

Report on Sediments in Mammoth Cave, Kentucky

by

William E. Davies and E. C. T. Chao

Prepared for

U. S. NATIONAL PARK SERVICE

by

U. S. GEOLOGICAL SURVEY

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ADMINISTRATIVE REPORT

August, 1959

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REPORT ON SEDIMENTS IN MAMMOTH CAVE, KENTUCKY

by

William E. Davies and E. C. T. Chao

INTRODUCTION

In 1953 the U. S. National Park Service made informal inquiries of the U. S. Geological Survey concerning the initiation of studies on stream gaging and sedimentation in Mammoth Cave. These studies were to pertain to the problem of sediment deposition in the lower portions (Echo River) of the cave. Funds available at that time only permitted the placing of staff gages in the cave and at prominent points of resurgence near the cave and a reconnaissance study of the occurrence of ground water (Brown, 1953). Sampling of sediments in the cave was done in April, 1953 when one of the authors (Davies) visited the cave. Additional samples were taken in 1956 by Davies when he was at Mammoth Cave as a participant in the first Geological Survey conference on ground water in limestones. The study of sediments was started as a Geological Survey project by both authors in 1958 with funds supplied by the National Park Service. The material presented here is in some respects incomplete. The findings regarding the source of sediments now entering the cave are considered as final; the information as it pertains to interpretation of the origin of older cave sediments, both clastic and chemical, is incomplete. The latter information, in its present state, is presented to aid naturalists in interpretation of the features observed in the Cave.

The authors gratefully acknowledge the assistance of Charles Milton, Geological Survey, for his suggestions and guidance in petrographic studies as well as for his aid in the field in 1953 and ensuing petrographic checks.

Bennett T. Gale and John M. Good of the National Park Service have aided greatly in coordinating the project in the Park Service and have contributed many helpful suggestions, as well as companionship during field work. Perry Brown, Superintendent of Mammoth Cave National Park, and his staff have literally offered the keys to the cave during all of the field work and have gone out of their way many times to give support. Richmond Brown and Gerth E. Hendrickson, Geological Survey, accompanied the authors in the field and guided them to many of the significant surface features that were examined. Thanks are due the owners and operators of Crystal Cave and Great Onyx Cave for permission to extend sampling to their properties.

SCOPE OF STUDY

The detailed study of sedimentation and stratigraphy in caves is relatively recent. Since 1948 Davies has investigated the stratigraphy of fills in 40 caves. The early studies consisted primarily of measurement and description of beds. The shortcomings of this approach were soon obvious, and later studies involved mechanical analyses and other physical tests of stratigraphic units and mineralogical (petrographic) studies. In Mammoth Cave, Crystal Cave, Salts Cave, and Great Onyx Cave 11 samples were collected in 1953, 5 in 1956, and 61 in 1958. Collection of these samples was on a random basis as there was no existing information available to serve as a guide; random, however, in this case, should not be interpreted as nonsystematic for the plan followed in sampling was to cover the vertical and horizontal range of all significant fills as far as possible.

To establish the relation between surface and cave sediments 52 samples of surficial soils were collected. The samples were from sinkholes above and adjacent to the area where the cavern system is developed. Samples were also collected from channel or embankments of surface streams that drain towards the caverns on the Pennyroyal Plain south of the cavern area. Recent alluvial sediments of the Green River were collected to compare with the sediments inside the cave that were deposited by recent floods. Samples of the Big Clifty sandstone that caps the limestone on the Mammoth Cave plateau and its saprolite as well as residual soil of the limestone were also studied.

At each section of cave fill detailed stratigraphic measurements were made. About 50 such sections were recorded; samples of specific beds in the section were obtained for laboratory analysis. The position of the stratigraphic sections of the fill were plotted on large-scale maps of the cave that were made from surveys from 1936 to date. Vertical positions of the sections were obtained by measurements tied to benchmarks in the cave. Samples obtained on the surface of the ground were referenced to 1:24,000 scale topographic maps of the Geological Survey. Laboratory studies of the physical characteristics and the mineralogy of the cave fills were made for the purpose of establishing criteria for correlation within the fills.

SETTING

Location

Mammoth Cave is in west-central Kentucky approximately midway between Louisville, Kentucky (91 miles) and Nashville, Tennessee (95 miles). The cave is in the Mammoth Cave National Park, 11 miles west of Cave City, Kentucky which is the main point of access to the Park.

Topography

Mammoth Cave is beneath the Mammoth Cave Plateau. The plateau is a broken upland at 740 to 860 feet elevation (referred to sea level), in the vicinity of the cave (figs. 1a, b). Areas of the plateau on which the upland is intact are in the form of "ridges", one to two miles wide and 5 to 8 miles long. The ridges are bounded by elongated, intersecting deep sinkholes. The sinkholes are as much as 280 feet deep and generally have steep sides. The individual sinkholes are as large as a mile in diameter. The bases of the sinkholes are generally alluviated and are flat to gently rolling.

Green River has cut a deep narrow valley across the Mammoth Cave Plateau. At present the flood plain is narrow and discontinuous. Throughout most of the National Park it is 20 to 35 feet above the average low water level. It is generally 100 to 500 feet wide. Terraces are developed poorly along Green River in the vicinity of Mammoth. A discontinuous terrace is at an elevation of 460 to 470 feet. Because the level of the river is maintained by a dam and lock near Brownsville with a pool level of 425 feet, the terrace is 35 feet above the river in the western part of the park and 45 feet in the eastern part.

The southern boundary of the Mammoth Cave Plateau is a prominent scarp, the Dripping Springs Escarpment, which is about 200 feet high. On the south is the Pennyroyal Plain, a rolling, sinkhole-studded plain, at 720 to 770 foot elevation. Most of the sinkholes are 20 to 60 feet deep, as much as 80 feet in diameter, and generally have gentle, smoothly sloping sides. Commonly several sinks are joined to form an elongated depression or sink valley.

The northern boundary of the Mammoth Cave Plateau is roughly along the northern boundary of the Park where, by an indistinct rise, it grades into the higher, more dissected plateau formed by the Pottsville strata.

Drainage

Most of the drainage on the Mammoth Cave Plateau and the Pennyroyal Plain is subterranean. On the plateau most of the surface drainage is confined to the sides and floors of large sinkholes. In some large sinkholes (gulfs), such as Cedar Sink and Mill Hole, large subterranean streams rise, flow across the alluvial floor, and disappear underground again within a short distance.

On the Pennyroyal Plateau between Smiths Grove and Park City, several large streams, Gardner Creek, Sinking Creek, Little Sinking Creek, and Sinking Branch, flow west for several miles and then disappear underground in swallets at the head of large karst valleys.

Geology

Mammoth Cave is in limestones of Mississippian age (Weller, 1927; McGrain and Walker, 1954; Pohl, 1938). In the area around the Park the rocks range from the upper part of the Meramec group to the middle part of the Chester group. The Pennyroyal Plain is developed on the oldest rocks in the area, the St. Louis limestone. This limestone is thin to medium-bedded, gray to dark gray in color, generally very fine-grained, and near the top it is argillaceous and cherty. It is about 300 feet thick in the Mammoth Cave area.

Above the St. Louis is the Ste. Genevieve limestone which lies along the northern edge of the Pennyroyal Plain and beneath the Mammoth Cave Plateau. This limestone is thick to thin-bedded and contains some cross-bedding. It ranges from very fine-grained to crystalline and oolitic; some chert is present. The color is white to gray. In the Mammoth Cave area it is about 200 feet thick.

The Chester group in the vicinity of Mammoth Cave consists of the Renault limestone, the Paint Creek formation, and the Big Clifty sandstone. The Renault limestone is thick-bedded, fine-grained to oolitic, white to gray in color. Calcareous shale is present in a few beds. The Renault is 70 feet thick.

The Paint Creek formation is a massive oolitic, fossiliferous, light gray limestone. Cross-bedding is common. The formation is 50 feet thick.

The youngest formation on the plateau in the vicinity of Mammoth Cave is the Big Clifty sandstone. This is a massive, gray and brown sandstone, in part cross-bedded. This formation is the cap rock of the plateau and it is 50 to 65 feet thick in the area of the park.

Gross features of geologic structure are relatively simple on the Mammoth Cave Plateau. The general dip is to the northwest at about 30 feet to the mile. Several faults with small throw occur in the area. Joints in the limestone within the cavernous area of the plateau are irregular and poorly developed.

SURFICIAL DEPOSITS

Sinkholes

To trace the source of sediments now being deposited in the lower part of Mammoth Cave, samples were obtained from sinkholes and at the swallow points of several subterranean streams on the Pennyroyal Plain south of Mammoth Cave. The sediments were similar in physical characteristics to the sediments, both old and recent, in the cave. The only significant difference was in color. Most of the sinkhole deposits were dark brown and the stream deposits brown or tan; the red tints, common in the older cave fills, were lacking.

The sinkhole deposits (figs. 1a, b) were dark brown residual silts contaminated with varying proportions of sand from the Big Clifty sandstone. In Monroe Sink, 7 miles southeast of Mammoth Cave, there are two small dry swallets in the floor of the sinkhole. In both swallets the fill forming the floor of the large sinkhole is well exposed. The section in the eastern swallet (fig. 2) shows:

Top

	<u>feet</u>
Dark brown clayey silt with thin clay layers	10
Reddish brown plastic clay	4
Dark brown silt (sample 57)	6

The section in the western swallet is the same except that a fragipan^{1/} of reddish brown silt with rock fragments is present 6 feet below the top of the section.

^{1/} Compact horizons rich in silt and sand, and usually low in clay.

The silt deposits in the swallets contain a large quantity of plant debris and numerous scattered small, angular fragments of limestone, sandstone and chert. The brown silts (samples 55, 57 (Monroe sink) and 68 (Double Cellars) have gradation curves similar to those of the sandy silts in Mammoth Cave.

In Monroe Sink the shallow stream channels contain thin discontinuous deposits of sand. The sand washed into the sink is derived from the Big Clifty Sandstone and is carried by intermittent streams during heavy rain. The quantity of sand is very small compared to the silt on the floor of the sink. Sample 56 is from a small dry sand wash in Monroe Sink.

Small sinkholes that do not have swallets are numerous on the Pennyroyal Plain. They are mostly 50 to 100 feet in diameter and 5 to 10 feet deep. The floor is flat to slightly concave in shape and is formed of thick alluvial deposits. The alluvium is primarily silty clay. At the surface the clay is brown or yellow in color but below a depth of one foot it is dark gray (sample 52 from sink 1 mile west of Salem Church; sample 10 from sink 1,000 feet north of the swallow point of Sinking Creek). Small sinkholes without swallets that were sampled on the Mammoth Cave Plateau contain dark brown silty sand (samples 202, 203 from Violet City Entrance, Mammoth Cave).

Karst Valleys

Samples of sediments obtained from near the swallow holes of major streams (fig. 3) vary greatly in grain size. The swallow holes are at the ends of long karst valleys; upstream from the swallow hole the valleys have the same form as regular, joint-controlled stream valleys in limestone. Seepage into the limestone occurs throughout the valleys but at the point of swallow the valleys end abruptly in a low scarp of limestone beneath which the stream sinks to subterranean channels. At the end of the valley there are generally several swallow holes but the streams commonly sink at only one or two places (fig. 4). The other swallow holes are blocked by large quantities of driftwood, fence wire, and similar debris. During floods, primarily in the spring, the lower parts of the karst valleys are flooded to a depth of 10 to 20 feet. During this period drainage is through all the swallow holes that are open. As the debris blocking swallow holes rots, the swallow hole is opened by the flushing action of floods. As a result the submergence point of the stream changes over the years.

Alluvial deposits on the floors of karst valley were sampled near the swallow holes of Sinking Creek, Little Sinking Creek, Gardner Creek, and on unnamed creeks 1 mile west of Stovall, and 1,000 feet west of Mt. Vernon Church. The deposits are mainly brown silt and silty clay. At the swallow hole 1,000 feet west of Mt. Vernon Church the following section is exposed:

Top at level of floor of karst valley

	<u>Feet</u>
Brown clay (sample 13)	6.0
Dark brown silt	0.7
Brown clay	2.0

At the swallow hole of Gardner Creek the channel is cut 7 feet below the floor of the karst valley and there is exposed:

Top

	<u>Feet</u>
Dark brown silty clay (sample 54)	4.0
Gray clay	0.5
Gray fat clay, yellow on surface (sample 53)	3.0

Similar silt on floors of karst valleys are at the swallow holes of Little Sinking Creek (sample 6), sink east of Hays (sample 7), Sinking Creek (sample 8), and the karst valley 1 mile west of Stovall (sample 15).

Deposits of light brown to tan sand and gravel are common in or adjacent to the stream channels that have been cut into the floor of the karst valleys. The sand is angular and fine-grained; the gravel is composed mainly of angular fragments of chert similar to that which is in the weathered zone of the limestones near the base of the St. Genevieve and the top of the St. Louis on the Pennyroyal Plain. Sand was sampled from deposits at the swallow holes of Sinking Creek (sample 9), the sink 1,000 feet west of Mt. Vernon Church (sample 12), and the sink 1 mile west of Stovall (sample 14).

Terraces along Sinking Creek occur as much as 50 feet above the stream and a prominent terrace is developed at 20 to 30 feet. A quarter of a mile west of the Warren-Barren County line, the 20- to 30-foot terrace is formed of 6 inches of brown-gray silt with chert blocks and fragments of limestone and sandstone. Below this is 2 feet of yellow-brown silty clay (sample 11) at the base of which is a hardpan of clay

and limonite 6 inches thick. This is followed by light gray clay about a foot thick. Adjacent to the terrace deposits is red silty clay residual from the weathering of limestone bedrock. The material contained in the terrace is similar to that deposited in the area of the swallow points of Sinking Creek.

Gulfs

Subterranean streams flowing beneath the Mammoth Cave Plateau resurge and flow along the floors of large deep sinks (figs. 5, 6). These sinks, often called gulfs, are a quarter to a half mile in diameter at the top and as much as 140 feet deep. The streams resurge from caves at the south side of the gulfs and flow as surface streams in narrow, deep channels to swallow holes at the north end of the gulfs. The floor of the gulfs are alluvial deposits 30 or more feet thick. In Mill Hole (Park City quadrangle) the floor is red-brown silty clay containing a large amount of vegetable debris (sample 2). Similar material with some sand layers, forms the floor of Cedar Sink (samples 60 and 62). The silt is laminated with bedding conforming to the topography.

At the point of resurgence in the gulfs the sediments are very sandy, consisting of tan, fine sand interlayered with brown sandy silt. These deposits are in mounds 6 to 10 feet high (fig. 7) on the north side of the resurgence pools (sample 1, Mill Hole; sample 59, Cedar Sink).

