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Contents

APRIL 1970

NATIONAL SPELEOLOGICAL SOCIETY

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The Society serves as a central agency for the collection, preservation, and dissemination of information relating to speleology. It also seeks the preservation of the unique faunas, geological and mineralogical features, and natural beauty of caverns through an active conservation program.

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The Geology of Moaning Cave, Calaveras County, California

By Harry W. Short *

ABSTRACT

Moaning Cave is a composite vertical solution cavity and domepit that has formed in upper Paleozoic limestone of the Calaveras Formation. Although domepit features have developed on the ceiling of the Main Room, solution activity has predominated in forming the cave.

The geologic agents responsible for the evolution of this phreatic cave have also limited its horizontal extent. Local faulting has elevated the limestone in which the cave occurs. Faults north and south of and an apparent fault west of the cave entrance control its horizontal extent in these directions. A fracture in the west wall of the Main Room is suggestive of faulting, but evidence of this has been obscured by solution activity.

Regional uplift produced a well-defined joint set, accelerated stream downcutting, and lowered the water table around the cave. The joints in the metamorphosed limestone around the cave carried ground water to the permeable band of limestone in which it occurs. These waters enlarged the cave to its present size and deposited thick travertine on most of the walls in the Main Room. Undoubtedly, due to the vertical nature of the cave, these waters eventually reached the water table by draining out through the bottom of the cave.

INTRODUCTION

Moaning Cave is situated on the western slope of the Sierra Nevada Mountains in Calaveras County, California. It is easily accessible north of Sonora, through Columbia State Park on the Columbia-Vallecito Road or from Angels Camp to Vallecito on Highway 4. A narrow blacktop road, 2 miles south of Vallecito, leads to the cave entrance on a steep hillside above Coyote Creek.

Moaning Cave was acquired by Mr. Addison Carley in 1921 and has been open commercially since 1922. The cave is managed by Mr. Charles T. Murray, P. O. Box 122, Vallecito, California 95251.

The search for the rooms reported by early explorers of Moaning Cave is being continued by members of the Stanislaus Speleological Association and students from local colleges. Members of the Grotto, led by Mr. Marshall Bryden, are systematically exploring numerous fractures and solution cavities in and around the cave and have dug several exploration shafts in the floor of the main room.

The cave has been reported by various writers to be over 400 ft. deep. However, surveys conducted by William Wise and others (1952), Thomas Rohrer (1957), and the author show that the vertical distance from the cave entrance to the lowest point on the floor of the Lake Room is 254 ft. (Fig. 1). The vertical distance from this point to a small room below the Lake Room is about 80 ft. Therefore, the true maximum depth of Moaning Cave is approximately 334 ft.

Climate and Soil: The summers are characterized by high temperatures, low rainfall,

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and low humidity. The winters are rainy, with moderate temperatures and occasional snow in the lower elevations. The higher elevations experience freezing weather and heavy snowfalls.

Much of the surface area around Moaning Cave is covered by a thin, reddish residual soil, from a few inches to 3 ft. thick (terra rosa, Thornbury, 1954, p. 18). It also occurs as a filling in the joints and solution cavities

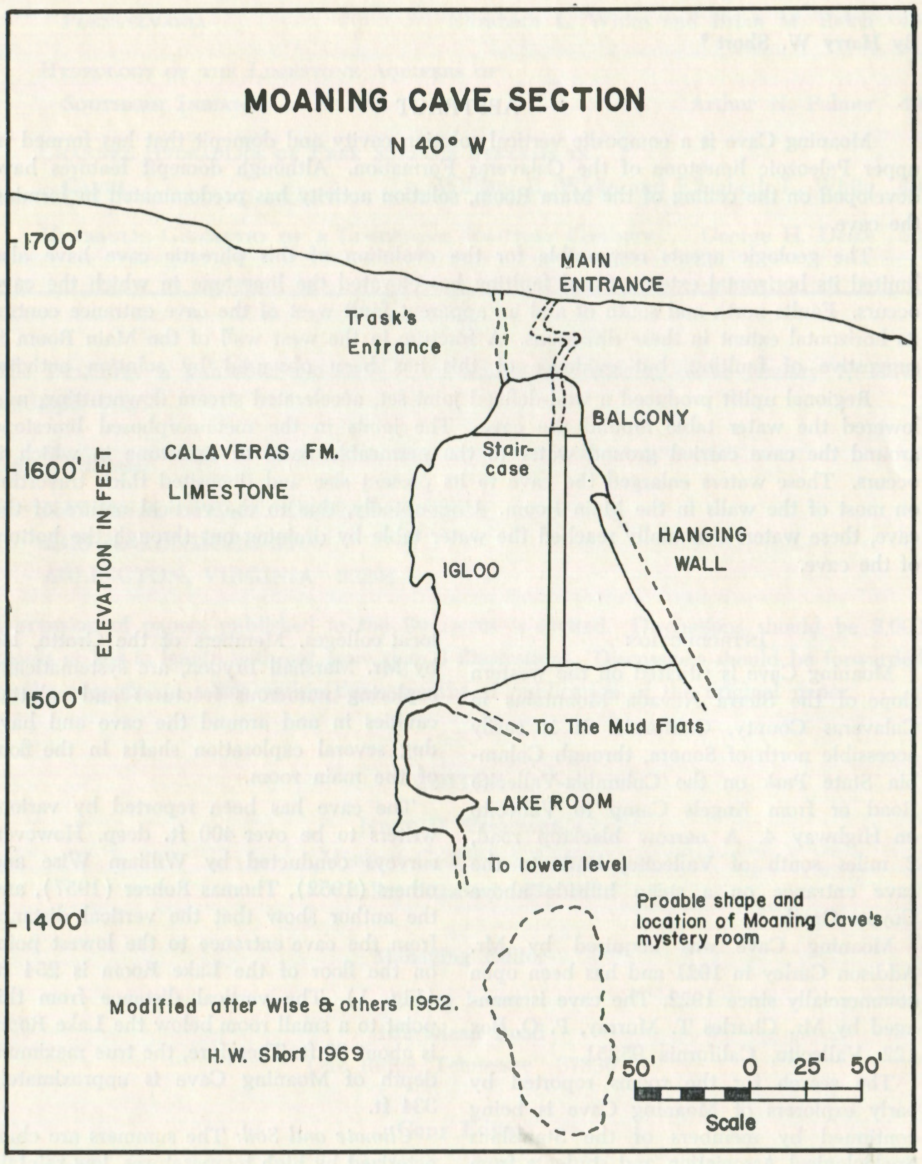

Figure 1. Section through Moaning Cave showing main features of the cave and the probable location and shape of the mystery room.

around the cave and as a matrix in the breakdown on the floor of the Main Room.

Karst Features: Well-defined karst features are nearly absent in the vicinity of Moaning Cave. A natural bridge south of Moaning Cave, small solution cavities, and enlarged joints filled with residual soil are the only remaining evidence of a former karst surface.

Drainage: Coyote and Wades Creeks, with gradients of 330 and 270 ft. per mile, respectively, have incised deep valleys into the limestone on either side of Moaning Cave (Fig. 2). Coyote Creek disappears underground along the limestone-slate contact west of the cave late in the summer. An unnamed stream on the northwest corner of the property flows only during the rainy season (Fig. 3).

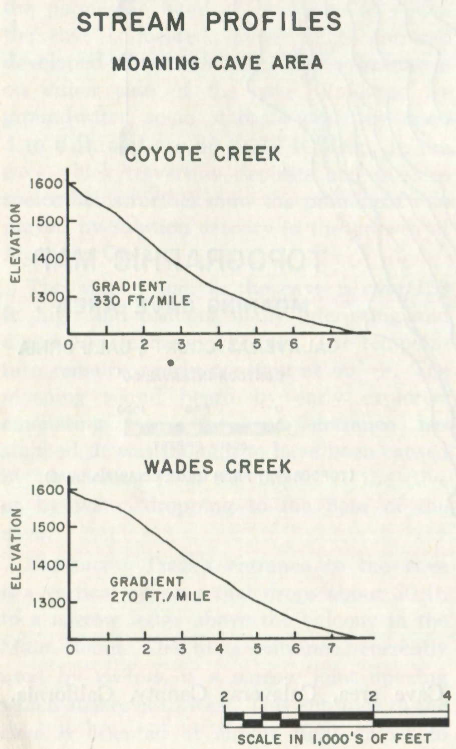

Figure 2. Stream profiles in the Moaning Cave area.

