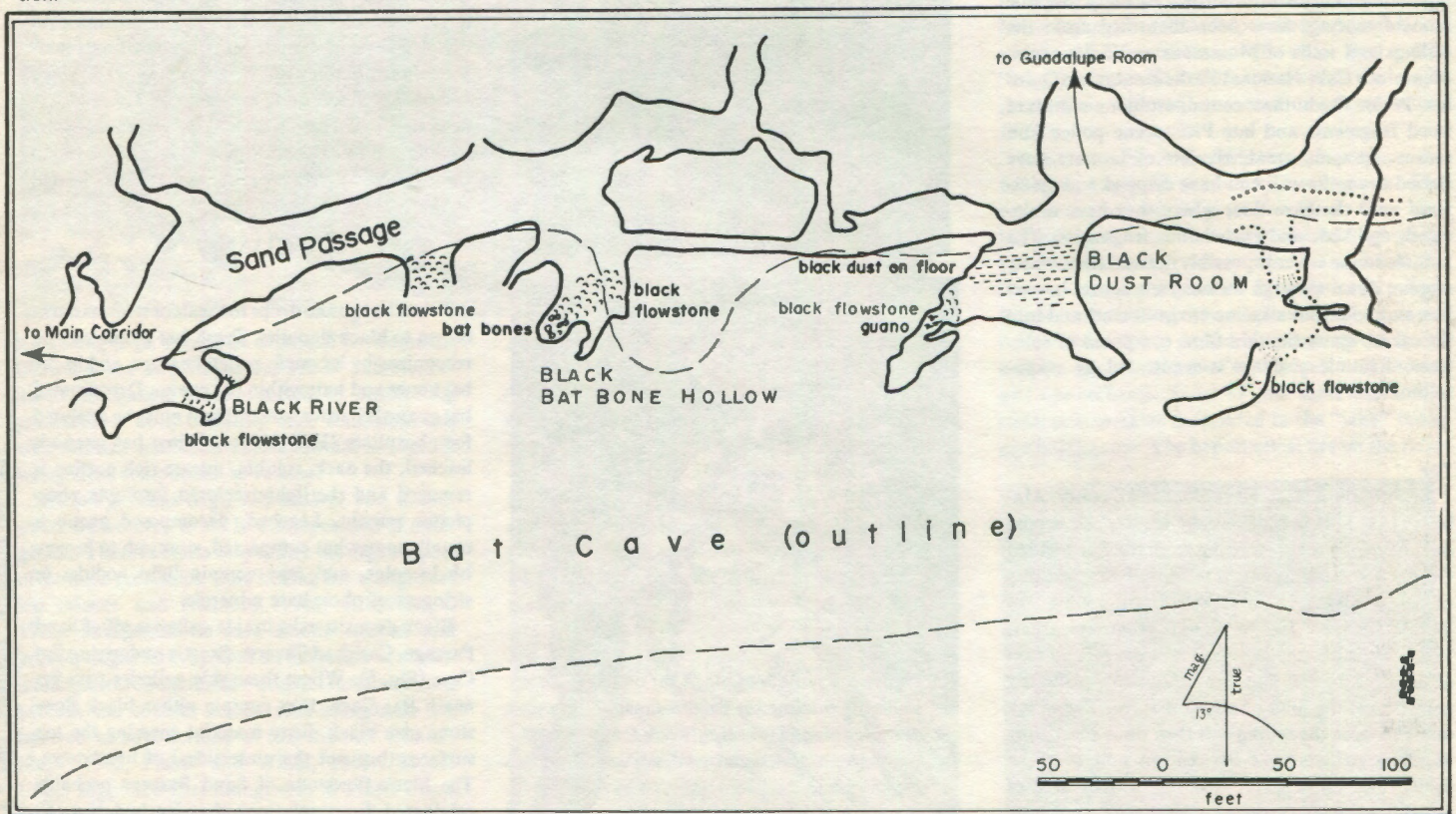


Table 1. Criteria for Recognizing Different Black Cave Deposits.

Black Substance	Field Identification	Analysis
Manganese	Variable: as black cave fill, wall coatings, stains on speleothems coatings on stream pebbles and cobbles.	Positive manganese test Identification of an individual mineral must be by X-ray diffraction or infrared spectroscopy coupled with chemical analysis
Soot a. Torches, lanterns b. Carbonaceous material settling out of solution c. Guano fires	a. Black coatings on ceilings and upper walls. Rubs off easily; can be removed with soap and water. b. Coats only upper surfaces and not undersides of floor breakdown, speleothems and cave ledges. c. Guano ash in floor guano.	Graphite (C) line may be present in X-ray diffraction pattern (d = 3.37)
Guano a. Bat guano b. Rat guano	a. Fresh guano: smell, pelletized nature, bat bones and hair. Decomposed guano: orange color, compacted, bat bone remnants, nodules or stringers of phosphate minerals. b. Rat middens, amberat	Chemical analyses; nitrogen-phosphorus ratios (Hill, 1981a)
Humate and other carbonaceous matter	Varnish-like deposits on walls or stringer deposits in floor sediments. Possible wood fragments.	Chemical tests, X-ray diffraction and infrared absorption

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NSS POLICY FOR CAVE CONSERVATION

The National Speleological Society believes: That caves have unique scientific, recreational, and scenic values; That these values are endangered by both carelessness and intentional vandalism; That these values, once gone, cannot be recovered; and That the responsibility for protecting caves must be assumed by those who study and enjoy them.

Accordingly, the intention of the Society is to work for the preservation of caves with a realistic policy supported by effective programs for the encouragement of self-discipline among cavers; education and research concerning the causes and prevention of cave damage; and special projects, including cooperation with other groups similarly dedicated to the conservation of natural areas. Specifically:

All contents of a cave—formations, life, and loose deposits—are significant for its enjoyment and interpretation. Therefore, caving parties should leave a cave as they find it. They should provide means for the removal of waste; limit marking to a few, small and removable signs as are needed for surveys; and, especially, exercise extreme care not to accidentally break or soil formations, disturb life forms, or unnecessarily increase the number of disfiguring paths through an area.

Scientific collection is professional, selective, and

minimal. The collecting of mineral or biological material for display purposes, including previously broken or dead specimens, is never justified, as it encourages others to collect and destroys the interest of the cave.

The Society encourages projects such as establishing cave preserves, placing entrance gates where appropriate, opposing the sale of speleothems, supporting effective protective measures, cleaning and restoring over-used caves, cooperating with private cave owners by providing knowledge about their caves and assisting them in protecting their caves and property from damage during cave visits, and encouraging commercial cave owners to make use of their opportunity to aid the public in understanding caves and the importance of their conservation.

Where there is reason to believe that publication of cave locations will lead to vandalism before adequate protection can be established, the Society will oppose such publication.

It is the duty of every Society member to take personal responsibility for spreading a consciousness of the cave conservation problem to each potential user of caves. Without this, the beauty and value of our caves will not long remain with us.

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