During floods the floors of the gulfs are covered with water; in 1937 flood waters filled Mill Hole to its rim and were over 120 feet deep. 2/ During floods the stream boils up at the point of resurgence and logs as well as coarse sand and pea-sized gravel are carried into the pool in the gulf. The sand and gravel settles in mounds close to the place of resurgence; silt is deposited along the floor of the gulf.

Residuum

The residual soil from the limestone on the Pennyroyal Plain is a red silty clay. In some zones sand, chert, and rock fragments are common. The surface of the limestone bedrock is very irregular, and were the soil removed it would form a series of pinnacles and furrows with relief as much as 6 or more feet. The red silty clay fills the

2/ Personal communication from Mr. Locke whose residence is near Mill Hole.

furrows and forms a thin cover over the pinnacles. Typical of the red silty clay are sample 4 from a roadside cut one-half mile south of Mill Hole and sample 101 from a roadside cut 700 feet east of Monroe Sink on Kentucky Highway 70.

In most places on the Pennyroyal Plain, a mile or more from the Dripping Springs Escarpment, erosion is slight and distinct horizons are developed in the soil. On Kentucky Highway 70, one mile east of Cave City the profile is well exposed (fig. 8). At the top is a foot of tan sandy silt (sample 51) below which is 8 feet of red silty clay (sample 50). The division between the tan and red zones is distinct; the band of gradation is less than an inch thick. The sand in the upper zone and the apparent absence of sand in the lower zone could result from residual or ancient transport of sand from the Big Clifty sandstone by slopewash or it could be derived from the breakdown of cryptocrystalline quartz lenticules (often cited in the field as chert) within the limestone.

About 1,000 feet west of Pursley Cemetery is a cut along a farmer's lane that exposes 7 feet of residual soil over limestone:

Top	<u>Feet</u>
Brown sandy silt	1.0
Red clayey silt (sample 16)	3.0
Zone of angular chert blocks as much as 6 inches in size in a red sandy silt	0.5
Red silt (sample 17)	0.5
Yellow brown sand (sample 18)	2.0

The sand contained in this deposit has an interesting genesis. In quarries and deep road cuts the limestone bedrock contains very little siliceous material. In the weathered zone cryptocrystalline quartz is very common and forms beds that replace the limestone but retain the original structures of the limestone. The quartz lenticules in turn weather to a very fine red-stained sand. The sand contained in the sandy horizon of the soil on the Pennyroyal Plain is probably derived from the breakdown of the cryptocrystalline quartz developed in the weathering of the limestone rather than from remnants of weathered Big Clifty sandstone.

Residuum from the upper part of the Ste. Genevieve limestone in the Mammoth Cave Plateau is generally gray-brown sandy silt. A sample (204) obtained from a limestone pocket 400 feet south of Mammoth Cave Ferry contained aggregates of white fine-grained calcite about one-half inch in size. The sand fraction in the residuum is probably contamination from the Big Clifty.

The Big Clifty sandstone weathers to a tan silty sand (samples 200, 201 from Bruce Hollow). The sand is tan in color and the grains are clear and angular. Saprolite is developed in the residuum of the Big Clifty. Along the road west of Salts Cave, 600 feet northwest of the Park boundary, 5 feet of saprolite is exposed in an eroded cut. The saprolite consists of bands of purple, red and yellow sand. The sand grains are clear and angular (sample 86).

Flood Plains

Flood-plain deposits along Green River and the resurgent points of major subterranean streams on the Green River are similar to those in gulfs and swallow holes in karst valleys. On flood plains, however, sand deposits are dominant and silt is of secondary importance. At the Turnhole on the south bank of the Green River the flood plain consists of layers of brown to tan sand 5 to 6 inches thick (sample 67) alternating with layers of dark brown silt and vegetable litter an inch thick. At the point where the River Styx connects with Green River the top 2 feet of alternating sand (samples 100, 207) and silt are similar to the deposits at the Turnhole. Below this is silty gray clay 10 feet or more thick.

The terminal resurgence of the underground streams that rise in Mill Hole and Cedar Sink is probably the Turnhole. During high water some water flows out of a cave about 200 feet west of the Turnhole. At the entrance to the cave are banks of sand 4 feet high that are similar to those at the place of resurgence in Mill Hole and Cedar Sink. The sand banks contain layers of white to tan sand 1 to 3 inches thick (sample 65) alternating with layers of dark brown sandy silt 5 to 12 inches thick (sample 66). Similar deposits are at the resurgent point of River Styx (sample 99) and Echo River (samples 97, 98) but in these deposits the sand is thin and the sandy silt beds are dominant.

CAVERN SEDIMENTS

Cavern Features

Mammoth Cave is the largest cave in the area, extending the whole length of Mammoth Cave Ridge (fig. 1a). Approximately 28 miles of cavern passage have been mapped, and several more miles surveyed (fig. 9). In addition many miles of unmapped small passages exist. The major passages extend along Mammoth Cave Ridge and are on three levels. The upper level at mean elevation 600 or more feet extends from the Historic Entrance to Violet City Entrance via Broadway and connecting passages. The passages from near Cathedral Domes via Boone and Kentucky Avenues also correspond to this level. An intermediate level with mean elevations 500 to 600 feet, extends from Carmichael Entrance along Cleveland Avenue and Sillimans Avenue. Most of the New Discovery is at this level. The lower level passages are along Echo and Roaring Rivers at 420 to 500 feet. Detailed descriptions of the passages are available in several guidebooks and popular publications (Hovey, 1912; Randolph, 1924; Livesay, 1953).

Crystal Cave is another large cave in the area. Passages are reported to aggregate more than 26 miles in length and are on several levels similar to Mammoth Cave (Lawrence and Brucker, 1955). Salts Cave is developed in two levels at 580 to 600 feet and 630 to 650 feet. The main passage extends northwards for more than 5,000 feet. Great Onyx Cave is developed primarily on one level at about 520 to 550 feet. A subordinate lower level is reported to exist 30 or 40 feet below the main level. The cave trends east and southeast for about 6,000 feet.

Cavern Fills

One of the most conspicuous features of all the caves of the Mammoth Cave area is the large amount of clastic material that has been deposited in the cavern passages. In many exposures the fill is packed tightly to the ceiling and its nature is revealed in excavations made in opening the cave for public use.

Stratigraphy of fills. - The sequence of fills in all the caves is similar in gross features. The fills generally have sand in the lower portion changing abruptly to gravel and coarse sand in the middle and upper portions; the top of the fill, where it extends to the ceiling, is composed of fine silt and clay. Typical of such a sequence is at the Chaperon (fig. 10), a small side passage off Boone Avenue, where the following is exposed:

Chaperon Section

(Section in cut along small-sized passage 50 feet from Boone Avenue)

Top of section; beds of fill are packed tightly against ceiling

	<u>feet</u>
1. Red silt and clay; upper foot laminated and variegated (sample 45)	2.5
2. Gravel, pebbles $\frac{1}{4}$ inch in size	1.0
3. Tan sand, irregular beds $\frac{1}{2}$ to 2 inches thick; a few pebble beds with pebbles up to $\frac{1}{2}$ inch in size; distinct manganese stain band in middle of unit	2.0
4. Gravel, pebbles $\frac{1}{4}$ inch in size; pebbles well-rounded, stained black; red silt and sand matrix (sample 46)	2.0
5. White to tan sand; black manganese stain band 1 foot and $\frac{1}{2}$ feet above base (sample 47)	2.0

Limestone floor of passage

Total thickness of fill 9.5

Similar sequences in Mammoth Cave are at the abandoned Ladies Room in River Hall (fig. 11), the Wooden Bowl Room, Pensacola Avenue near its entrance, Marion Avenue, and at the junction of Boone and Kentucky Avenues (fig. 13). In New Discovery a similar section is along the floor of Big Avenue 400 feet west of the Rimstone Dam.

In Marion Avenue at the base of the elevator shaft the following sequence is exposed in cuts made for the walkway (fig. 12):

Top at ceiling

	<u>Feet</u>
Red silty clay, upper 1 foot variegated, laminated (sample 45)	2.5
Gravel, $\frac{1}{4}$ -inch pebbles	1.0
Tan sand, irregular beds, $\frac{1}{2}$ to 2 inches thick; some pebble beds, pebbles $\frac{1}{2}$ -inch size; black stain 1 foot above base	2.0

	<u>feet</u>
Gravel, 1/4-inch pebbles well-rounded, stained black; many highly polished; red silt and sand matrix (sample 46)	2.0
Tan to white sand, black zones 1 and 1.5 feet above base (sample 47)	2.0

In Salts Cave the following section is well-exposed in a wall blocking a large cave passage at the end of Dismal Valley (figs. 14, 15).

Top at ceiling

	<u>Feet</u>
1. Black manganese-stained clay; deposit is irregular in shape and thickness with pendant-like projections into the adjacent beds	1.0
2. Red clayey silt with sandy silt interbedded (sample 82)	5.0
3. Alternating light and dark brown sand in beds about 1 inch thick	2.0
4. Irregular bed of gravel with rounded to angular pebbles; cross-bedded. Tan sand beds 1/4-inch thick, interbedded in middle part of section; gravel stained dark brown to black, a few pebbles leached white; some original slumping present in beds (sample 83)	1.0
5. Slumped bed of white sand; some brown sand interbedded. Two beds of gravel, each 1 inch thick; pebbles leached white	2.0
6. Gravel, pebbles stained dark brown to black; present in slumped part of section; grades laterally into beds 4 and 5	(1.0)
7. Interbedded and cross-bedded white and light brown sand; beds 1/2 to 2 inches thick (sample 84)	4.0
	15.0

Base at floor level; floor composed of sand and gravel

One hundred feet south across the slump forming Dismal Valley is a section of fill that lies below bed 7. This exposure contains 10 feet

bright red and yellow sandy silt with numerous lenses of gravel 2 to 4 inches thick; pebbles in the gravel are well-rounded and $\frac{1}{4}$ inch in diameter.

Another common sequence of cave fill consists of alternating beds of silt and sand. In the Historic Section of Mammoth Cave such a sequence is well developed at several points. The measured sections below are typical of this type of fill.

Section Opposite Entrance to Gothic Avenue (fig. 16)

Top at ceiling of cave

	<u>Feet</u>
1. Calcite (cave onyx) with helictites filling opening between cave fill and ceiling; opening a result of shrinkage and settling of fill	0.3
2. Red-brown silty clay with irregular sandy band in middle (sample 21)	2.0
3. Buff-colored fine sand, cross-bedded (sample 22)	8.0
4. Orange red, fine sand (sample 23)	<u>8.0</u>
	18.3
Bedrock and fallen rock carries to level of cave path in Broadway	15.0

Side Passage from Bottomless Pit to Washington Pit

Top at ceiling

1. Orange-red silty sand; thin clay lenses up to one foot long	4.0
2. Buff to white fine sand, cross-bedded	1.0
3. Orange-red silty sand alternating with layers of light brown sand; layers 2 to 6 inches thick	<u>2.0</u>
	7.0

Sims Pit Avenue

Section is at end of small passage to south off Sims Pit Avenue, 200 feet from Broadway; fill was partly excavated to open passage (CCC Survey Station 8A)

Top at ceiling

	<u>Feet</u>
Red silty clay	0.5
Orange-red silty sand	2.0
Buff sand	0.5
Orange-red silty clay (sample 34)	3.0
White sand (sample 33)	<u>2.0</u>
Base on rock floor	8.0

The silt and sand fill occurs commonly along Broadway, parts of Marion Avenue, at the Hippodrome, parts of Cleveland Avenue, Pensacola Avenue, in the vicinity of Richardson Spring, the Hall of Great Relief, and at the Methodist Church. In the New Discovery section of Mammoth Cave this type of fill is common along the Big Avenue from the Rimstone Dam to Paradise. It is well exposed along the path 100 feet east of Onyx Avenue.

New Discovery, 100 feet east of Onyx Avenue

Top

	<u>Feet</u>
1. Dark brown sand and gypsum	1.0
2. Red brown silty clay (sample 92)	4.0
3. Brown silty sand with lenses of dark brown silty clay	1.0
4. Red brown sandy silt	4.0
5. Dark and light brown sand	<u>4.0</u>
Base at trail level	14.0

In Salts Cave the sand and silt fill is common along the main cave passage extending from the old entrance to the Chapman Entrance. It is also present throughout the main passage of the Great Onyx Cave and along most of the public route in Crystal Cave.

Recent Cavern Sediments

Recent sediments in Mammoth Cave are accumulating in the areas flooded seasonally by Echo River and other subterranean streams. Floods commonly rise 35 feet above the normal water level and the invading waters bring large quantities of sand and silt into the cave. After spring floods, accumulations of sediments covering the pathways are 3 to 15 inches deep. The deposits consist of alternating layers of sand and silt with some vegetable debris. Near Minnehaha Falls, where Echo River rises from beneath a limestone ledge, is a mound 20 feet high formed of tan sandy silt (sample 42) alternating with brown clay and silt layers. This mound is similar to the sand mounds at the resurgent points in Cedar Sink and Mill Hole. Between Echo River and Roaring River tan, ripple-marked sand (sample 43) is deposited annually to a depth of a foot or more. Pockets of coarse sand and pea-sized gravel also are in this area near Echo River. At the opposite end of Echo River near Shakespeare Hall the sediments consist of alternating layers of gray silt (samples 25, 317) about one inch thick and tan sand $\frac{1}{4}$ to 3 inches thick (samples 87, 318). Higher up in this area, at the limit of flooding in the Dead Sea, the deposit is gray clay (samples 26, 206). At Minnehaha Island which is 200 feet from the rise near Minnehaha Falls, the sediments consist of alternating layers of brown silt (sample 316) and brown sand (sample 315); the layers of both silt and sand are about 2 inches thick.

Other Cavern Deposits

In Chief City on the Historic Entrance - Violet City Route in Mammoth Cave - there are extensive deposits of niter earth. This material is a dark brown dust derived from the desiccation of bat guano. The deposit is 2 to 4 inches thick and overlies fallen rock. The fallen rock is 4 to 8 feet thick and in turn is underlain by a thick cave fill. The niter earth, based on radiocarbon dating of the carbonaceous material in the desiccated guano, is more than 38,000 years old.^{3/} Chemical analysis of niter earth, recent bat guano, and saltpeter earth mined in Mammoth Cave are in table 1.

Semiquantitative spectrophotographic analysis by Harry Bastron, Geological Survey, of desiccated guano from Chief City showed calcium present in quantities in excess of 10 percent, aluminum and magnesium each more than 1 percent, and manganese, iron, titanium, chromium, vanadium, zirconium and barium were each 0.01 percent or more; nickel and boron 0.001 percent or more.

^{3/} Dated by Meyer Rubin, Geological Survey.