Study Area: The area studied in this report is in the west-central portion of Sec. 32, T. 3 N., R. 14 E., Calaveras County, California. The area is bounded by: the Columbia-Vallecito Road on the east, Coyote Creek on the west, an east-west line through the intersection of the Columbia-Vallecito and Moaning Cave Roads on the north, and an east-west line through the confluence of Coyote and Wades Creeks on the south.

Acknowledgments: The author thanks the following people who assisted in the preparation of this report: Addison Carley, Charles Murray, Marshall Bryden, Ralph Squire, William Boone, and my wife Delores.

History

Early accounts of Moaning Cave are somewhat vague and lacking in detail. None of them mention the Igloo (Fig. 4), the most spectacular speleothem in the cave; perhaps it went unnoticed in the dark by the early explorers. Other features of the cave—the original opening, the narrow rock ledge above the floor of the Main Room, the Liberty Cap, the earth mound on the floor of the Main Room, and the human skeletal remains—were described and are discernible in Moaning Cave today.

The first written account of the exploration of Moaning Cave appeared in the *Daily Alta California* on December 7, 1851 (Wallace, 1950). The account describes the descent and exploration of the cave by Mr. J. B. Trask, the first State Geologist of California. Mr. Trask described the Main Room and a second room directly below it, over 100 ft. high, which contained several human skeletons. He also reported two other rooms, neither of which have been located.

In October and November of 1853, the *Daily Alta California* again carried accounts of Moaning Cave. This time the cave had been entered and explored by a group of Frenchmen. They claimed to have found 300 petrified human bodies, presumably in the room reported by Trask below the Main Room. Several human skulls, collected by the Frenchmen, were later placed on display in San Francisco.

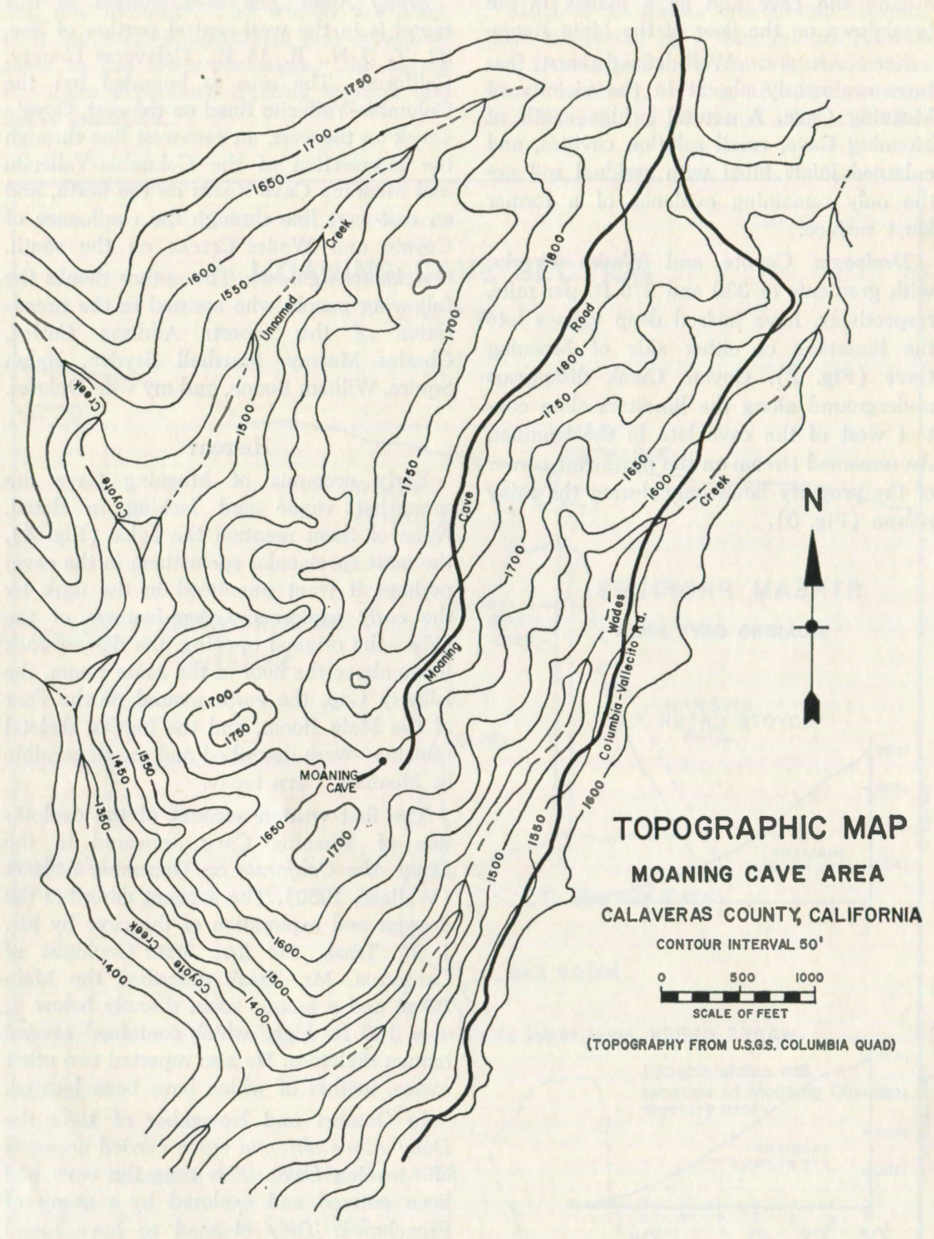

Figure 3. Topographic map of the Moaning Cave area, Calaveras County, California.

The cave then apparently remained unexplored and unpublicized for 68 years until Mr. Carley obtained the property. He first entered the cave on December 25, 1921, and according to him, the cave looks the same today as it did then. The mystery of the second large room still remains.

Description

Moaning Cave is a vertical composite solution cavity and domepit which has developed in a band of permeable limestone. Blocks of limestone have fallen from the hanging wall and ceiling of the Main Room, but solution activity has predominated in forming Moaning Cave.

After regional uplift and the subsequent lowering of the water table, ground water enlarged the cave to its present size. Joints undoubtedly transmitted ground water to the permeable band of limestone in which the cave is located. These joints are well developed in the harder, dense limestone on either side of the cave. Enlarged by groundwater, some of these joints are open 4 to 6 ft. and are 40 to 50 ft. deep. In the cave, thick travertine deposits and massive speleothems further show the prominent role played by solution activity in the growth of Moaning Cave.

The Main Room in the cave is over 120 ft. high and contains many interesting and unusual speleothems (Fig. 1). The temperature remains nearly constant at 59° F. The moaning sound heard by early explorers emanating from the cave entrance has stopped. It was thought to have been caused by air rushing from the mouth of the cave or by water dropping to the floor of the cave.

Entrances: Trask's entrance to the cave is a vertical opening that drops about 30 ft. to a narrow ledge above the balcony in the Main Room. The main entrance, currently used by visitors, is a narrow joint opening which strikes northwest. This entrance to the cave is oriented at almost right angles to the bedding and drops vertically to a point about halfway down called Maggie's Corner. Here the passage makes an abrupt left turn, and for a short distance it is nearly horizontal and follows the bedding. It then makes a sharp right turn toward the balcony and the steel staircase and once again is joint-oriented.

Main Room Ceiling: From the balcony, the northeast-striking bedding in the limestone, two large stalactites growing from the ceiling, and the ledge below the original opening can be seen (Fig. 5). The largest stalactite, over 16 ft. long, is a composite of several smaller stalactites which have grown together and are gradually deteriorating from the lack of moisture. To the left of this is a single stalactite in good condition which is over 6 ft. long and is several inches in diameter.

Main Room Floor: The floor of the Main Room is covered with massive blocks of breakdown which are mixed with a reddish clay soil that apparently washed in from the surface through joints or fractures in the limestone. The breakdown was derived from the walls and ceiling by seismic and solution activity. In plan view the floor is roughly oblong in shape, approximately 90 ft. long with a maximum width of 50 ft.

Main Room Walls: The walls of the Main Room, except for the hanging wall, are covered with thick flowstone (travertine) deposits, randomly oriented shields, and stalactites. The focal point of attraction in this room is the Igloo, which sits high up in the northwest corner of the room. The Igloo is a massive composite speleothem over 27 ft. high (Fig. 4) composed of several shields which have coalesced during various stages of growth. These shields apparently grew on numerous blocks of limestone which protrude into the room. Much of this detail, however, has been concealed by deposition of flowstone curtains or draperies around the original shields.