PHYSICAL CHARACTERISTICS OF CAVE FILLS

Mechanical analysis of the fill material provides data for grouping it into six types. Most of the gravel fills consist of pebbles generally an inch or less in size in a matrix of fine sand. The pebble fraction (larger than 4.5 mm) is generally 30 to 50 percent of the sample. Pebbles are subrounded to well rounded and many of the pebbles have a highly polished surface; the polished pebbles are very abundant in the section exposed at the Ladies' Room (River Hall). In practically all the gravel beds, pebbles stained black by manganese oxide are common. A typical gradation curve for the gravel (fig. 17) is that obtained from the section at the Chaperon (sample 46). Sample numbers 24, 39, 44, 46, 73, 76, 78, 80, 83, 85, 90, 93, 209, 210, 212 are included in this type.

The sand fills show little variation in distribution of grain size. They are white, tan, reddish brown, and brown in color and are dominantly fine sand. The fragments are generally clear, angular, and are mainly quartz. The sand is well bedded where exposed in cross-section. At all exposures cross-bedding is well developed. Sands in the cave fill, in recent cavern alluvial deposits, and from sinkholes are similar in size distribution and shape of grains. The grading curve for sand (fig. 18) obtained from the excavated passage leading south from Sims Pit Avenue (sample 33) is typical for this type of deposit. Samples 33, 47, 77, 86, 89, 319, and 323 are of this type. Two samples (40 and 74) contain small quantities of pebbles (2 to 10 percent). The sand fraction, however, is similar to the other samples included in the fine sands.

Liquid limit of the sand is about 24 percent; plastic limit is indeterminate. Field moisture equivalent is 19.5 to 21.1. Shrinkage limit is 0; in most of the sands slight expansion occurred on setting. Shrinkage ratio is 1.44 to 1.54. Specific gravity is 2.57 to 2.61 for composite samples.

Silty sand is very common in many of the fills in Mammoth Cave. These fills are similar to the sand. The silty sand is mainly tan to brown in color. The gradation curve for the deposit in the sand bank at the end of Pensacola Avenue (sample 27) is typical of the silty sands (fig. 19). Samples 20, 22, 23, 27, 29, 30, 31, 38, 48, 71, 81, 82, 84, 312 and 314 are silty sands. Average Atterberg limits of the silty sand are: liquid limit 22 percent; plastic limit 18.5 percent; field moisture equivalent 20.7 percent. Shrinkage limit is 16.3 percent and the shrinkage ratio is 1.76. Specific gravity averaged 2.60.

Sandy silt in the cave is present in a few of the fills sampled. It is gray to brown in color. Sample 313 from a narrow, horizontal wall pocket at Richardson Spring shows the typical size distribution of the sandy silt (fig. 20). Other samples are 41, 64, 69, 79, 88, and 313. Other average physical characteristics are: liquid limit 29.6 percent; plastic limit 14.6 percent; field moisture equivalent 30.9 percent; shrinkage limit 8.2 percent; shrinkage ratio 2.14; specific gravity 2.59.

The most extensive type of fill in Mammoth Cave is silt. It is red-brown, brown and gray in color. Most of the silt contains 5 to 20 percent fine sand and about the same amount of clay. In general the red-brown silts have a higher clay content than the brown or gray silt. Sample 34 from a side passage off Sims Pit Avenue is typical of the gradation of the silt (fig. 21). Other samples of silt are 19, 34, 35, 36, 37, 49, 72, 94, 211, 321, 322, 326, 327. Plastic limit of the silt ranged from 14.1 to 18.5 percent, field moisture equivalent 37.3 to 39.4 percent, liquid limit 30.8 to 35.0 percent, shrinkage limit 18.2 to 22.7, shrinkage ratio 1.63 to 1.78, and specific gravity 2.46 to 2.60.

Silty clay is present near the top of many fills in Mammoth Cave. It is red to red-brown in color and generally laminated. Commonly it forms a packing between the top of coarser sediments and limestone ceiling. Small irregular lenses of clay are often present in the silty clay.

The silty clays are typified by the gradation curve (fig. 22) for a sample collected at the Chaperon off Boone Avenue (45). Other silty clay samples are 70, 75, 92, 95, 96, 320, 325.

Plastic limit of silty clay averaged 24.1 percent, liquid limit 26.9 percent, field moisture equivalent 30.2 percent, shrinkage limit 24.3, shrinkage ratio 1.57, and specific gravity 2.56.

Clay is commonly cited as the major constituent of cavern fills. In Mammoth Cave clays are very rare. Only two true clay samples were collected, one from the top bed of the section (fig. 16) opposite the entrance to Gothic Avenue (sample 21) and the other from New Discovery 500 feet from the entrance (sample 95). The former occurs as a thin bed of red clay that is packed between coarser sections of the lower fill and the ceiling. The second sample of clay was from an anastomosing tube exposed in the wall of a passage.

MINERALOGY OF CAVE FILLS AND SURFACE DEPOSITS

The purpose of the mineralogical study of the fills is two fold - determination on the basis of heavy mineral composition the source of material that is being deposited in sections of the cave from present-day floods, and the study of the mineralogy of the cave fills with respect to their stratigraphy and the geologic history of the cave.

A collection of 128 samples was made from sinkholes, road cuts, flood plains and cave fills. Of these, 72 samples from cave fills, 21 from bottoms of sinkholes, 9 from road cuts, 8 from flood plains and 3 from the saprolite of the Big Clifty sandstones were studied.

The fraction selected for heavy mineral study was passed through 80-mesh sieves. The clay fraction was removed from each sample by washing with water prior to separation. Heavy minerals from each sample were obtained by bromoform separation. The heavy mineral fractions were mounted on slides in Canada balsam and studied under the microscope. The unmounted heavy fractions in small glass trays were also examined under the binocular and petrographic microscope. Mineral identification was based primarily on optical properties and if necessary confirmed by X-ray powder diffraction methods.

A rough estimate instead of a quantitative grain count of the relative abundance of heavy minerals was made because preliminary grain count trials did not yield consistent results; for consistency the frequency of mineral species would have to be corrected, since only a particular fraction of the sample was analyzed for heavy minerals. Although in the past, frequency of detrital minerals has been successfully used as criterion of correlation, the relative abundance of detrital heavy mineral of the simple mineral suite typical of the Mammoth Cave National Park does not seem diagnostic enough to be relied upon for correlation. The frequency varies in a random fashion between various authigenic minerals and with the elevation at which the sampling was done. For this report a semiquantitative designation is used as follows (tables 2-7):

<u>Category</u>	<u>Definition</u>
5	Mineral makes up more than 80 percent of the heavy fraction
4	" " " 50 to 80 percent of the heavy fraction
3	" " " 20 to 49 percent " " " "
2	" " " 5 to 19 percent " " " "
1	" " " less than 5 percent of the heavy fraction

The light fraction of one-third of all the samples was examined. Most consist essentially of quartz with variable amounts of gypsum, some chert, carbonate, and feldspars. Information obtained from these does not seem to warrant a more detailed study of the light fraction of the remaining samples.

Mineral Assemblage of Surface Sediments

Sediments from sinkholes. - The heavy mineral assemblage of the sinkhole sediments studied varies little. It consists of zircon, tourmaline, rutile, goethite or other iron oxide, leucoxene, and chromite (fig. 23). Authigenic brookite, anatase, and collophane are present in some of the samples. Of sporadic occurrence are fluorite, apatite, muscovite, garnet, and, in one sample, spherulites of rhodochrosite. Most of the sinkhole samples contain a larger fraction of opaque minerals than of transparent minerals. The heavy fraction ranges from less than 0.1 to nearly 0.6 percent of the bulk sample.

The light mineral fraction of the sinkhole sediments consists essentially of quartz with occasionally a few grains of feldspar.

The coarse fraction (greater than 80-mesh) of these sediments consists commonly of quartz grains, plant debris, and limonitic nodules or fragments. Brown sandstone pebbles, gray or white chert and limestone fragments are present in many samples (for example, 52, 54, 55 and 59).

Sediments from surface soils. - Samples 16, 17, 18, 50 and 51 are typical residual soils overlying the limestone. Samples 101 and 204 are from pockets in limestone. Sample 4 is mostly residual but may have been contaminated by transported soil, and sample 11 is an alluvial soil overlying limestone.

The heavy mineral suite from these samples (table 3) consists of goethite, leucoxene, chromite, zircon, tourmaline, authigenic brookite, anatase, and commonly collophane, and is not distinguishable from that of the sinkhole sediments. Sample 18, a residual soil, has an unusually high proportion of leucoxene (table 3).

The light mineral fraction of the residual soil consists mostly of subangular to angular clear quartz and variable amounts of brown collophane. Calcite is generally absent. Sample 204 collected from a limestone pocket, however, consists chiefly of calcite aggregate with minor amounts of quartz.

The coarse fraction (greater than 80-mesh) is mostly quartz with fragments or subrounded grains of aggregates of quartz. Some of these (for example, sample 17) which are believed to be typical residual soil of the limestone, contain reddish brown subrounded sandstone grains. Although it is possible that contamination may have occurred, petrographic analysis indicates that the insoluble residue of the limestone contains a typical suite of heavy minerals very similar if not identical to the suite of the Big Clifty sandstone (to be described below).

Sediments from flood plains. - Flood-plain sediments show large amounts of opaque minerals, chiefly limonitic grains plus leucoxene and chromite (fig. 24 and table 4). The small amounts of non-opaque heavy minerals consist of the same stable suite of minerals as those of the sinkholes or mantle soils, namely zircon, tourmaline, rutile, and brookite.

The light fraction consists chiefly of quartz and a few grains of chert and feldspar. Many of the quartz grains show secondary overgrowths.

The coarse fraction (greater than 80-mesh) consists mostly of clear quartz with reddish brown iron-oxide-coated grains, plant debris, some chert, and occasionally small rounded grains of sandstone.

Mineral Assemblage of the Weathered Big Clifty Sandstone

Three samples of the Big Clifty sandstone which caps the cavernous limestone area were collected: one a saprolite from a single bed (86) 600 feet west of Salts Cave, another from a single bed of weathered sandstone in Bruce Hollow (200), and the third (201) a composite sample taken across beds of weathered sandstones in Bruce Hollow. The heavy mineral assemblage of the three samples is as follows (fig. 25):

Sample Number	Goethite & Iron Oxide	Leuco-xene	Chromite	Zircon	Tour-maline	Ru-tile	Brook-ite	Ana-tase
86	3*	3	2	2	2	1	1	
200	4	2	2	3	2	1	1	1
201	4	2	1	2	1	1		

* Semiquantitative designation same as tables 2-7.

The light mineral fraction consists essentially of quartz, minor amounts of chert, and a few grains of feldspar. Some of the quartz grains show secondary overgrowths.

Heavy Mineral Assemblage of Cave Sediments

The cave passages in Mammoth Cave are roughly on three interconnected levels. Similarly, on the basis of mineral assemblage, the cave sediments are divided into three levels: the low level from 420 to about 500 feet, the intermediate level from about 500 to about 600 feet, and the high level at elevations of more than 600 feet (fig. 9).

Low level cave sediments (elevations of 420 to about 500 feet). - Samples collected from the banks of Echo River and its flood area at elevations of 424 to 456 feet (Samples 25, 26, 42, 43, 87, 315, 316, 317 and 318) are recent sediments deposited either by underground streams or flood waters backed into the cave from the Green River. Samples 88, 89 and 90 from River Hall are from points high enough so that they are not likely to be affected by recent flood or seepage of the cavern. Samples 29, 69, 70 and 324 from New Discovery, Cathedral Domes, and Pensacola Avenue came from higher levels but are sediments deposited by present-day seepages.

The heavy mineral assemblages of these sediments (fig. 26 and table 5) are similar to and are indistinguishable from those of the surface sediments shown in tables 2 to 4 and the heavy mineral assemblage of Big Clifty sandstone. This is true also for samples 88, 89, and 90 (Abandoned Ladies' Room, River Hall) which are cross-bedded sediments undoubtedly deposited by moving water through the caves. In contrast to most of these sediments from medium and high level, the low level cave sediments do not contain authigenic celestite, barite, or gypsum.

Intermediate level cave sediments (elevations of about 500 feet to about 600 feet). - Most of this group are random samples from cave fill. The random sampling was made primarily because the fill was thin or looked uniform throughout the section. Sections 10 or more feet thick with cross-bedding or well-defined members were sampled vertically (samples 45 to 47, 72 to 74, 75 to 77). All the samples collected contain the same suite of heavy minerals as those of the low level (table 6) but in addition most of them contain either authigenic celestite or barite, or both, and in some gravel lenses, manganese minerals.

Samples from Silliman Avenue (40 and 41), Pensacola Avenue (27 and 30), New Discovery (93, 321, 322, 325 and 326), Cleveland and

Marion Avenues (79 and 80), and Great Onyx Cave (36, 38 and 39), are notable because all heavy fractions of these sediments contain authigenic celestite. Of these, the heavy fraction of sample 36 from Cleveland Avenue consists essentially of celestite (fig. 27), and heavy fractions from 35 (Great Onyx Cave), 321 and 93 of New Discovery Cave and 39 of Cleveland Avenue contain 50 to 80 percent of celestite. The well-formed celestite crystals are a fraction of a millimeter to a little more than 1 mm. long and are uniformly distributed as loose grains in the deposit. Massive celestite has not been observed in these deposits. The light fraction of all of these samples consists essentially of quartz with variable amounts of gypsum crystals.

Of special interest are samples 75, 76 and 77 from the section near the base of the elevator shaft. Authigenic barite is found in the yellowish brown and brown cross-bedded sand at the base of the section, traces of barite and celestite in the gravel a little higher up, and more abundant celestite in the reddish brown and red sandy silt above. Gypsum, associated with celestite, is found only in the sandy silt and silt and is absent in the gravel and sand below.

Samples 72, 73, and 74 were collected from a section at the junction of Boone and Kentucky Avenues some 25 to 30 feet higher in elevation than the section at the base of the elevator shaft. Here barite is present in the heavy fraction from cross-bedded light brown sand free of gypsum (Sample 74) near the bottom of the section, whereas both barite and celestite are present in the reddish-buff silt (Sample 72) in the upper section. The red silt is separated from the cross-bedded sand by lenses of gravel (Sample 73) which contain flaky manganese minerals.

The samples collected from a section at Chaperon off Boone Avenue (45, 46, and 47) are 10 to 20 feet higher in elevation than the section at the junction of Boone and Kentucky Avenues. These samples all contain authigenic barite and no celestite or gypsum. The gravel lenses in the middle part of the section contain abundant manganese minerals.

High level cave sediments (elevations about and greater than 600 feet). - Samples 19, 20, 21, 22, 23, 33, 34, 48, 49 and 312 are from the Mammoth Cave, and 210, 211 and 212 from Crystal Cave about 1 mile north-northeast of Mammoth Cave; 81 to 85 are from Salts Cave, 1½ miles east of Mammoth Cave. These high level cave sediments also contain the same general suite of heavy minerals as those of the low level cave fills, but as is shown in table 7, they may also contain barite (fig. 28). From tables 5 and 6, it is evident that barite is of more common occurrence in the high level fills. Furthermore, except for sample 19, gypsum is absent from all samples which contain barite but no celestite.

Heavy Minerals of Surface and Cave Sediments

The heavy mineral assemblage of the typical surface deposits such as those of the mantle soil, sinkhole, and flood plains, and the low level recent cave fills of Mammoth Cave consists of zircon, tourmaline, rutile, brookite, anatase, collophane (carbonatian fluorapatite), goethite, leucoxene, chromite, and small amounts of hematitic magnetite. The heavy mineral assemblage of the intermediate and high level cave sediments are characterized by the presence of either authigenic celestite or barite, or both together, and less commonly apatite, and rancieite (?) associated with another unidentified manganese mineral.

The locations of samples of surface sediments are shown on topographic maps of the Mammoth Cave area (figs. 1a, b) and the location of the cave sediments are shown on a skeleton map of the cave (fig. 9). The assemblage of the heavy minerals and their relative abundance are given in tables 2 to 7.

Zircon. - Zircon is one of the most abundant transparent minerals of both surface and cave sediments. Most of the zircons are water clear; some are of pale to deep pink or violet color. Many are well rounded, or stubby prisms with rounded edges, but some are long needle-like with length more than five times the cross-section dimension (fig. 29). Zircon of different colors and shape usually occurs in the same sample. None are zoned, or distinguishable from sample to sample.

Tourmaline. - Like zircon, tourmaline is ubiquitous. It is common in both the surface and the cave sediments. Most of the tourmaline is brownish black to pale greenish-grayish brown, but clear pink, blue, and green tourmaline are also abundant. Most of the grains are well rounded; a few retain rather sharp prismatic outline (fig. 30). Many tourmaline grains contain minute needle-shaped inclusions too small to be identified optically.

Rutile. - Although ubiquitous in both surface and cave sediments, rutile is not generally abundant. It is red, deep red to yellowish brown, mostly rounded, with a few grains retaining their prismatic habit (fig. 31). Most are transparent; brownish opaque (X-ray powder pattern No. 13453) and bluish gray opaque grains (X-ray Film No. 13733) also occur, both with adamantine to pearly luster; these gave X-ray powder patterns of rutile. Leucoxene, authigenic brookite, and anatase are commonly associated with rutile.

Brookite. - Brookite is widespread but usually in lesser amounts than rutile. It is generally lemon yellow to yellowish brown in color, and usually 0.1 to 0.2 mm. in length. It is generally rectangular with well-developed crystal faces. It is easily identified optically by its extreme dispersion, positive sign, and high index of refraction. Brookite in many places occurs either in single crystals (fig. 32) or in aggregates, sometimes adhering to quartz; it is also in minute yellow glassy crystals attached to white round grains of leucoxene (fig. 33).

Anatase. - Authigenic anatase is less common than brookite. It also appears in rectangular platy grains (fig. 34). It is generally distinguishable from brookite by its pale gray to bluish gray color and optically by its uniaxial negative sign and low birefringence.

Celestite. - Authigenic celestite is characteristically abundant in many samples obtained from intermediate levels of the cave (such as samples 35, 36, 37, 38, 39, 93, and 321) where gypsum is also abundant. Gypsum and celestite, however, are never found intergrown. The celestite crystals are water clear, elongated, doubly terminated with well-developed faces. They occur singly and in rosettes or radiating groups (fig. 35). In many places, celestite is the sole or dominant heavy mineral of the fill (fig. 27, and table 6). Saw-tooth structure was observed on a few celestite crystals. Sediments with saw-tooth celestite usually occur at high levels in the cave. The characteristic clear elongated crystal habit, low birefringence, and parallel extinction make celestite easy to identify under the binocular or petrographic microscope. The identification was confirmed by X-ray powder patterns (Film nos. 13468 and 13614).

Barite. - Authigenic barite is less common than celestite and is found usually at high levels in the cave. Barite, unlike celestite, constitutes less than 50 percent of the heavy fraction of the samples in which it occurs. The barite crystals have two habits. Usually they are flat, platy with sharp terminations (fig. 36) and are clear to pale yellowish in color. These are found more commonly at high levels. Less often barite occurs in very fine grains and forms minute clusters or spheres intergrown with quartz (fig. 37). Authigenic barite is easily distinguished from celestite by its crystal habit under the binocular or from grains mounted in thin section. Optical properties of barite and celestite are very similar. The identification of barite was confirmed by its X-ray powder pattern (Film nos. 13456 and 13638) and semiquantitative spectrographic analysis.

Collophane. - Fragments of collophane, many clearly fossil remains, are present in many samples. They range from white through pale yellow to brown, and have rather low birefringence; some are nearly isotropic. The mean index of refraction ranges from 1.595 (white) to 1.610 (reddish

brown). The X-ray powder pattern is identical to that of carbonatian fluorapatite (Film nos. 13644 and 13738).

Garnet. - Garnet is in only a few samples. It is pale pink, angular to subrounded, and usually has a hackly or etched texture (fig. 38, X-ray film no. 13647).

Chromite. - This is the most abundant opaque black mineral in all the samples examined. It usually occurs as octahedral crystals, some showing rounding (fig. 39). It is readily identified by its octahedral habit and non-magnetic property. X-ray powder patterns (Film nos. 13640, 13740, 13759, 13761, 13767, and 13769) and X-ray fluorescence further confirm the identification of chromite.

Goethite. - Goethite is usually the most abundant opaque mineral of the heavy fraction. It occurs mostly in irregular grains, aggregates of minute cubic crystals (X-ray film no. 14008), or many distinct pseudomorphs of pyrite (fig. 40). Goethite is especially abundant in surface sediments and in gravel lenses in the cave.

Leucoxene. - Without exception, leucoxene occurs in well-rounded grains and is white to pale yellowish-brown (fig. 33). It is opaque under the microscope, and gave a rutile X-ray diffraction pattern (Film no. 13454). In a few samples, leucoxene is the predominant opaque mineral.

Rancieite (?). - The mineral tentatively referred to as "rancieite", calcian psilomelane (in Dana's system of mineralogy, p. 572) occurs as clusters of black flaky aggregate intergrown with another unidentified bronze flaky manganese mineral (figure 41). These manganese minerals occur in several samples (nos. 46, 47, 72, 73, 76 - table 6). The black flaky aggregate gave an X-ray powder pattern with strong lines at $d = 9.58\text{\AA}$ and $4.82\text{\AA}$ which are in reasonable agreement with a powder pattern of "rancieite" from Mine de Fillols, Ariège, France, obtained by M. Fleischer from Dr. M. J. Orcel. The identification, however, is not positive because the poorly crystalline material from Mammoth Cave gave rather inferior powder patterns. The pattern of the other phase, the bronze flaky mineral, is unidentified. Further work on better material is necessary to identify these manganese minerals.

Rhodochrosite. - This was found in one sample (53) where it occurs as minute spherulites, pale yellowish brown to reddish brown (fig. 42). The round grains show typical spherulitic structure under crossed nicols. It has refractive indexes $\omega = 1.815$ $\epsilon = 1.598$. The identification is confirmed by X-ray powder pattern. A semiquantitative spectrographic analysis of the material is being made.

Apatite, fluorite, muscovite, and hematitic magnetite are also present in some of the samples. Except for the hematitic magnetite, the quantities of these heavy minerals are extremely small, generally not more than one percent of the heavy fraction when present.

Hydrous Sulfate Minerals

Gypsum - The occurrence of gypsum flowers in certain parts of Mammoth Cave (for example, Paradise of New Discovery Cave and Valley of Flowers in Silliman Avenue) is world famous. Undoubtedly the beautiful curved radiating or clustered crystals of gypsum are of secondary origin crystallized from solution moving through joints, cracks, bedding, and cross-bedding of the limestone close to the cavern walls. Also present, however, is gypsum believed to be of primary origin such as that found as clusters or grains uniformly distributed in the cave fill. The distinction between primary and secondary gypsum and the general occurrence, origin, and distribution of gypsum can not be understood without more detailed work. The present study suggests that gypsum associated with the cave fill may be primary, that is, precipitated as the sediments were deposited. This hypothesis will be discussed in the next section.

Hydrous sodium sulfate - A clear needle-like mineral as much as 20 millimeters long and less than a millimeter in cross-section, covers limestone surfaces in Cleveland Avenue of Mammoth Cave, and surfaces of limestone blocks in Dismal Valley of Salts Cave. This mineral has been called epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$). An X-ray powder pattern was made for each of the samples collected from Cleveland Avenue and from Dismal Valley. Spontaneous dehydration of the originally hydrous mineral caused the sample from Cleveland Avenue to give a thenardite (Na_2SO_4) pattern with traces of quartz and gypsum as impurities, and the sample from Dismal Valley to give a different pattern, of Na_2SO_4 (III) (a high temperature anhydrous sodium sulfate which has never been found in nature), with a trace of quartz. Another sample of this mineral was collected by the cave naturalist at a later date from which the optical properties were roughly determined prior to dehydration of the mineral, precautions having been taken against dehydration. The mineral is biaxial negative, has a low birefringence, with the mean index of refraction of about 1.395. The dehydrated mineral from Dismal Valley which gives a Na_2SO_4 (III) pattern was chemically analysed; the analysis by J. J. Fahey of the Geological Survey is as follows:

	<u>Percent</u>	<u>Na₂SO₄ (Theoretical)</u>
Na ₂ O	40.75	43.64
CaO	0.70	
MgO	0.13	
K ₂ O	0.10	
SO ₃	53.40	56.36
CO ₂	0.90	
Cl	0.10	
SiO ₂	1.65	
Al ₂ O ₃	0.30	
Fe ₂ O ₃	0.08	
H ₂ O-110°C.	0.45	
H ₂ O+110°C.	<u>1.00</u>	<u> </u>
	99.56	100.00
	<u>0.02</u>	<u>Oxygen corrected</u>
	99.54 for 0.10 Cl	

The rough index of refraction of the mineral, the chemical composition and the rapid dehydration on exposure to air strongly suggest that the mineral is mirabilite (Na₂SO₄ · 10H₂O). The undehydrated mineral was X-rayed in a capillary tube in saturated Na₂SO₄ water solution as well as in an index oil medium. Both X-rays gave identical powder patterns which, however, are different from published powder data on mirabilite. Hydrous sodium sulfate crystals are easily synthesized in the laboratory, with optical properties close to that of mirabilite (Larsen and Berman, 1934), biaxial negative with mean index of refraction between 1.390 and 1.400. A spindle of synthetic crystals made in the normal way gave X-ray powder patterns essentially thenardite but in one case also a definite trace of Na₂SO₄ III pattern. This suggests that grinding may convert hydrous sodium sulfate to anhydrous Na₂SO₄ III.

Thus if $\text{Na}_2\text{SO}_4(\text{III})$ is to be recognized as a natural mineral, proof must be obtained that such conversion took place in the cave by natural processes. The synthetic sodium sulfate hydrate was also X-rayed in capillary tube in saturated sodium sulfate solution and at various temperatures at about 10°C . (ranging from 6° to 15°C . during the run) and about 26°C . (ranging from 24° to 28°C . during the run). One single powder pattern was obtained which agreed well with that of the natural mineral from Mammoth Cave. It is concluded that the natural mineral is hydrous sodium sulfate resembling mirabilite. However, some uncertainty exists as to whether mirabilite itself actually conforms to the formula $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$. The synthetic hydrate is being analysed to determine the true water content.

CONCLUSIONS

Sources of Recent Sediments along Echo River

All the transported sediments in the Mammoth Cave area including old and recent cave fills, sinkhole fills, deposits at swallow and resurgent points of underground streams, and flood-plain deposits are similar in characteristics except for two features: (1) the red orange color common in old cave fills is lacking in the other sediments, and (2) barite, celestite, and gypsum, present in some of the old cave fills, are not present in the other sediments.

The mineral assemblage (including the common presence of plant debris) of the flood sediments in Mammoth Cave (table 5) is in all aspects similar to that of the flood plain of Green River (table 4) and the sinkhole sediments (table 2). If material from the medium and high level sediments of the cave containing authigenic celestite, barite and large amounts of gypsum were transported to the present flood level, some traces of celestite would be expected as well as redeposited gypsum. Both celestite and gypsum are absent in the flood level sediments in the cave. Therefore the evidence strongly indicates that much if not most of the sediments in sections of the cave subject to flooding come from sources outside of the cave. Because of the direct connection between Echo River and Green River and the fact that the quantity of coarse sediments in the Echo River and related passages increases towards the rise point in the cave closest to Green River, and are similar to the sediments on the flood plain of Green River, it is probable that the sediment now being deposited in the lower part of Mammoth Cave comes from Green River.

Subterranean Drainage

Echo River and other streams in the lowest part of Mammoth Cave are sloughs of underground streams connecting with Green River. The ebb and flow of Echo River in part reflects the stages in Green River. However, stream stages on the Pennyroyal Plain are believed to influence Echo River also. Some surface drainage from areas immediately adjacent to the cave as well as drainage from the Pennyroyal apparently finds its way to Echo River. This is evident from dye tests made by the Louisville Gas and Electric Company at Three Springs (Anderson, 1925) as well as from the correlation of well stages on the Pennyroyal and the stages of Echo River.

The subterranean drainage of the Pennyroyal Plain is very complex. Large areas have no surface streams but are underlain by large underground streams. Most of these underground streams, as in Hidden River Cave (Horse Cave, Kentucky), have no surface tributaries. However, an area of 50 square miles south of Park City and Rocky Hill has surface drainage via nine creeks. The creeks are in karst valleys and surface drainage terminates at swallow points in the west or north end of the karst valleys. It is probable that some of the subterranean drainage from these creeks passes through Mill Hole and Cedar Sink to re-surge at the Turnhole while another part of the subterranean drainage apparently reaches Echo River.

Old Cavern Fills

A comparison of the numerous sections measured in the cave indicates a general uniform sequence in accumulation of the cave fills. Most of the fills contain silt and sand at the base grading upwards to gravel and sand, then silt, and at the top laminated silty clay. Horizontal correlation of the various sections is not possible as the fills change over short distances. This indicates that the fill probably developed progressively from point to point in the cave. Deposits of the same age may occur at a higher elevation in the southeast part of the cave than in the northwest part of the cave.

The silty clay at the top of the fill, commonly packed tightly against the ceiling, is probably developed as a result of the fill sealing off portions of passages allowing only the finer material to be carried into the areas blocked off.

There is no evidence in Mammoth Cave of an unctuous red clay fill developed under phreatic conditions. All red silty clay in the cave is deposited on a clastic fill of coarse material and apparently is a continuation of a non-phreatic sequence.