The east wall, from top to bottom, is festooned with a series of interconnected stalactites that resemble cigars in shape. They are 3 to 6 ft. in length or longer, and they are tapered on the ends where they connect to the speleothem above and below.

The hanging wall, in complete contrast to the rest of the room, is completely devoid

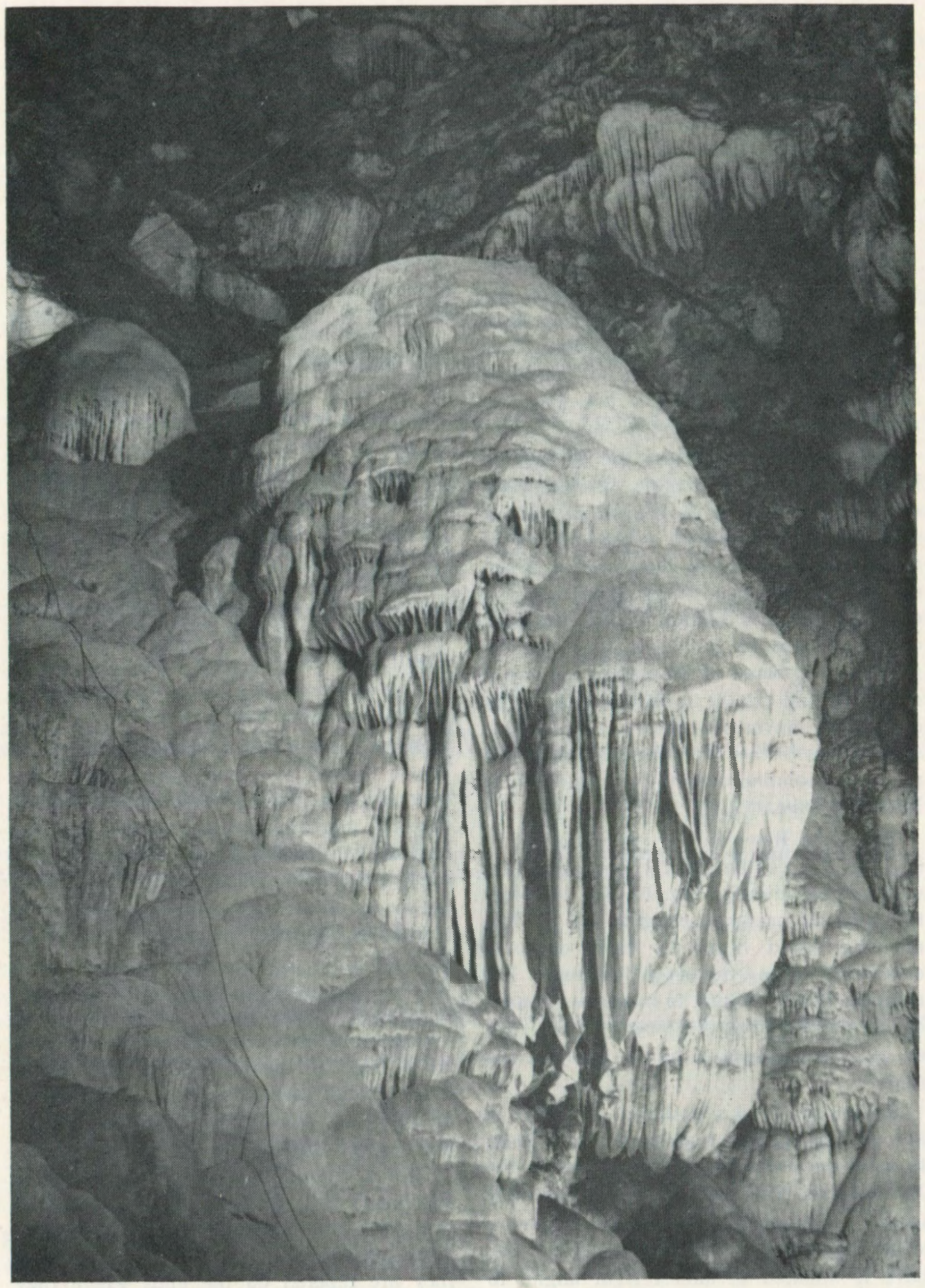

Figure 4. The Igloo is the center of visitor attention in the Main Room of Moaning Cave. This massive speleothem, 27 ft. high, is a series of shields and curtains that coalesced during various stages of growth.

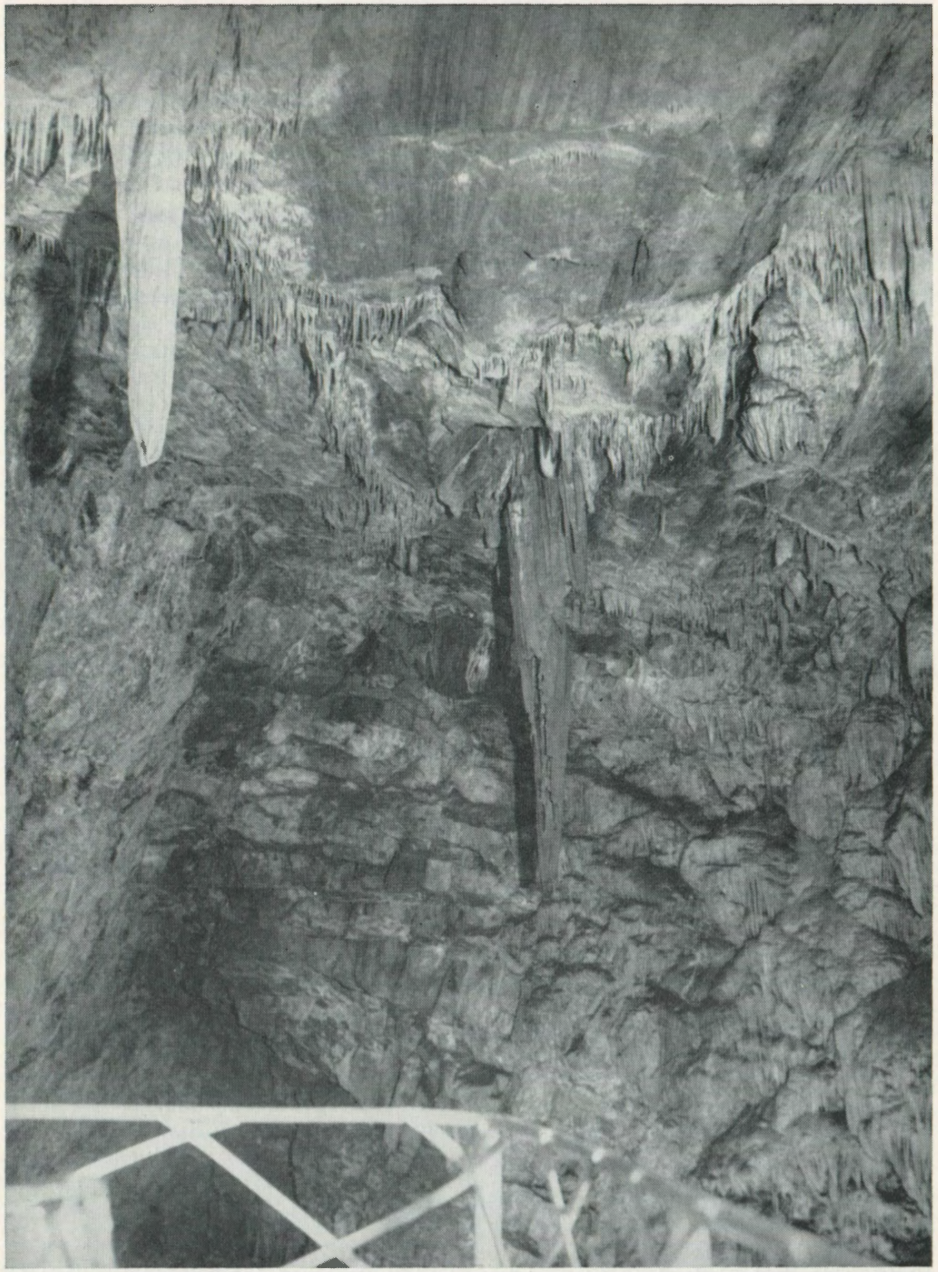

Figure 5. Traces of the bedding, two stalactites, and flowstone deposits as seen from the balcony in the Main Room. The distant stalactite is deteriorating due to a lack of moisture, however, the stalactite in the foreground is in good condition. Photograph courtesy of Addison Carley.

of speleothems except for some small branching trails of calcium carbonate which vaguely resemble waterfalls. This wall is a massive block of limestone which has separated from the main limestone mass along a bedding plane and now leans slightly into the room. When it came loose, the top third of it broke off and fell to the floor, contributing significantly to the breakdown on the floor of the room. The wall is supported at the base by breakdown, soil fill, and two large limestone blocks near the intersection of the west wall. These supporting blocks, well cemented in place, appear to be flat-lying beds. However, close examination reveals that they are actually huge blocks of limestone which fell from the walls or ceiling of the cave.