The major constituents of the old cavern fills are similar to recent fills in sinkholes, flood plains, and swallow points in karst valleys. It is probable that the old material is derived from the same sources that furnish material for recent fills - namely sand from the Big Clifty sandstone, chert from weathered zones of the Ste. Genevieve and St. Louis limestones, and silt and clay from the limestones of the Mammoth Cave Plateau and the Pennyroyal Plain. The red color prevalent in the older cave fills and lacking in recent fills (brown and gray are dominant) indicates that the climatic conditions at the time the material was transported and deposited may have been different than they are at present. The red color is from a stain of iron oxide closely associated with a small amount of clay in the sediments. The clay and the color are the same as in the red residual soils on the limestone of the Pennyroyal Plain. Further interpretation of the conditions at the time of deposition of the old fills follows in the conclusions concerning mineral assemblages.

Occurrence and distribution of gypsum, celestite, barite and manganese minerals

It is necessary to distinguish the primary or secondary origin of authigenic minerals if they are to have value in using them as criteria for stratigraphic correlation. If the authigenic mineral is primary, that is, deposited from the same environment as the sediments, then it is a good if not a better criterion than the use of relative frequency of detrital minerals. If the authigenic mineral is introduced later, after the deposition of the sediments, then it is of secondary origin and can not be depended on as criterion for stratigraphic correlation. The evidence in the old fills in Mammoth Cave favors the primary origin of celestite and its associated gypsum and barite because:

a. Celestite and barite are dispersed uniformly in the sediments in either single grains or in radiating or parallel aggregates. So far no veinlets or concentration of celestite or barite have been found along cracks or joints in limestone or within the sediments such as would be expected if percolating ground water had deposited these authigenic minerals after the sediments have been laid down.

b. Most of the authigenic barite occurs in the older fills at higher levels than those of the younger fills in which celestite is found.

c. When both authigenic minerals are found in the same section, barite underlies celestite. This indicates that well-crystallized barite is an older authigenic mineral than celestite; this is consistent with the observation in b. In the fill located at the base of the elevator shaft (fig. 12), barite occurs in the cross-bedded yellowish brown and brown sand of the lower part of the section whereas celestite and gypsum with a trace of barite occur in the red to reddish brown sandy silt and silt of the upper part (table 5, nos. 75, 76, and 77).

The barite in the red silt is intergrown with quartz forming minute irregular aggregates, unlike the well-crystallized and much larger crystals that occur in the lower part. If the authigenic celestite and barite were deposited by percolating ground water from above subsequent to the deposition of the sediments, the barite would be deposited first because barite is least soluble in water as compared to celestite and gypsum. Barite, therefore, would be more abundant in the upper part of the section; such distribution is not the case.

d. Red silty clay commonly caps fills that contain gypsum and celestite. The red silty clay is apparently free of gypsum. If the gypsum and celestite were introduced by percolating ground water they should be abundant on the side of the clay near the wall and ceiling and within the clay. This is not the case.

e. Where quarry operations in the vicinity of Mammoth Cave encounter natural cavities in the limestone with no fill in them, the cavities contain no gypsum deposits. However, where cavities containing gypsum are encountered, the gypsum is associated with clastic sediments partially or completely filling the cavity.

f. Celestite- and gypsum-bearing sediments are usually reddish-brown to red silt or sandy silt and the barite-bearing sediments are usually cross-bedded yellowish brown and brown sand. The reddish brown silt generally overlies the cross-bedded sand, separated locally by lenses of gravel with manganese minerals indicating a change or possible interruption of sedimentation between the two types of deposits.

This evidence (a to f) strongly indicates that authigenic celestite, barite, and gypsum that occur at medium and high levels in the cave (550 to more than 600 feet) are probably of primary origin and may therefore be suitable as criterion for correlation of the cave fills.

Origin and Deposition of Cave Fills

In arriving at a hypothesis concerning the genesis of the cave fill, two assumptions are made:

- (1) That the most active stage of cavern formation occurs at the level near the water table and that the water table remained at that level for a long period of time.
- (2) That the oldest portion of the cave is at the highest elevation and that younger portions are at successively lower elevations.

With respect to the sediments of the Mammoth Cave system, the following history of development may be postulated:

Stage 1. Passages at high elevations (about or greater than 600 feet) were excavated by solutions of ground water. The caverns formed during this period would have standing water in some parts containing the insoluble matter of the limestone such as collophane, quartz grains and a simple suite of heavy minerals and soluble calcium, carbonate, and bicarbonate ions. Probably some strontium and barium ions derived from the limestone were also present. The standing water would be enriched in cations dissolved from the limestone by percolating vadose water. Because of the low concentration of sulfate ions in this standing water, no sulfate minerals were precipitated at this period (no sulfate minerals occur at the base of the sediments). Surface streams loaded with white, yellowish brown and brown sand entered the cave and as the velocity of flow decreased, sediments were deposited, especially where the stream encountered standing water in the cave. A low concentration of sulfate ions brought in by the stream would have precipitated the barite which is found in these sediments today.

Stage 2. Uplift with subsequent down-cutting in the area was followed by a temporary static period with the water table at the 550- to 570-foot level. Another series of cave passages was excavated and integrated by slowly moving water in the zone near the water table. Streams entering the cavern system in the latter part of this period brought in some deposits of gravel and large amounts of reddish brown to red sandy silt and silt. The standing water within the cave also contained the insoluble matter from the limestone and small to moderate amounts of strontium ions in addition to other ions. The high content of gypsum and celestite in these fills indicates that the streams which brought in the red silt contained a high concentration of sulfate ions, similar to streams that traverse semi-arid desert areas. The semi-arid condition during a period of desiccation with drastic lowering of

water table is also consistent with the color of the sediments. Thus authigenic celestite and primary gypsum were deposited together with the sediments.

Stage 3. Further lowering of the water table occurred with the establishment of a local base level less than 500 feet in elevation. Fills in the lower part of the cave were brought in by waters low in sulfate, and authigenic sulfate minerals were not formed in these fills. During this and subsequent periods, the older clastic cave sediments were partially eroded and gypsum from the red silts was redissolved and redeposited in the intermediate levels of the cave forming beautiful gypsum flowers such as those of the New Discovery Cave.

RECOMMENDATIONS

The occurrence of authigenic celestite and barite are likely to be of great importance in the geologic history of the region around Mammoth Cave. The following investigations are proposed to complete the studies of these mineral occurrences:

(1) The possibility that authigenic celestite and barite may be of secondary origin, although remote, is not completely ruled out (i. e., the celestite, or gypsum may have been derived from the limestone by percolating ground water). Detailed examination of the occurrences and distribution of sulfate minerals including gypsum within the cave and in the limestone should be made.

(2) Complete investigation of sodium sulfate hydrate and the unknown manganese mineral in the fills should be made. If the sulfate were introduced by surface water under semi-arid desert condition as postulated, then surface water would be a likely source for the sodium.

(3) Study of more complete sections of cave fills. This study would include the dark red clay which is present locally in the uppermost part of the fills to determine its relation to sulfate deposition.

(4) The study of the distribution and significance of manganese-bearing gravel.

(5) A comprehensive hydrologic study of the area should be made in order to determine the source and movement of ground water and the interrelations of ground water and the sediments in the cave. This study would include dye tests, detailed mapping of hydrologic features, the installation of automatic water stage recorders and chemical analyses of ground water to show the subterranean movement of polluting salt brines present in Green River.

(6) Study of the geomorphology of the Mammoth Cave area should be done in detail so that cavern features can be tied to corresponding surface features.

REFERENCES

- Anderson, R. B., 1925, An investigation of a proposed dam site in the vicinity of Mammoth Cave, Kentucky: Ms. on file Louisville Gas and Electric Company, Louisville, Ky., 13 p.
- Brown, Richmond F., 1953, Reconnaissance of geology and ground water in the vicinity of Mammoth Cave National Park: Ms. on file, National Park Service, Washington, D. C.
- Croghan, John, 1845, Rambles in Mammoth Cave during the year 1844: Morton and Griswold, Louisville, Ky., 101 p.
- Hovey, Horace C., 1912, Mammoth Cave of Kentucky: John P. Marton, Louisville, Ky., 131 p.
- Larsen, Esper, and Berman, Harry, 1934, Microscopic determination of the non-opaque minerals: U. S. Geol. Survey Bull. 848, second edition, 266 p.
- Lawrence, Joe, Jr. and Brucker, Roger W., 1955, The Caves Beyond: Funk and Wagnall, New York, 283 p.
- Livesay, Ann, 1953, Geology of the Mammoth Cave National Park area: Kentucky Geological Survey, ser. IX, Sp. Publ. 2, 40 p.
- McGrain, Preston and Walker, Frank H., 1954, Guidebook field trip Mammoth Cave Region, Barren, Edmonson, and Hart Counties, Kentucky: Geological Society of Kentucky, 32 p.
- Palache, Charles, Berman, Harry, and Frondel, Clifford, 1946, Dana's system of mineralogy, seventh edition: John Wiley and Sons, Inc., New York, v. I, 834 p.
- Pohl, E. R., 1938, Geology of Mammoth Cave National Park: Ms. on file, National Park Service, Washington, D. C. and Mammoth Cave, Ky., 113 p.
- Randolph, Helen F., 1924, Mammoth Cave and the cave regions of Kentucky: Standard Printing Co., Louisville, Ky., 156 p.
- Weller, J. Marvin, 1927, Geology of Edmonson County: Ky. Geol. Surv., series VI, v. 28, 246 p.

APPENDIX

INTERPRETIVE MATERIAL

Fills. - The fills common throughout the cave are formed of sand, gravel, silt and clay. The general sequence is sand near the base successively overlain by gravel, sand, silt, and clay. The sources of material forming the fills were the products of weathering from the surface limestone and sandstone. The material was transported into the cave by surface streams shortly after the passageways were dissolved out to their mature size. At the time the fills were brought into the cave the ground-water level was high and the passages were flooded. The water level fluctuated and parts of the fill were deposited in flooded areas and other parts in open stream channels. Most of the fills are packed tightly to the ceiling indicating that the clay which was deposited last was laid down in pools.

The fills have an orange-red color which is different from the gray and brown typical of the sediments now being deposited in Echo River. The red color possibly indicates that arid conditions in the region around Mammoth Cave existed when the older fills were laid down. The polished pebbles in the gravel fills also are indicative of arid surface conditions.

Sites for pointing out feature:

- (1) Base of Elevator Shaft, sequence of sand-gravel-silt well exposed.
- (2) Between Bottomless Pit and Washington Pit, cross-bedding is well shown in cut here.
- (3) Wooden Bowl Room, gravel is exposed here.
- (4) Mule Stall, gravel and sand are exposed.
- (5) Junction of Boone and Kentucky Avenues, complete sequences of fill, sand-gravel-clay.

Gypsum-Barite-Celestite. - These sulfate minerals are closely related to the cavern fills. They apparently were deposited at the same time as the fills. It is envisioned that the cavern passages had large pools of water, similar to Echo River, at the time most of the fills were laid down. The water contained significant quantities of barium, strontium, and calcium in solution. The streams bringing the fill material into the caves at first contained only small quantities of sulfate. Initially this was enough to precipitate the barium in the form of barium sulfate (barite). As time went on the stream water was higher in sulfate reflecting more arid surface conditions. As the sulfate content increased there was enough available to form celestite (strontium sulfate) which is more soluble than barite. With continued increase in sulfate in the stream and pools the more soluble calcium sulfate (gypsum) was finally precipitated. The barite and celestite crystals in the fills are too small to be seen with the naked eye but the gypsum is in crystals an inch or more in length. The gypsum flowers on the walls and ceiling of the passages are secondary, having been dissolved from the original gypsum and redeposited.

Site for pointing out feature:

- (1) Path level Cleveland Avenue near Diamond Ceiling, gypsum in sand.

Sodium Sulfate. - The mineral growth on the floor and walls at the junction of Orpheus Garden and Cleveland Avenue has been referred to as Epsom Salts (Magnesium sulfate). Laboratory examination indicates it is a relatively rare hydrous sodium sulfate, mirabilite. Exact determination of the mineral is difficult as the slightest disturbance causes loss of water and a change in the mineral. This sodium mineral is another feature hinting that an arid climate existed at the time the fill was deposited.

Site for pointing out feature:

- (1) Cleveland Avenue at Orpheus Garden.

Echo River. - Echo River, River Styx, and Roaring River are underground streams that connect with Green River. A rise in Green River is reflected in a rise in the underground streams. However, rises in the water table of the Pennyroyal also are reflected in rises in Echo River even though Green River does not rise. The rise of Echo River is often rapid and large quantities of sand and silt are brought into the cave. The sand drops quickly after entering but the silt settles out slowly while the cave is flooded. For each flood there is a bed of sand

several inches thick covered by a thinner bed of silt. As the river falls it drains slowly from the cave and leaves most of the sand and silt in the passages that were flooded. The recent sediments in the flooded areas differ from the older cave fills in their brown and gray color (old fills are orange or red) and in the lack of gypsum, barite and celestite. This indicates that very little of the old fills are now being eroded and moved into the lower cave.

Thirty years ago dye put in one mile east of Mammoth Cave at Three Springs appeared in Echo River, indicating that some of the sinkholes on the plateau above the cave drain into the cave. Dye put in other sinks on the plateau indicate that subterranean drainage east of Houchins Valley drains east to Pike Spring. The subterranean drainage basin of Echo River is apparently the area of Houchins Valley and the north part of Mammoth Cave Ridge as well as portions of the Pennyroyal.

In other parts of the park there is a system of extensive subterranean streams. On the Pennyroyal Plain south of Mammoth Cave there are several large creeks that sink underground. The subterranean course for some of them apparently is to the north to Mill Hole and Cedar Sink where they flow across the bottom of large sinkholes. The discharge point for this drainage is probably the Turnhole on Green River.

Sites for pointing out feature:

- (1) Echo River between Minnehaha Island and Minnehaha Falls.
- (2) Shakespeare Hall.

Niter earth. - The source of nitrates in the niter or saltpeter earth is of interest. Chemical analysis of bat guano and niter earth indicate a close relation. The steps from guano to niter appear to be as follows: bat guano, desiccated guano dust, and leaching of nitrates from guano dust to cave fill. Nitrate concentration in these stages is:

	<u>Percent</u>
Fresh guano	1.89
Desiccated guano (Chief City)	0.27
Cave fill beneath guano	0.39
<u>Niter earth at saltpeter diggings</u>	<u>0.43</u>
Niter earth after leaching in saltpeter vats	0.01

Based on this a yield of 4.2 pounds of potassium nitrate could be processed from a bushel (135 pounds) of niter earth. This is close to the 3 to 5 pounds recorded as having been produced during the time saltpeter mining was carried on in the cave (Croghan 1845).

Site for pointing out feature:

- (1) Saltpeter vats, Rotunda.

Age of deposits. - Little is known concerning the age of deposits in caves. The desiccated guano dust in Chief City was dated by carbon-14 methods to be older than 38,000 years. This indicates that Mammoth Cave and most of the deposits in it pre-date the last ice age. The desiccated guano in Chief City lies on top of a rock fall which in turn lies on 20 feet of silt and sand. The latter deposits are probably considerably older than the guano and may date over 100,000 years.

Site for pointing out feature:

- (1) Rotunda in connection with discussion of saltpeter.

Table 1. Chemical Analyses of Guano and Niter Earth

Sample Number	SiO ₂	CaO	SO ₃	P ₂ O ₅	H ₂ O	CO ₂	Nitrate Nitrogen																		
1				2.7	35.6	1.16	1.89																		
2				1.4	24.0	0.05	0.01																		
3				11.4	6.1	1.08	0.27																		
4				11.5	7.8	0.73	0.39																		
5				4.8	11.9	9.16	0.43																		
6				0.3	2.1	5.11	0.01																		
7	25.3	22.1	8.6	10.6	30.4*		1.00																		
* includes H ₂ O, C, CO ₂																									
<table><tr><td>Sample</td><td>1</td><td>Fresh guano</td></tr><tr><td></td><td>2</td><td>Caye earth beneath guano</td></tr><tr><td></td><td>3, 7</td><td>Old desiccated guano from Chief City</td></tr><tr><td></td><td>4</td><td>Caye fill beneath old guano, Chief City</td></tr><tr><td></td><td>5</td><td>Niter earth at saltpeter diggings</td></tr><tr><td></td><td>6</td><td>Leached niter dirt</td></tr></table>								Sample	1	Fresh guano		2	Caye earth beneath guano		3, 7	Old desiccated guano from Chief City		4	Caye fill beneath old guano, Chief City		5	Niter earth at saltpeter diggings		6	Leached niter dirt
Sample	1	Fresh guano																							
	2	Caye earth beneath guano																							
	3, 7	Old desiccated guano from Chief City																							
	4	Caye fill beneath old guano, Chief City																							
	5	Niter earth at saltpeter diggings																							
	6	Leached niter dirt																							
Analysis by M. K. Carron, George T. Burrow, Irving C. Frost, Henry H. Lipp, and Lewis F. Rader, Geological Survey																									

THEORY OF THE EARTH AND ITS HISTORY

The theory of the earth and its history is a branch of geology which deals with the origin and development of the earth and its various parts. It is a science which seeks to explain the processes which have shaped the earth and its features, and to determine the sequence of events which have taken place since the earth was first formed.

The theory of the earth and its history is based on the study of the earth's rocks and fossils.

The study of the earth's rocks and fossils is the basis of the theory of the earth and its history.

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Table 2. Heavy mineral assemblage of sediments from sinkholes, Mammoth Cave National Park, Kentucky

Sample Number	Locality	Percent Heavy	Opaque			Non-opaque										Total Opaque	Total non-opaque	
			Goethite and Iron oxide	Leucoxene	Chromite	Zircon	Tourmaline	Rutile	Brookite	Anatase	Collophane	Fluorite	Apatite	Rhodochrosite	Muscovite			Garnet
1	Mill Hole, resurgence, south end.	0.23	4*	2	1	2	2	1	1	1	1						5	2
2	Mill Hole, swallow hole, north end.	0.20	4	2	1	2	2	1			1	1					5	2
6	Sinks of Little Sinking Creek, 100 ft. from swallet.	0.14	4	3	1	2	2	1			1						5	2
8	Sinks of Sinking Creek, east swallet.	0.15	2	1	1	4	2	2	1	1	1						2	5
9	Sinks of Sinking Creek, west swallet.	0.23	2	1	1	4	2	1		1	1						2	5
12	Sink west of Mt. Vernon Church, east side, sand wash in stream.	0.44	4	1		3	2	1									4	3
13	Sink west of Mt. Vernon Church, west side, bank.	0.03	4	1	1	3	2	1									4	3
14	Large sink 1 mile west Stovall, from stream channel.	0.24	4	2	1	2	2	1	1		1						5	2
15	Large sink, 1 mile west Stovall, from bank.	0.12	5	1	1	2	2	1	1								5	2
52	One mile west of Salem Church, shallow sink, 100 ft. south of road.	0.17	5	2	1		1		1		1		1				5	2
53	Sinks of Gardner Creek, bottom of stream channel.	0.54	4	1	1		1							3			4	3
54	Sinks of Gardner Creek, bank of stream.	0.18	5	1	1	2	1				1						5	2
55	Monroe sink, west swallet.	0.14	4	2	2	2	1	1	1						1		5	2
56	Monroe sink, sand wash 100 ft. southwest of west swallet.	0.20	2	2	1	3	2	2	1								3	4
57	Monroe sink, east swallet.	0.21	3	3	2	3	2	1	1	1						1	4	3
59	Cedar sink, south end, sand bank.	0.14	4	3	1	2	1	1	1		1						5	2
60	Cedar sink, north swallet, silt bank.	0.19	5	2	1	2	1	1			1						5	2
62	Cedar sink, north end at pool.	0.18	5	1		2	1	1	1		1	1					5	2
68	Double Cellars, base of sink.	0.18	4	2	1	2	2	1					1			1	4	3
202	Violet City sink.	0.24	3	3	2	2	2	1	1	1							4	3
203	Violet City sink.	0.36	3	3	3	3	2	1	1								4	3

*Semi-quantitative designation:

5 - More than 80 percent of the heavy fraction

4 - 50-80 percent of the heavy fraction

3 - 20-49 percent of the heavy fraction

2 - 5-19 percent of the heavy fraction

1 - Less than 5 percent of the heavy fraction

Table 3. - Heavy mineral assemblage of sediments taken from mantle soil along Road cuts, Mammoth Cave National Park, Kentucky

Sample Number	Locality	Percent Heavy	Opaque			Non-opaque						Total opaque	Total non-opaque	
			Goethite and iron oxide	Leucoxene	Chromite	Zircon	Tourmaline	Rutile	Brookite	Anatase	Collophane			Apatite
4	1/2 mile south of Mill Hole, cut west side country road.	0.28	4*	2	1	2	1	1					5	2
11	Surface soil, road cut 1/4 mile west of Barren County line, south side Sinking Creek.	0.50	4	1	1	3	2	1					4	3
16	1,000 feet West Pursley Cemetery, red silt layer.	0.24	1	2	1	3	3	1	1				3	4
17	1,000 feet West Pursley Cemetery, lower red silt layer.	0.66	2	3		3	3	1					3	4
18	1,000 feet West Pursley Cemetery, yellow brown sand layer at base.	0.03	1	5	1	1	1	1	1	1			5	2
50	Ky. Highway 70, 1 mile east of Cave City, road cut, 3 ft. from top.	0.31	3	1	2	3	2	1	1		1		4	3
51	Ky. Highway 70, 1 mile east of Cave City, road cut, top.	0.20	3	2	1	3	1	1				1	3	4
101	Ky. Highway 70, 700 ft. east Monroe Sink, pocket in limestone along road cut.	0.49	4	1	1	2	1	1	1		2		5	1
204	1/4 mile south of Browns Ferry, pocket in limestone.	0.07	4	3	1	2	1	1	1		1	1	5	1
			* Semiquantitative designation 5 - More than 80 percent of the heavy fraction 4 - 50-80 percent of the heavy fraction 3 = 20-49 percent of the heavy fraction 2 - 5-19 percent of the heavy fraction 1 - Less than 5 percent of the heavy fraction											

Table 4. - Heavy mineral assemblage of flood-plain sediments, Mammoth Cave National Park, Kentucky

Sample Number	Locality	Percent Heavy	Opaque			Non-opaque							Total opaque	Total non-opaque	
			Goethite and iron oxide	Leucoxene	Chromite	Zircon	Tourmaline	Rutile	Brookite	Anatase	Collophane	Fluorite			Apatite
65	Cave entrance, 100 feet west of Turnhole, sand bank.	0.12	3*	4	1	1	1	1	1	1				5	2
66	Cave entrance, 100 feet west of Turnhole, silt in bank.	0.14	3	3	2	3	1	1	1				1	4	3
67	Turnhole, flood-plain deposit.	0.29	4	3	2	2	2	1	1					5	2
97	Echo River resurgence, sand at water level 10 ft. stage.	0.13	3	3	2	2	1	1			1			5	2
98	Echo River resurgence, dark brown clay from bank.	0.22	3	3	1	3	1	1	1					4	3
99	River Styx resurgence, sand at water level 10 ft. stage.	0.20	4	2	1	2	1	1	1		1	1		5	2
100	Flood plain, River Styx and Green River.	0.21	3	3	2	3	2	1	1	1	1		1	4	3
207	Flood plain, Green River at River Styx.	0.27	3	3	2	2	2	1	1	1	1			5	2
	* Semiquantitative designation 5 - More than 80 percent of the heavy fraction 4 - 50-80 percent of the heavy fraction 3 - 20-49 percent of the heavy fraction 2 - 5-19 percent of the heavy fraction 1 - Less than 5 percent of the heavy fraction														

Table 5. - Heavy mineral assemblage of low level (420 ft. to about 500 ft. elevation) cave sediments, Mammoth Cave National Park, Kentucky

Sample Number	Locality and General Description	Elevation in feet	Percent Heavy	Opaque			Non-opaque								Total opaque	Total non-opaque	
				Goethite and iron oxide	Leucoxene	Chromite	Zircon	Tourmaline	Rutile	Brookite	Anatase	Collophane	Fluorite	Muscovite			Garnet
315	Echo River, Minnehaha Island, yellow-brown sand.	424	0.27	3*	2	2	3	2	2	1		1				4	3
316	Echo River, Minnehaha Island, lumpy brown silt.	424	1.40	2	2	2	4	2	2	1		1			1	3	4
87	Echo River at Lake Lethe, 11 ft. stage, brown sand.	435	0.15	3	3	2	2	2		1		1				5	2
42	Echo River, southwest end, gray-brown sandy silt.	451	0.17	3	3	2	2	2	1			1				5	2
43	Minnehaha Falls, recent deposits, yellow sand.	452	0.17	3	3	2	2	2	1		1	1				5	2
317	River Styx, Shakespeare Hall, pale gray-brown silt.	423	0.38	3	3	2	3	2	2			1				4	3
318	River Styx, Shakespeare Hall, brown sand.	424	.21	4	3	2	2	2	1	1	1	1				5	2
25	River Styx, at water level, brown silty fine sand.	435	0.20	3	3	2	2	2	1	1		1	1			5	2
26	Dead Sea, recent flood, brown sandy silt.	456	0.12	5	2	1	2	2				1	1		1	5	2
88	River Hall, abandoned Ladies' Room, brown sand.	482	.20	4	3	2	2	2	1	1		1				5	2
89	River Hall, abandoned Ladies' Room, yellow sand.	479	1.10	2	1	2	4	2	2							3	4
90	River Hall, abandoned Ladies' Room, sandy gravel.	475	.26	3	2	2	3	2	2	1		1				4	3
324	New Discovery, stream channel, end of Big Avenue, brown silt.	490	.55	2	2	1	4	2	1	1	1	1				3	4
69	Cathedral Domes, base of Dome 5, gray-brown gravelly sand.	502	0.85	2	2	1	4	2	2	1		1	1			2	5
70	Cathedral Domes, base of Dome 4, light brown clayey silt.	500	0.45	4	3	1	2	1	1	1		1		1		5	2
29	Pensacola Avenue, end, flood channel, dark brown sand.	510	0.84	2	1	2	4	2	1							3	4

Samples Nos. 87, 43, 317, 318, 26 and 324 contain plant debris; the others do not

* Semiquantitative designation

5 - More than 80 percent of the heavy fraction

4 - 50-80 percent of the heavy fraction

3 - 20-49 percent of the heavy fraction

2 - 5-19 percent of the heavy fraction

1 - Less than 5 percent of the heavy fraction

Table 6 - Heavy mineral assemblage of intermediate level (from about 500 ft. to about 600 ft.) cave sediments, Mammoth Cave National Park, Kentucky

Sample Number	Locality and general description	Elevation	Percent Heavy	Opaque				Non-opaque											Total opaque	Total non-opaque	
				Goethite and iron oxide	Leu- coxene	Chrom- ite	Man- ganese Mineral	Zir- con	Tour- ma- line	Ru- tile	Brook- ite	Ana- tase	Celes- tite	Ba- rite	Collo- phane	Gar- net	Mus- co- vite	Apa- tite			Fluo- rite
40	Silliman Ave., Valley of Flowers, buff-brown pebbly coarse sand.	493	0.82	2*	2	1		4	2	2	1		2		1					2	5
41	Silliman Ave., Valley of Flowers, brown silty sand.	491	0.12	3	3	2		2	2	1	1		2					1		4	3
44	Pass of El Ghor, Mule Stall, pea-sized sandy gravel.	502	0.31	3	2	1		3	2	1	1				1					4	3
27	Pensacola Ave., light brown silty sand.	512	0.47	2	2	2		3	2	1			2							3	4
30	Pensacola Ave., 300 feet from entrance, brown silty sand.	520	0.25	4	2	1		2	2				1		1					5	2
314	Passage from Bottomless Pit to Washington Pit, yellow sand.	515	0.19	3	3	2		2	2	1	1		1							4	3
313	Richardson Spring, yellow sand.	535	0.43	3	2	2		3	2	1	1				1		1			3	4
35	Great Onyx Cave, end of public section, light brown sandy silt.	523	1.44	1	1	1		2	1	1	1		4		1					2	5
37	Great Onyx Cave, end of public section, brown silt.	525	1.1	1	2	1		3		2			3						1	2	5
323	New Discovery, end of Big Ave., brown sandy silt.	495	0.19	3	3	2		3	2	1	1									4	3
322	New Discovery, end of Big Ave., reddish brown silt.	497	0.12	4	3	2		1	1	1	1		1		1					5	2
321	New Discovery, near Forks of Cave, brown silt clear aggregate.	515	0.34	2	1	1		2	1	1	1		4		1					2	5
319	New Discovery, 100 feet east of Onyx Ave., alternating red-tan sand.	550	0.23	3	3	2		2	2	1	1		1		1					4	3
325	New Discovery, upper level passage 1,000 feet from rimstone dam.	570	0.08	4	3	1		1	1	1	1		1		1					5	2
326	New Discovery, at passage to Roaring River, brown sandy gravel.	540	0.06	4	3	1		1	1				1		1					5	2
93	New Discovery, gravel, junction Roaring River, 300 ft. north of rimstone dam, coarse sandy gravel.	540	1.35	2	1	1		2	1	1	1		4		1		1			2	5
95	New Discovery, anastomoses pocket, 500 ft. from cave entrance, brown clay.	562	0.22	4	3	1		2	1						1					5	2
96	New Discovery, anastomoses pocket, 200 feet from cave entrance, pale brown sandy silt.	565	0.15	4	2	1	1	1	2	1					2					5	2
36	Cleveland Avenue, Diamond Ceiling, buff silt from fill.	550	1.05	1	1	1		1	1	1	1		5							2	5
38	Cleveland Avenue, at Orpheus Garden, brown silt.	547	0.10	3	3	1		2	2	1	1		2		1					4	3
39	Cleveland Avenue, Jenny Lind's Table, brown gravelly sand.	550	1.86	1	1	1		3	2	1	1		4		1					2	5
80	Marions Ave., 400 ft. from 3 Way Junction, brown gravelly sand.	515	1.10	2	1	1		3	2	2	1		1	2	1					3	4
79	Marions Ave., 400 ft. from 3 Way Junction, mostly gypsum.	518	0.23	3	3	1		2	1	1	1		3		1		1			4	3