The west wall, which slopes 30 to 40° into the room, is covered with thick travertine deposits and numerous small shields and draperies which have grown over breakdown blocks protruding into the room.

Below The Main Room: Other interesting features of Moaning Cave, not viewed by the public, are found below the Main Room. An opening underneath the Igloo leads to a passageway that goes to the Mud Flats and the Lake Room.

The Mud Flats, so named because of an accumulation of mud on the floor of the passageway, is essentially a large breakdown area. The passageway winds around between massive breakdown blocks and reenters the Main Room at several different points. Some of the shafts to this area have been filled with material excavated during exploration of the Main Room. The passageway to the second large room in Moaning Cave, reported by Trask and others, will probably be found somewhere in this maze of breakdown.

A left turn below the Igloo leads to a vertical shaft that drops over 50 ft. to the floor of the Lake Room (Fig. 6). This room, irregular in shape, is about 15 ft. high, 7 to 10 ft. wide, and 21 ft. long. It contains many interesting speleothems. There are numerous soda straws, white flowstone deposits, helictites, stalactites, and a small rimstone pool which contains clusters of aragonite crystals. The soda straws are aligned normal to the strike of the bedding which is exposed on the ceiling of the room (Fig. 7). The limestone in this area is very soft and thinly bedded; water percolates through readily, keeping the speleothems in an active state of growth.

A narrow, steeply dipping shaft below the floor of the Lake Room leads to another small room about 80 ft. below the Lake Room. The water table has not been intersected even though both rooms are below the surface elevation of Wades Creek.

Geology

The geology of the Sierra Nevada Province has been complicated by periods of folding, faulting, granitic intrusion, metamorphism, vulcanism, weathering, and glaciation. The oldest rocks exposed in the vicinity of Moaning Cave consist of a series of metasediments and limestone, schist, and slate. The limestone has been largely altered to dolomite except for the band of soft, permeable limestone in which the cave has developed. This band of light to dark gray, thinly laminated limestone has a high concentration of black minerals. Three solution cavities 15 to 20 ft. deep occur in this softer limestone on a ridge northeast of the cave. The schist near the cave entrance is deeply weathered, and the slate, exposed along Coyote Creek, is very hard and fresh.

These rocks contain bands of thinly laminated marble, granitic intrusives, and wide quartz-muscovite dikes. Sharp minute folds in the banded marble suggest that it was plastically injected into the limestone (Eric, Stromquist, and Swinney, 1955). The schistose nature of the quartz-muscovite dikes suggests that they may have been injected into the limestone along fault planes.

An accurate age determination for the Calaveras formation is almost impossible, because periods of intense deformation have largely destroyed the fossil assemblage in these rocks. A late Paleozoic age has been assigned to the Calaveras formation because it contains fossils of Permian age in its upper part.

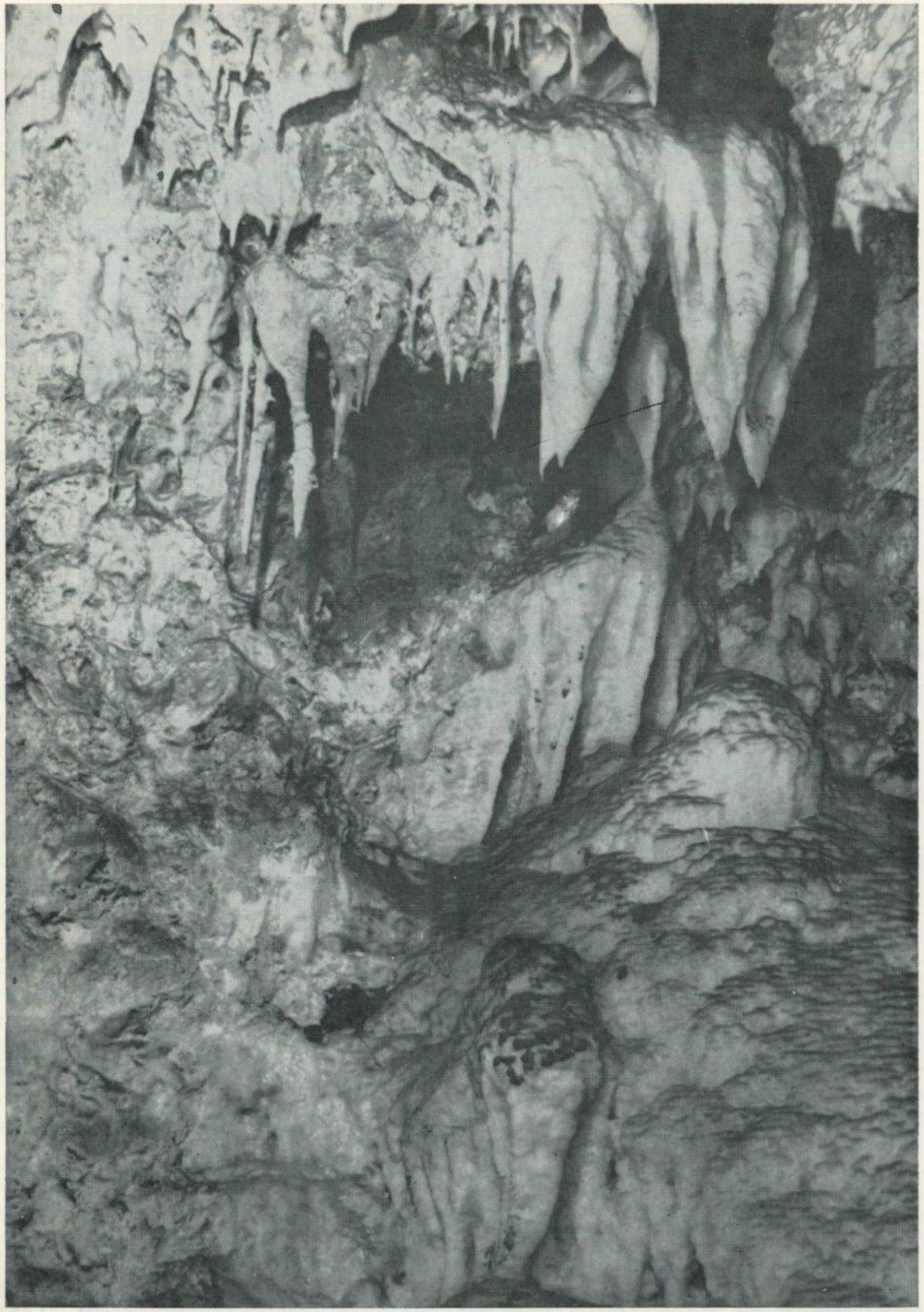

Figure 6. Thick flowstone deposits on breakdown blocks at the top of the vertical shaft to the Lake Room.

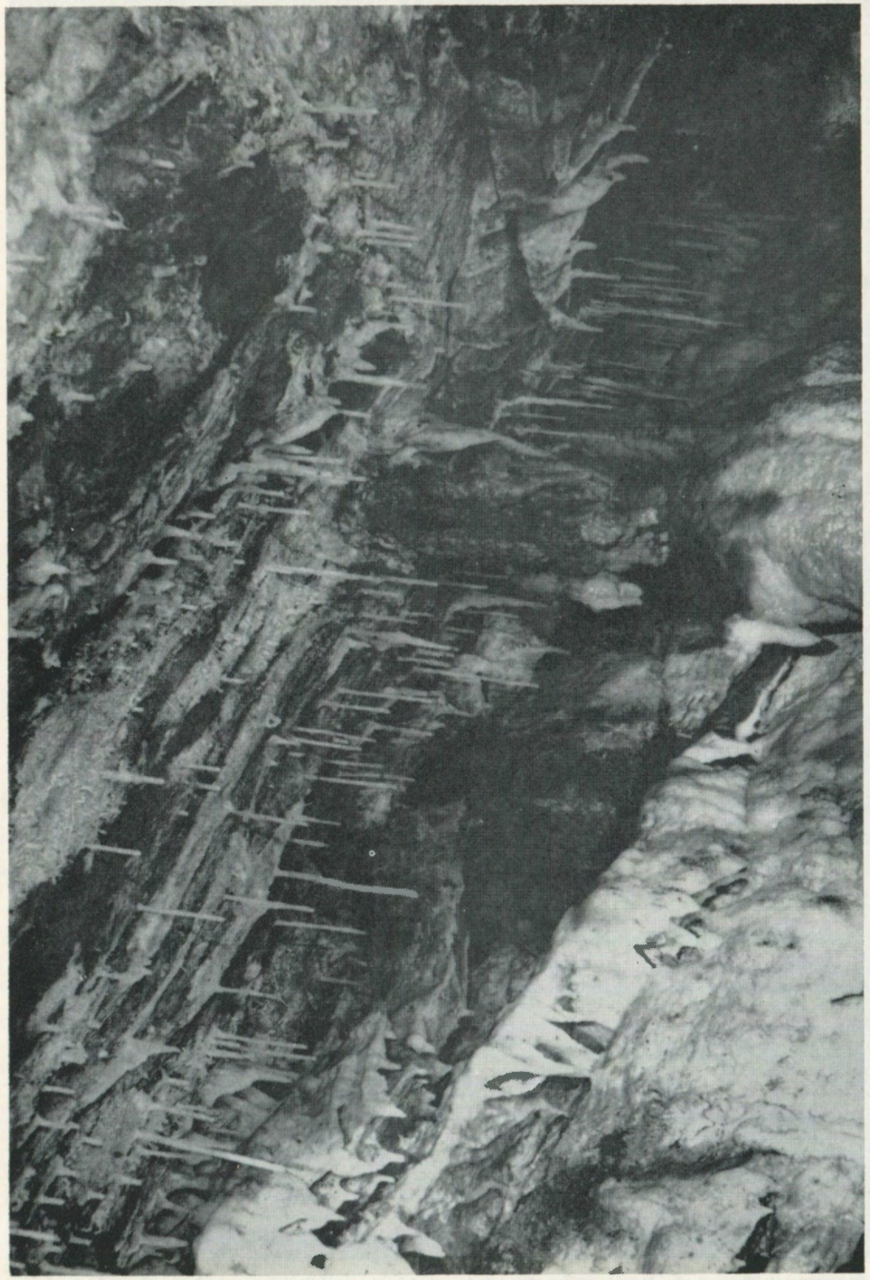

Figure 7. Noticeable on the ceiling of the Lake Room is a faint bedding trace, soda straws, helictites, and several small stalactites. The soda straws are aligned normal to the bedding plane.

Faulting and Seismicity: Moaning Cave is adjacent to the famous Mother Lode fault zone of northern California which trends northwest across southwestern Calaveras County. Movement associated with these faults has generally been in a reverse direction (Clark and Lydon, 1962). Eric, Stromquist, and Swinney (1955) recognize four periods of faulting within the Mother Lode System that have brought rocks of the Calaveras formation into juxtaposition with those of the Jurassic Amador group. They also contend that later normal movement has occurred along some of the earlier reverse faults.

The limestone-schist contact north of the entrance to Moaning Cave has been mapped as a normal fault contact (Alling, 1925). The contact strikes northeast parallel to the foliation of the schist and dips steeply southeast. There is no evidence that this was an earlier reverse fault along which later normal movement has occurred, and geologic details along this contact have largely been obscured by weathering. However, the blocky and broken nature of the limestone along the contact and slickensides in the schist indicate that movement of some type has taken place.

The earliest record of seismic activity affecting the Sierra Nevada was reported in the writing of John Muir (Egenhoff, 1964). Early in the morning of March 26, 1872, a tremendous earthquake shook the whole state, from Shasta in the north to San Diego County in the south. On July 9, 1877, a report of an earthquake was recorded on the register of the Murphys Hotel, Murphys, California, just 7 miles from Moaning Cave. No information about the quake was noted except to say that three shocks occurred at 11 a.m. (Morgan, 1969).

The evidence suggests that faulting and seismic activity have also contributed to the evolution of Moaning Cave. The separation of the hanging wall from the limestone mass in the Main Room apparently attests to this. The hanging wall is oriented normal to the bedding, and there is no visible proof that ground water solutions created this phenomenon.

An almost vertical fracture in the west wall of the Main Room may have resulted from faulting or seismic activity. The fracture is open about 1 ft. and intersects the joint trend at nearly right angles and the bedding at an oblique angle. The presence of this fracture is not necessarily *prima facie* evidence of faulting, but this assumption has been made because its attitude is not normal to either the joint or bedding trend.

Bedding and Jointing: Northeast-striking bedding which dips steeply southeast and a joint set at nearly right angles to the bedding are the prominent linear features around Moaning Cave. The bedding is generally vague in the metamorphosed limestone but is well developed in the softer limestone. The bedding strikes N 45-70° E and dips steeply southeast. The joint set in the area strikes N 15-40° W and dips very steeply northeast. Approximately half of the joints mapped around the cave site were vertical (Fig. 8).

There is also evidence that water flowing normal to the bedding has contributed partially to the growth of the cave. Northeast of the cave entrance, there is a vertical opening in the softer limestone that drops 19 ft. to a strike-oriented passageway. This passageway extends southwest for 70 ft., where it terminates in a small room. An angel wing 4.5 ft. long, about 3 ft. wide, and nearly 1 inch thick hangs from the ceiling of the room.

Historical Geology

Past geologic events can be related to the growth and development of caves in the limestone "facies" of the Calaveras formation. Although this paper is specifically oriented toward Moaning Cave, the same analogy could reasonably be applied to the many other caves that occur within this formation. Therefore, the geologic history of Calaveras County must be reviewed and the chain of events which have occurred outlined to determine the geologic age of Moaning Cave.

Deposition of marine sediments intercalated with volcanic products during the late

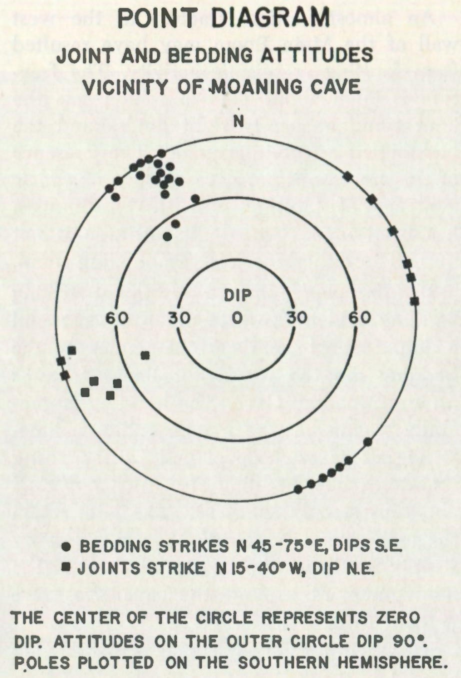

Figure 8. Point diagram of joint and bedding plane attitudes in the vicinity of Moaning Cave.

Paleozoic provided the materials for the Calaveras formation. The marine sediments formed the limestone in which Moaning Cave has evolved. Near the end of the Paleozoic Era, perhaps in late Permian or early Triassic time, a deep synclinal trough began to develop. Marine sedimentation and submarine volcanism prevailed, and by the end of the upper Jurassic, the material which formed the Cosumnes, Logtown Ridge, and Mariposa Formations were deposited.

The Jurassic period was culminated by the Sierra Nevadan Orogeny. The Mesozoic seas withdrew from the county, and the flat-lying Jurassic beds were folded into complicated northwest-trending folds which were faulted, metamorphosed, and repeatedly intruded by igneous magmas.

During the early Cretaceous, there was a long period of erosion, probably accompanied by chemical weathering, which greatly lowered the elevation of the Sierra Nevada Mountains. Bateman and Wahrhaftig (1966) estimate that erosion extended to a depth of 9 to 17 miles. Rivers incised channels into gold-bearing rocks of the Sierra Nevada batholith which had intruded the Paleozoic and Mesozoic rocks. By late Cretaceous another seaway had deposited thin fossiliferous beds along the western edge of the Sierra Nevada batholith. This was followed by erosion which continued into the early Tertiary and further lowered the Sierra Nevada.

In early Tertiary the climate changed to subtropical, erosion continued, and deep chemical weathering prevailed. Heavy minerals, especially gold, previously eroded from Mesozoic rocks were redeposited and concentrated into rich placer deposits in Eocene stream channels. The Eocene Epoch ended with the advent of intense volcanism throughout the Sierra Nevada. Tremendous quantities of volcanic ash fell which buried the Eocene stream channels. During the Miocene a new drainage system containing rich placer deposits developed and was covered by volcanic materials.