(Continued on the following page)

Table 6 (Continued from preceding page)

Sample Number	Locality and general description	Elevation	Percent Heavy	Opaque				Non-opaque											Total opaque	Total non-opaque	
				Goethite and iron oxide	Leucoxene	Chromite	Manganese mineral	Zircon	Tourmaline	Rutile	Brookite	Anatase	Ceolite	Bastite	Collophane	Garnet	Muscovite	Apatite			Fluorite
78	Marions Ave., 850 ft. from elevator shaft, brown gravelly sand.	545	0.66	2	2	2		3	2	2	1	1								3	4
71	Martel Ave., top of stairs, light brown silty sand.	540	0.27	3	3	2		2	2	1	1		1	2	1		1			5	2
77	Base of elevator shaft, brown sand.	545	0.26	2	3	1		3	2	1	1	1		1	1					4	3
76	Base of elevator shaft, limonitic brown gravel.	547	4.65	4	1	1	2	1	1	1	1		1	1	1					5	2
75	Base of elevator shaft, reddish brown silt.	550	0.39	3	3	1		1	1	1	1		3	tr	1					4	3
24	Wooden Bowl Room, pebbly gravel, reddish brown.	560	1.08	1	1	2		4	2	2	1		1							2	5
205	Cyclops Ave., brown gravelly sand.	575	0.44	4	3	2		2	1	1	1		1		1			1		5	2
31	Fox Ave., Wrights Rotunda, brown silty sand.	572	0.21	4	2	1		2	2	1										4	3
74	Junction Kentucky and Boone Ave., light brown silty sand.	575	0.88	2	2	1		4	2	1	1			1	1					2	5
73	Junction Boone and Kentucky Ave., brown sandy gravel.	577	2.64	4	1	1	2	2	1	1	1									5	2
72	Junction Boone and Kentucky Ave., reddish buff silt.	578	0.27	4	2	2	2	2	1	1	1	1	1	1	1		1			5	2
47	Boone Ave., Chaperon, yellow coarse sand.	589	0.87	2	2	1	1	4	2	2	1			1	1		1			2	5
46	Boone Ave., Chaperon, limonitic gravel.	591	0.98	2	1	1	4	2	1	1	1			1			1			4	3
45	Boone Ave., Chaperon, reddish brown silt.	600	0.37	2	3	1		2	1	1	1			2		1				4	3
209	Rotunda, wall pocket, gray stony sand.	590	0.75	2	1			1	1	1			5		1					2	5

* Semiquantitative designation

5 - More than 80 percent of the heavy fraction

4 - 50-80 percent of the heavy fraction

3 - 20-49 percent of the heavy fraction

2 - 5-19 percent of the heavy fraction

1 - Less than 5 percent of the heavy fraction

tr - trace

Table 7. - Heavy mineral assemblage of high level (about and greater than 600 feet) cave sediments, Mammoth Cave National Park, Kentucky

Sample Number	Locality and general description	Elevation	Percent Heavy	Opaque				Non-opaque											Total opaque	Total non-opaque	
				Goethite and iron oxide	Leucoxene	Chromite	Manganese mineral	Zircon	Tourmaline	Rutile	Brookite	Anatase	Celesite	Bastnaesite	Collophane	Garnet	Muscovite	Apophyllite			Fluorite
19	Methodist Church, white sand.	605	0.28	3*	2	1		2	1	1				3	2					3	4
20	Methodist Church, light brown silty sand.	593	0.12	3	3	1		1	1	1	1			1	1	1	1			5	2
22	Methodist Church, light brown sand.	609	0.24	1	2	1		4	2	1	1				1					2	5
312	Methodist Church, brown sand.	606	0.10	1	2	1		4	1	1	1		2							2	5
23	Methodist Church, brown silty sand.	600	0.15	3	2	1		3	2	2	1				1					3	4
21	Methodist Church, red-brown silty clay.	613	0.54	2	1	1		1	1					1	5					2	5
49	100 yards east of Aero Bridge, north side Hippodrome, brown silt.	614	0.13	3	3	1		2	1	1	1	1		2	1	1				5	2
48	100 yards east of Aero Bridge, north side of Hippodrome, yellow sand.	612	0.29	3	2	2		3	2	1						1		1	1	4	3
33	Sims Pit Ave., yellow sand.	620	0.20	2	3	2		2	2	1	1			1						4	3
34	Sims Pit Ave., red-brown silt.	623	0.34	3	1	1		3	1	1				2						3	4
211	Crystal Cave, Rt. 1, Valley of Decision, tan sand.	620	0.12	3	3	1		1	1	1	1		1		1					5	2
210	Crystal Cave, extension Rt. 1, passage to left of casket, brown silt.	630	0.34	3	2	2		2	1	1	1				1	1				4	3
212	Crystal Cave, small passage, 100 ft. beyond pit, end of Rt. 1, gravelly sand.	650	3.72	1	1	2		4	1	2	1			2						2	5
85	Salts Cave, passage to Cairn passage 100 ft. in, brown gravelly sand.	696	1.92	1	1	1		4	2	2	1		1	1	1					2	5
81	Salts Cave, entrance to Dismal Valley, light brown sandy silt.	730	0.30	2	2	1		3	2	1	1	1	1	1	1	1				3	4
84	Salts Cave, terminus of Dismal Valley, yellow sandy silt.	731	0.14	2	4	2		2	1	1	1	1	1	1	1	1			1	5	2
83	Salts Cave, terminus of Dismal Valley, brown gravelly sand.	738	1.17	4	1	1	2	2	1	1	1		1	1		1				5	2
82	Salts Cave, terminus of Dismal Valley, brown silt.	744	0.20	3	2	2		2	2	1	1	1	1							4	3

* Semiquantitative designation

5 - More than 80 percent of the heavy fraction

4 - 50-80 percent of the heavy fraction

3 - 20-49 percent of the heavy fraction

2 - 5-19 percent of the heavy fraction

1 - Less than 5 percent of the heavy fraction

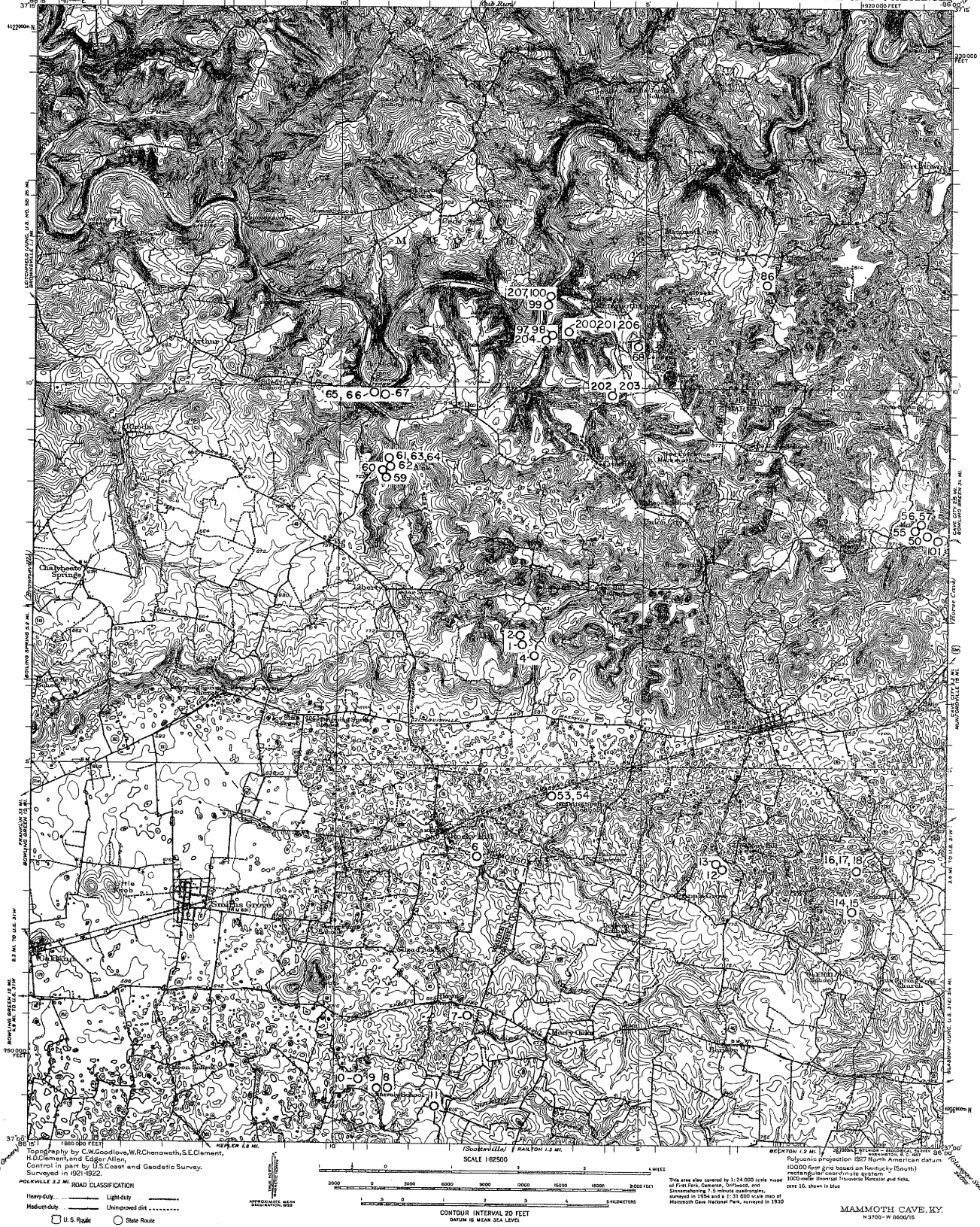
FIGURES

FIGURE 1a SEDIMENTS IN MAMMOTH CAVE

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

STATE OF KENTUCKY
REPRESENTED BY THE
DEPARTMENT OF MINES AND MINERALS

KENTUCKY
MAMMOTH CAVE QUADRANGLE



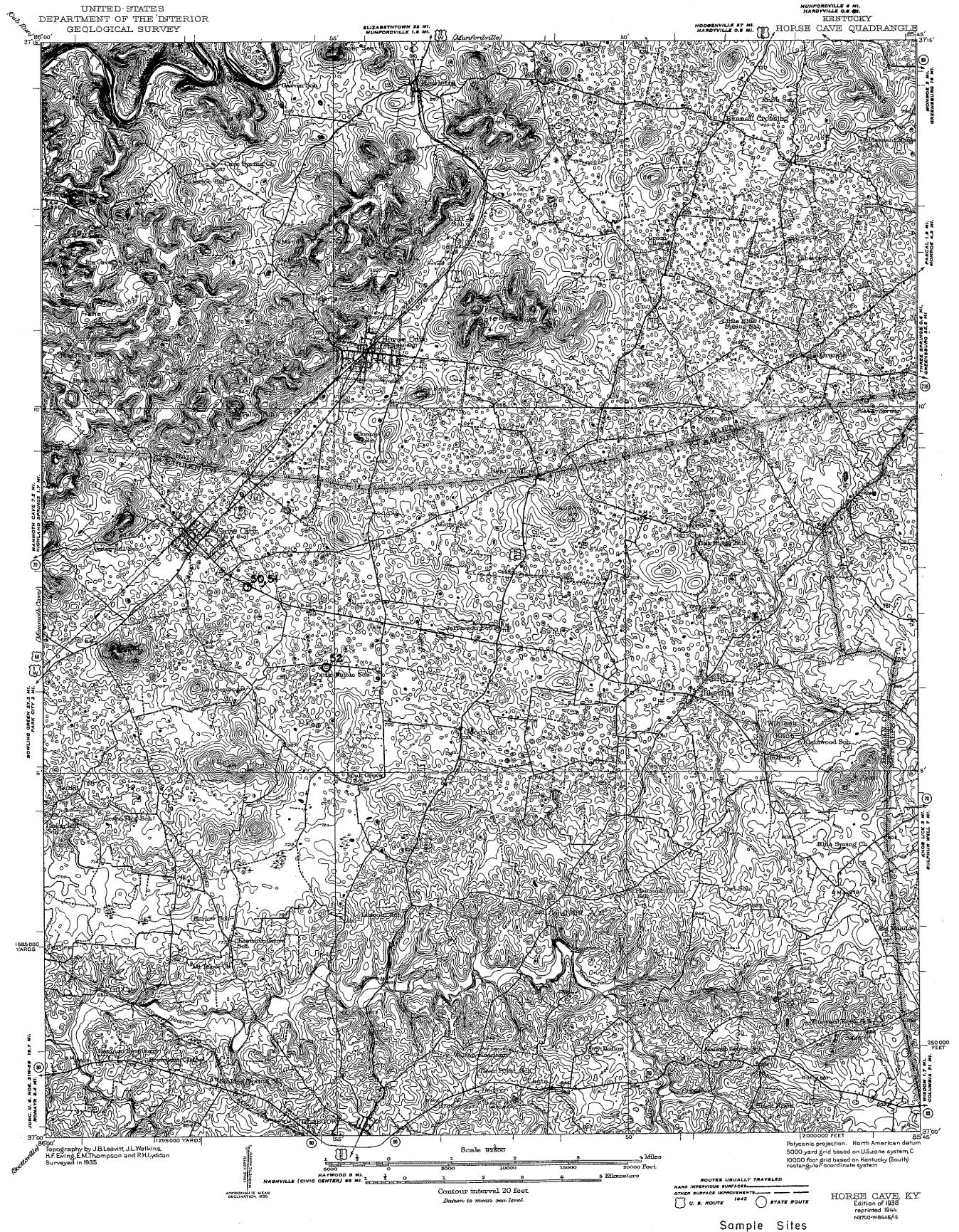




Figure 2.
Swallow hole
in
Monroe Sink.