Volcanism continued, with intermittent periods of quiescence, to further bury the Eocene and Miocene channel deposits under hundreds of feet of volcanic materials until late Miocene or early Pliocene. The final products of this intensive and prolonged period of volcanism were flows of andesite, basalt, and latite.

With the cessation of volcanic activity late in the Pliocene, the Sierra Nevada Mountains were rejuvenated. This was accompanied by faulting on the east flank and westward tilting of the Sierra Nevada, renewed stream erosion, stripping of much of the Cenozoic volcanic cover, and finally glaciation.

Since the retreat of glaciers from Calaveras County, the present climate and topography have developed. Both are probably much the same now as they were by the middle of the Recent epoch.

Age of Moaning Cave: The age of Moaning Cave is very difficult to accurately determine because of the complex prior geologic history. The cave probably didn't develop to any extent until the Pleistocene. Possibly the cave may have begun to evolve during the sub-tropical climatic conditions prevalent in the early Tertiary. However, this was followed by three periods of intense volcanism and one period of stream erosion. Burial by thick volcanic deposits would certainly have prohibited any type of cave development. Caves of any extent would not have survived the later vigorous tectonic activity which accompanied the rejuvenation of the Sierra Nevada Mountains in the Pliocene.

The most logical age for Moaning Cave would be Pleistocene. By this time massive, tectonic activity had ceased, a joint pattern was well developed in the older rocks, the drainage pattern of the major streams was in a westerly direction, and tremendous quantities of glacial meltwater were available to dissolve the carbonate rocks.

Conclusions

Regional uplift and associated faulting produced joints and elevated the limestone around Moaning Cave. The joints, thus formed, were the primary linear features indirectly responsible for the growth of the cave. Many of these joints are 5 to 6 ft. wide and extend downward to over 50 ft. They acted as conduits and allowed ground water to enter the permeable band of limestone in which the cave developed. Once inside the permeable limestone, the water percolated downward toward the water table, dissolving the limestone as it went. Undoubtedly, due to the vertical nature of the cave, these waters eventually reached the water table by draining out through the bottom of the cave. This seems like a reasonable hypothesis because Coyote Creek is lower than the lowest point in the cave and disappears underground in the late summer and the water table has never been encountered inside the cave.

The geologic agents responsible for the growth and evolution of the cave have also limited its lateral extent. Moaning Cave appears to be on the hanging wall of a reverse fault; if this assumption is correct, the cave may not extend vertically to any great depth. The schist-limestone contact 300 ft. north of the cave entrance and again just south of the entrance limits the width of the band of limestone in which the cave occurs. The limestone band extends northeasterly for several thousand feet but terminates in a saddle west of the cave which separates it from an adjacent limestone mass. A flexure in the strike of the bedding in the latter limestone deposit suggests that a northwest trending fault bisects the saddle.

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Proceedings of the Society

MEETING IN LOVELL, WYOMING, JUNE 1969

GEOLOGY SESSION

THE PARADISE ICE CAVES, WASHINGTON: AN EXTENSIVE GLACIER CAVERN

Charles H. Anderson, Jr. and William R. Halliday
Cascade Grotto, NSS

Winter exploration and study of the Paradise Ice Caves of Mt. Rainier, Washington, have led to new concepts of their extent, size, and speleogenesis. With more than a mile of known passage still unmapped, 1.5 miles have been mapped to date, most of it in passages many feet in diameter. The overall pattern is dendritic; streamflow appears to be the primary speleogenetic factor at early stages, with thermocirculation of air more important subsequently. The system was segmented by collapse during the study. Numerous seasonal speleothems of unexpected beauty were noted, and both speleothems and speleogens are illustrated.

CAVERN DEVELOPMENT IN THE SOUTHERN CANADIAN ROCKIES

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Department of Geology
McMaster University
Hamilton, Ontario, Canada

Between the U. S. border and the Peace River country, 400 miles to the north, the Rocky Mountains of Alberta and British Columbia constitute one of the greatest carbonate mountain systems of the world. Systematic investigation of their karst phenomena was begun by McMaster University in 1965 and has continued during the subsequent summers.

Many karst groundwater systems and accessible caves have been located. Some tentative generalizations may be made: (1) Caves and karst are best developed in thick, massively bedded limestones, such as the Palliser Formation (Devonian). They are more limited in mixed limestone-shale formations, which are very common, and almost entirely absent in the abundant dolomites. (2) Most of the cavernous rock is steeply dipping, and the greatest cavern density is found in the few areas of near-horizontal bedding. (3) The disruptive effects of multiple glaciation have been considerable. Active karst spring sites all appear very recent in age and unstable in location. Few stream sinks lead to caves of accessible dimensions. Active groundwater systems, some of them of immense discharge, are predominantly phreatic. Few of these are simple post-glacial creations; most are drastic modifications of older (inter-glacial) lines of flow. (4) In the southern part of the region there is an abundance of wholly fossil phreatic caves. They appear to be very old; some must almost certainly antedate the Pleistocene.

Development in three contrasting areas—the Maligne River basin in the north of the region, the Castleguard Col in the center, and Crowsnest Pass in the south—is summarized.

TWO CAVES IN ONE—THE DUNCAN FIELD SYSTEM, OKLAHOMA

Joseph M. Looney

Tulsa Grotto, NSS

Oklahoma's longest cave, the Duncan Field Cave System in Adair County, is one of several caves atop Dolly Mountain, all of which are developed in a system of joints that run parallel to the nearby Little Lee Creek Fault. The total length of the various explored caves on the mountain includes 18,000+ ft. in Duncan Field; 6,000+ ft. in Sam's Pit; 1,500 ft. in Third Cave; and less than 200 ft. each in Fence Pit, Catron Sink Cave, and Breakdown Cave. All this passage is crammed into an area of less than 40 acres, although the drainage in the entire super-system seems to be divided and resurges in two springs that are more than 2 miles apart. There appear to have been two distinct stages in the development of the caves. They are excavated in the 42-ft. thick Pitkin Limestone (Mississippian) which lies between the Fayetteville Shale (Mississippian) and the Hale Formation (Pennsylvanian), the latter a nearly impervious calcarous siltstone. There are two large shale layers in the Pitkin. Initially, it appears a bedding-plane-controlled cave developed at the Pitkin-Hale contact, enlarging along the uppermost and largest of these shale layers. This forms today the "maze level" of the system. There are high and dry abandoned stream passages and bewildering mazes that show little evidence of joint control at this level. Later, faulting and jointing apparently occurred in the Hale and allowed acid-charged water to seep through these joints, forming the larger passages in the cave, a set of more than 25 various paralleling joint-controlled passages, ranging from about 150 to more than 3,000 ft. long, averaging from 30 to 40 ft. high, and ranging from but 2 ft. to more than 70 ft. wide. All exhibit prominent ceiling joints which obviously controlled their formation. These joint passages actually intersect old bedding plane passages. Development of speleothems has been minor, although some interesting mineral crusts have formed on many walls. These include deposits of aragonite, gypsum, and barite. The water flowing into the cave through these joints has collected in a network of drain tunnels, most of them extremely small, which feed the one major stream passage, a tunnel about 3,500 ft. long. Tremendous breakdowns, formed where the overburden of Hale has collapsed, frustrate exploration of many promising areas. The explored caves lie beneath only a small portion of the mountaintop, and the potential for more cave is immense.

CLASTOKARST IN PALO DURO CANYON, TEXAS

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Pseudokarst is a collection of karst-like landforms, such as caves and sinkholes, which have formed in rocks or sediments much less soluble than limestone. In weakly-cemented clastic sedimentary rocks, many pseudokarst landforms result in part from mechanical suffosion, or piping. This type of pseudokarst has been called clastokarst. Mechanical suffosion is a process of subsurface erosion by which ground water selectively flushes finer particles from among coarser ones. Factors controlling mechanical suffosion include the physiography of the area and the characteristics of the eroded material and of the water. Content of swelling clays may be very important both to initiation of suffosion and intensity of erosion. Suffosion-initiated tubes are commonly enlarged by fluvial corrasion and may eventually become so large that they collapse.

Several areas of clastokarst are known in Palo Duro Canyon, near Amarillo in North Texas. Landslides at the base of steep canyon walls show abundant evidence of suffosion; one landslide of about 7,000 m² contains more than 10 caves. The largest—150 m long—is intersected in its upper part by about 15 distinct sinkholes. Its lower opening is an ephemeral resurgence. All caves in the area occur along the contact of landslide material and the underlying Permian sandstone. Tubes initiated by mechanical suffosion, perhaps along pre-landslide gullies, were enlarged by corrasion to as much as 3 m in diameter. Over-enlargement resulting in roof collapse is evident in many places. Suffosion, corrasion, and collapse are presently active in Palo Duro Canyon.

HYDROGEOLOGY AND CAVERN DEVELOPMENT IN THE SWAGO CREEK DRAINAGE BASIN, WEST VIRGINIA

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The Swago Creek drainage basin in Pocohantas County, West Virginia, contains several large caves and a complex underground drainage system. It has been under study for 15 years. This report is an interpretation of the development of the caves and the drainage pattern as a function of the structural and stratigraphic controls operating in the area.

The aquifer is the Greenbrier Limestone, here about 400 ft. thick. The Greenbrier contains two insoluble members, the Greenville Shale near the top of the section and the Taggard Formation in the middle. Recharge to the system is from stream run-off from clastic rocks higher on the mountain flanks at the top of the section. Discharge is through several cave springs at the bottom of the section. Drainage lines cross under major mountain ridges and drainage divides occur beneath the valley floors. Surface streams that run during flood often take entirely different routes from the underground drainage.

The Greenville Shale acts as an aquiclude and isolates the Alderson Limestone hydrologically from the remainder of the aquifer. A perched water body exists in the Alderson discharging through a series of small springs which often form the vertical shafts that are concentrated just below the Greenville. The Taggard Formation has acted to perch underground streams and to build the high hydraulic gradients necessary to derange the drainage. Some water spills from the Taggard by surface routes, but most cave systems have managed to cut the Taggard mainly by erosional processes.

A tentative history of the development of the Carpenters-Swago Cave System and Overholt Blowing Cave can be constructed from the structural and stratigraphic relationships.

EBB AND FLOW OF BIG SPRING, LILBURN CAVE SYSTEM, KINGS CANYON NATIONAL PARK, CALIFORNIA: A PRELIMINARY REPORT

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The normal flow at Big Spring, the discharge for the Lilburn cave system, is steady—with a linear relationship between the flow and the standing water level in the downstream end of the cave, the South Seas. On April 20, 1969 it was discovered that Big Spring was surging dramatically. On the following weekend, April 26-27, synchronous measurements of stage height at Big Spring and water level at the South Seas were obtained for a period of 4 hours. The period between surges varied from 2 hours to 12 minutes. A typical surge would rise from a low flow of 12.5 sec.-ft. to approximately 100 sec.-ft. in 2 to 3 minutes and then decline gradually back to the low flow in about 20 minutes. Sharp drops in the water level at the South Seas preceded the start of the surge at Big Spring by one minute and reached a minimum one minute before the surge began decreasing. The difference in elevation between Big Spring and the low water levels inside the cave at South Seas varied from 30 to 34 ft., and the high water levels varied from 35 to 49 ft.; the horizontal distance is 2300 ft.

This ebb and flow action is probably due to a siphon which carries the water from the South Seas to a lower reservoir which then empties at Big Spring. The variations in period and high water level may be due to variations in the amount of air sucked into the siphon when it breaks.

The system has three distinct flow patterns: (1) a steady linear flow at low rates, (2) an ebb and flow siphon action at intermediate rates, and (3) steady flow again at very high flow rates; the high water mark in the cave from last winter's torrential rains is 215 ft. above Big Spring.

THE CHEMICAL EVOLUTION OF SOME CAVE WATERS, INNER SPACE CAVERN, TEXAS

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The carbonate solution chemistry necessary for a chemical study of cave waters is generally well known. The chemical evolution of cave waters has been divided into three phases: a phase of absorption of CO_2 in the soil zone, a phase of carbonate bedrock solution, and a phase of adjustment to the cave atmosphere. Cave waters associated with the "Flowing Stone of Time" at Inner Space Cavern, Texas, were periodically sampled for 3 months. Analyses of these water samples were used to determine and interpret their evolution.

An increase in CO_2 content of the water of at least an order of magnitude must have occurred in the soil zone to account for the measured calcium content and pH of the water just entering the cave. The calcium and magnesium content of these waters generally agree with the dolomite solubility product of nearly 10^{-17} proposed by Holland but differs from the values of Garrels and Yanat'eva by two to three orders of magnitude. The water just entering the cave is undersaturated with respect to calcite, but degassing occurs rapidly and the CO_2 content of this water has decreased by over an order of magnitude when the water reaches the base of the flowstone mass. This water is then supersaturated with respect to calcite. The calcium content of bodies of standing water is equal or nearly equal to that expected at saturation and thus agrees with the accepted value of the solubility product of calcite. Precipitation of calcium carbonate from solution due to loss of CO_2 is seen to exceed that resulting from evaporation by a ratio of about 10:1. The high calcium to magnesium ratios observed in water just entering the cave indicate a selective solution of calcium over magnesium as ground water moves rapidly down through the dolomite bedrock overlying the cave. Finally, observations indicate that the precipitation of calcite is probably greater during dry periods than wet periods, when the ground water moves rapidly through the bedrock and the calcium content of water entering the cave is substantially lower.

SOME CONTOUR AND CAVE CONDUIT STATISTICS IN FLINT RIDGE, KENTUCKY

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The intersection angles of all cave passages shown on the 1964 CRF maps of the Flint Ridge Cave System with the 600, 700, and 800-ft. contours and with a grid of N-S lines, and of contours with the grid lines, were measured and analyzed statistically. Passage and contour intersection angles, as well as those for contour and N-S grid lines, were found to be randomly distributed. The cave system itself is, however, significantly oriented. A simple method for obtaining direction histograms directly from a cave map was developed.

The pattern of Swinnerton Passage was analyzed with a statistical "space series" method. The passage was found to be representable by a third-order autoregression with independent normally-distributed residuals. On this basis the passage was extrapolated through Flint Ridge to intersection with the Green River. The significance and limitations of such an analysis are discussed.

MEETING IN BOSTON, MASSACHUSETTS, DECEMBER 1969 GEOLOGY SESSION

GEOLOGICAL FACTORS INFLUENCING THE DEVELOPMENT OF CASSELL CAVE, WEST VIRGINIA

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Cassell Cave is on the east limb of the North Potomac Syncline in Pocahontas County, West Virginia, where the Mississippian Greenbrier Limestone crops out on the east flank of Back Allegheny Mountain. Four factors affecting the development of the cave are described:

(1) *Surface slope-structural dip relation:* Because the structural dip is opposite to the surface slope, the limestone is remarkably effective in capturing runoff. Only under flood conditions does any water cross the limestone. Captured water migrates northwesterly down dip into cave passages which divert it to the northeast. This has resulted in over 6.4 miles of passages in a narrow belt of limestone outcrop.

(2) *Joint control of passage direction:* The angular plan of passages, with straight segments alternating between northerly and northeasterly directions and occasional offsets to the west-northwest, indicate joint control. The dominant passage direction, N25°E, closely parallels the axis of folding and is attributed to tension joints resulting from folding.

A secondary maximum at N65°W is attributed to tension joints parallel to the direction of the major stress.

(3) *Control of passage elevation by lithology:* The separation of the limestone into several relatively soluble zones by more resistant standstones and shales has divided the cave into three distinct levels.

(4) *Modification of vertical control by faulting:* Thrust faulting has interrupted the continuity of the strata, making it possible for streams to descend to lower levels by circumventing rather than penetrating the resistant strata.

EFFECTS OF SUBTERRANEAN STREAM PIRACY ON LANDSCAPE DEVELOPMENT

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Investigations in the Cloverlick Valley of Pocahontas County, West Virginia, indicate that stream piracy through cave tunnels in the Greenbrier Series (Mississippian) has been important in the development of the present topography. It has been noted in the literature that the Cloverlick Valley is a cut-off meander of the Greenbrier River. Topographic evidence shows that the straightening of the river occurred by subterranean piracy through the limestones of the Greenbrier Series when the river eroded to that level. The inter-stream saddle between Cloverlick Creek and Laurel Run retains the elevation of the Greenbrier River at the time of piracy. Present-day stream channels sink immediately upon arriving on a limestone horizon, descend nearly vertically through enlarged joints, and then flow on relatively insoluble beds for some distance, usually until again reaching the surface. Underground stream patterns sometimes do and sometimes do not agree with surface patterns.

CAVE SEDIMENTS AND SEDIMENTARY ENVIRONMENTS ALONG THE ALLEGHENY FRONT: A PRELIMINARY REPORT

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This preliminary report on some of the geomorphological aspects of clastic cave fills is drawn from the author's forthcoming doctoral dissertation on sedimentation in caves of the Greenbrier Limestone along the base of the Allegheny Front in southeastern West Virginia. Previous studies are criticized for their failure to define the drainage net as the most important unifying factor in an attempt to relate surface and subsurface deposition. By treating each basin as a whole and examining streams, surface sedimentation, and cave fills within the basin, the author attempts to show that a relationship does exist.

The careful choice of a study site is emphasized. The Culverson Creek system is used as an example. Here relatively simple areal geology, linear outcrops of clastic source material, and a strike-oriented drainage pattern control some of the troublesome variables in sediment *source* and *distribution.* Through the use of traceable "identifiers", such as quartz pebbles derived from the Princeton and Pottsville formations, a hypothesis of stream reversal and subterranean piracy is verified. Samples of the following were taken for study: bedrock conglomerate source material at the headwaters of the present drainage net, quartz pebbles and transported conglomerate boulders along the main trunk channel to where a major sink receives all runoff, quartz pebbles from marker beds in caves flanking the trunk valley flood plain, quartz pebbles from within the present subterranean trunk conduit and at higher levels in the cave, ejects from the present rising along Spring Creek, and quartz pebbles from along a presumed high level, ancient surface runoff channel for a distance of 12 miles.

Preliminary results from laboratory tests in progress show a decrease in size and an increase in sphericity and roundness of quartz pebble samples in a downsteam direction along the ancient runoff channel, in the caves, and along the present surface trunk stream. Structural characteristics in the cave fills show an invasion of quartz pebble deposition, probably due to flooding sequences.

A once-in-a-hundred-or-more-years flood occurred while field work was in progress, which provided a rare opportunity for study of sedimentation under such conditions. Cave sediment traps which had, during the previous year, showed only silt and clay deposition were completely filled with pebbles and small boulders. Other spectacular examples of cutting and filling by flood action support the author's opinion that such infrequent floods are significant in the removal, deposition, and reworking of surface and subsurface clastic fills.

STRUCTURALLY CONTROLLED JOINT CAVES IN THE SHAWANGUNK MOUNTAINS, ELLENVILLE, NEW YORK

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A set of strongly developed three-dimensional right-angle joints have formed structurally controlled caves in two locations atop the Shawangunk Mountains near Ellenville, Ulster County, New York. The caves, located entirely in the Silurian Shawangunk quartzite conglomerate, are partially roofed crevices. They have probably formed since the end of the Pleistocene as the joint-controlled Shawangunk blocks slid down the western dip slope of a broad anticline. These western crevice caves extend to a depth of up to 120 ft. below the local topographic surface and retain ice throughout the year. Water of undetermined volume flows along the bottom of two of the caves.

Another set of crevice caves at the southwest end of the east-facing erosion scarp of the Shawangunk ridge, close to the anticlinal crest, has been formed in the jointed conglomerate as a result of undercutting of the cliff face by sapping and subaerial erosion of the underlying Hudson River shales.

Gravity sliding is probably facilitated along surfaces of shale partings or along the lower contact shale at the base of the Shawangunk conglomerate, although direct field evidence of this is difficult to obtain.

The areal extent of the western crevice caves is less than one square mile, whereas the undercut joint blocks, typical of the eastern erosion scarp, are present along several stretches of the 15-mile long cliff from Route 44/55 southwest to Sam's Point and northwestward along the Ellenville reentrant.

LEE CAVE, MAMMOTH CAVE NATIONAL PARK, KENTUCKY

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Lee Cave is located in the northwestern edge of Joppa Ridge in Mammoth Cave National Park. Entrance through a shaft and canyon complex leads into a large trunk passage at the western terminal breakdown. The trunk, evidence that a major cave system does exist under Joppa Ridge, extends 7000 ft. with cross-sections up to 50 x 100 ft. to an eastern terminal breakdown. Below the main trunk is a complex of smaller tubes, canyons, and vertical shafts. The surveyed length to date is 2.22 miles.

The trunk contains a thick clastic sediment sequence which contains facies ranging from cobbles in the west to fine silts and clays in the east. Breakdown activated by sulfate replacement and crystal wedging is common. Gypsum and epsomite occur as clumps of curved crystals, and other sulfates occur as thick crusts drifted onto up-facing sediment and breakdown surfaces. Cave life is sparse; there is a small bat colony and much evidence of cave rats, although no live rats have been observed. Smaller animals, except for crickets, have not been observed.

Pre-Columbian Indians entered the cave, probably through an entrance now closed in the eastern breakdown. Fragments of cane-torch material are scattered along much of the main trunk passage. Two stone cairns of unknown purpose occur. There is, however, no evidence of the mining activity common to Mammoth and Salts Caves. Lee Cave was named for T. E. Lee, pioneering cave explorer of South Central Kentucky, who descended the entrance pit in 1876.

BEHAVIOR OF ANNUAL FLOODS IN CARBONATE BASINS OF PENNSYLVANIA

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The behavior of floods in small basins is a strong function of the geology and geomorphology of the drainage basin. Flood response as a function of the geomorphology was studied for 114 basins which ranged from 2 to 200 mi^2 in Pennsylvania. Examination of these flood data showed that the limestone basins had a flood response quite different from that on noncarbonate rocks. A plot of the mean annual flood per square mile as a function of drainage area, for example, shows that limestone basins have a very low mean annual flood. Further, the flood is not a function of drainage area as is the case for clastic rocks. The flood hydrograph for limestone basins is smoothed by reducing its height and broadening its base. This can be accounted for by postulating very rapid infiltration of flood waters into temporary storage in the ground water reservoir. This temporary storage is then metered out over a period of time that is long compared to the duration of the flood pulse, but short compared with normal ground water discharge. This results in a flattening of the flood hydrograph and gives the basins a characteristic low response.

HYDROLOGY OF THE LIMESTONE AQUIFERS OF SOUTHERN INDIANA

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The karst aquifers of southern Indiana comprise a 400-ft. thick sequence of Mississippian limestone that dips to the west-southwest at an average of 30 ft./mi. Three major aquifers can be recognized: the massive Salem and upper Harrodsburg Limestones, which form the lowest of the three aquifers; the overlying shaly St. Louis Limestone; and the relatively thin-bedded Paoli and Ste. Genevieve Limestones, which form the uppermost aquifer. Extensive cave systems are found in all three units. Cave patterns and well data indicate that ground-water flow is strongly influenced by bedding planes in the upper part of the limestone sequence, with very little control by joints. Bedding-plane control of ground-water flow decreases downward in the section, and joint control increases to the extent that its influence is comparable to, or greater than, that of bedding planes. Caves in the two upper aquifers tend to be strongly concordant to the local geologic structure, with this tendency decreasing downward in the section. Recharge to the uppermost aquifer is restricted by an insoluble caprock, so that cave systems assume generally linear patterns, with few active tributaries. The two lower aquifers are exposed in an extensive sinkhole plain in which recharge takes place through each sinkhole, resulting in dendritic cave patterns. Most subsurface drainage paths in the sinkhole plain are genetically related to former surface routes whereas this relationship does not apply to drainage in the uppermost aquifer. Very few karst flow systems are developed in more than one of the three major aquifers.

CHANNEL HYDRAULICS OF FREE SURFACE STREAMS IN CAVES

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Elementary fluid mechanics is applied to cave conduits in which the stream has a free air surface. These are mainly passages with a canyon cross-section. Examples are taken from the Central Kentucky Karst. Estimation of Reynolds and Froude numbers for typical water flows in caves predicts that most cave streams flow in a sub-critical turbulent regime. An exception is the flow of thin water films down vertical shafts in which the flow may be supercritical and laminar. Channel widths vary systematically with both velocity and discharge. Slopes of channels calculated with the Manning equation agree with measured values for small canyons. Large canyons have very flat gradients and are interpreted as high points in an undulating conduit which lies near the water table. Composite passages in which a large tube has given way to a narrow canyon can be explained in terms of changes in flow regime rather than by decreases in discharge.

HYDRAULIC GEOMETRY OF A LIMESTONE SOLUTION CONDUIT

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The size of the passages in a large dendritic cavern system (Devils Icebox, Missouri) increases downstream in a manner similar to the changes in geometry exhibited by surface stream channels. The relationships can be used to show that part of the passage now used by the trunk stream is not actually part of the main solution conduit. Shape is statistically constant in large conduits, which differ in shape from some tributary passages. Passage geometry at a station may be complex, but the overall trends are not random solution effects. They are related to the hydraulic characteristics of integrated drainage systems.

Information for Contributors To The Bulletin

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

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

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

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

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

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