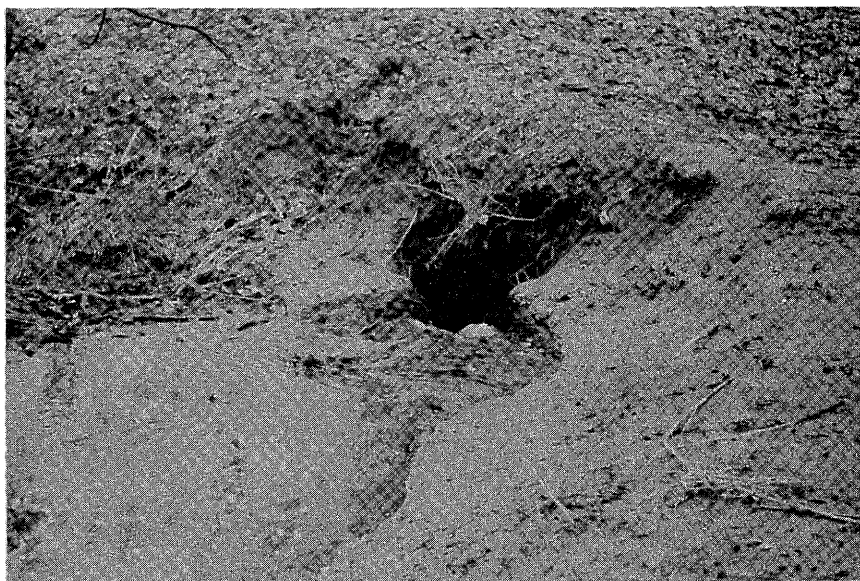


Figure 3. Swallow point of Gardners Creek.

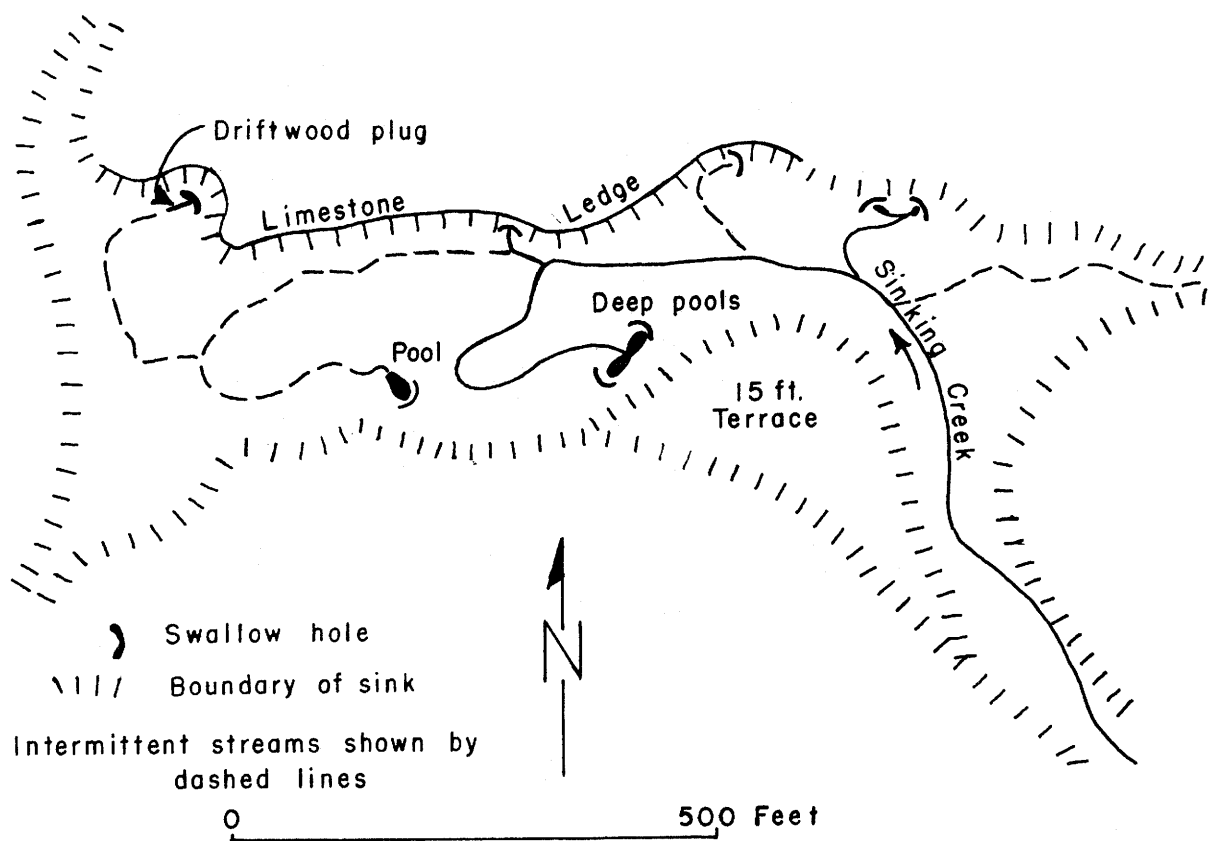


Figure 4. Sketch map of the swallow holes of Sinking Creek.

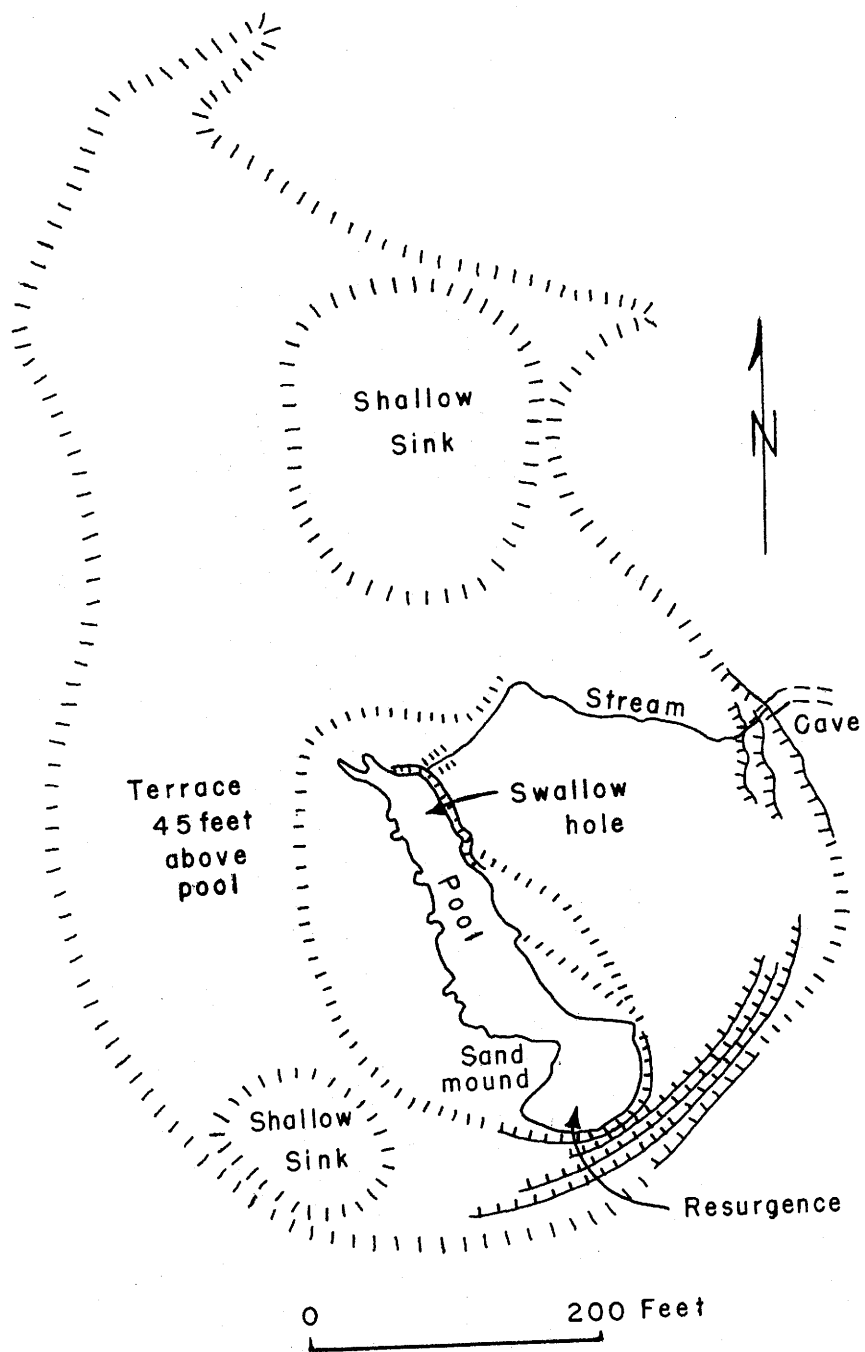


Figure 5. Sketch map of Mill Hole.

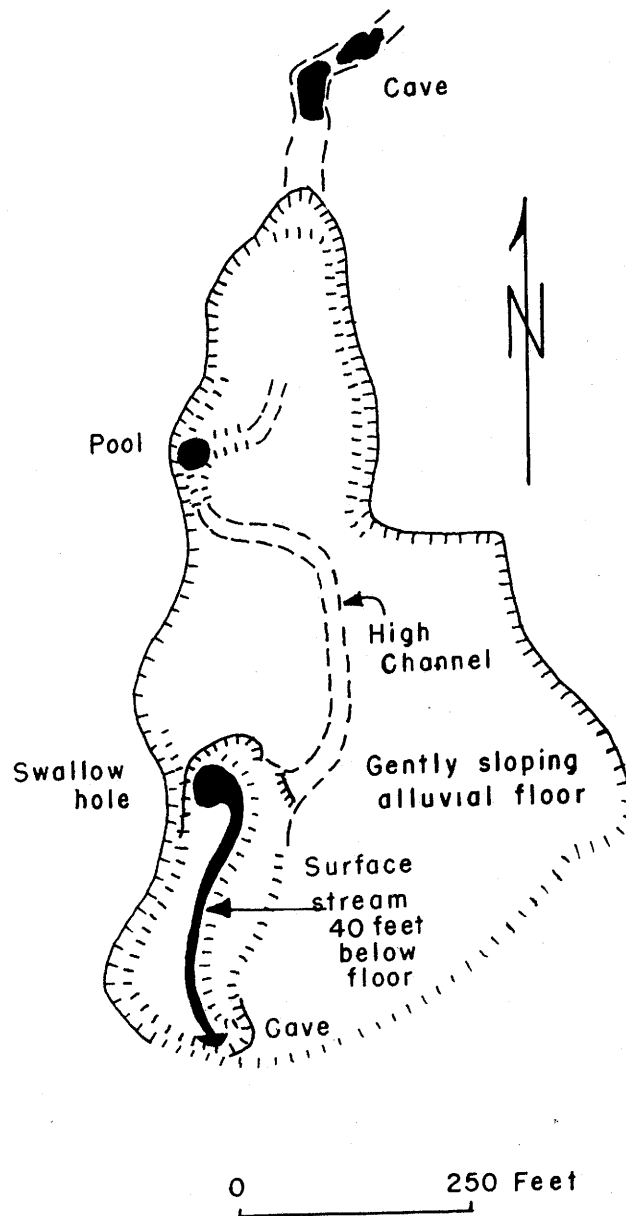


Figure 6. Sketch map of Cedar Sink.



Figure 7. Resurgent point in Mill Hole.



Figure 8. Residual soil over limestone, Kentucky Highway 70, 1 mile east of Cave City.

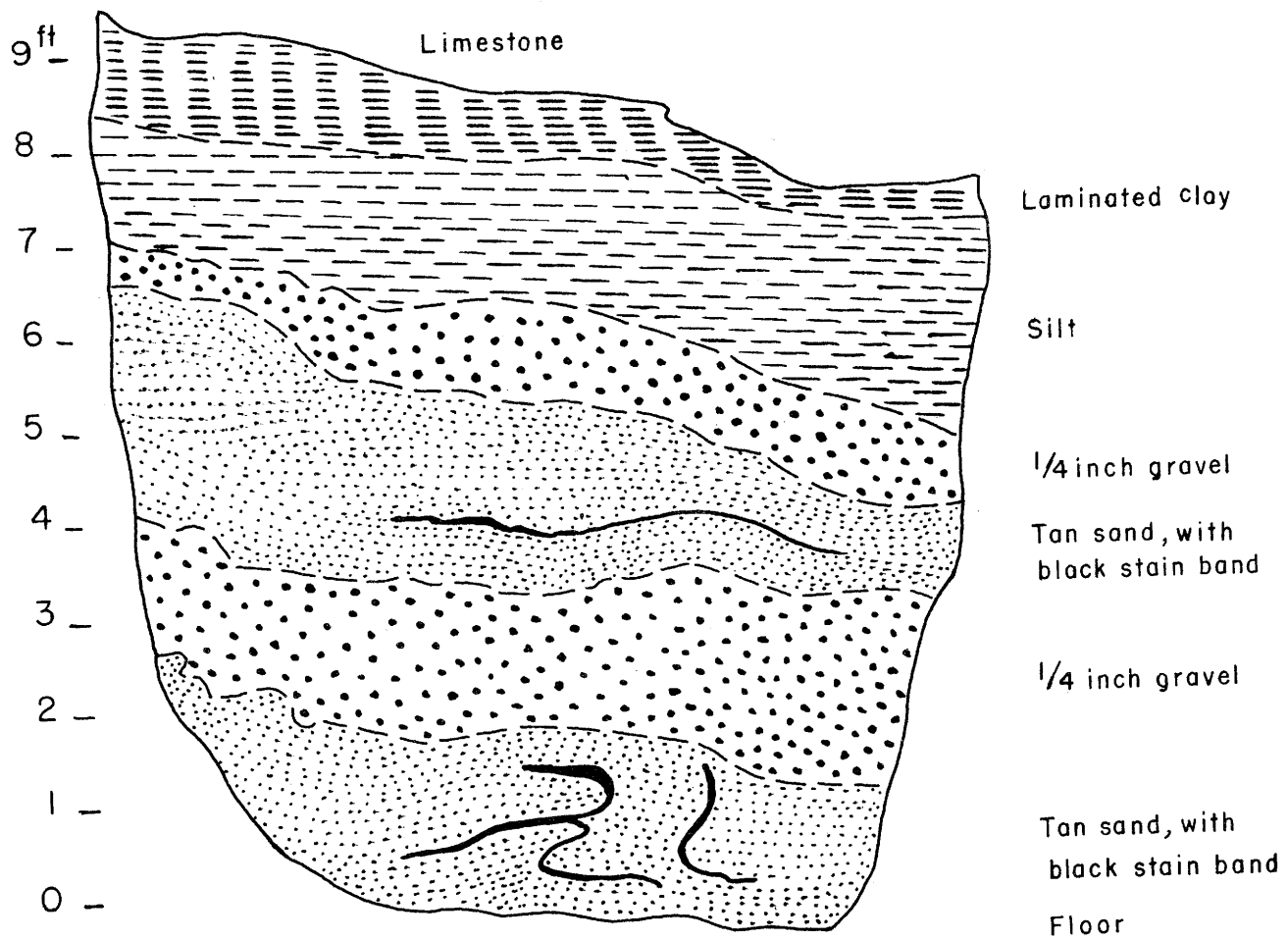


Figure 10. Section of fill at Chaperon.

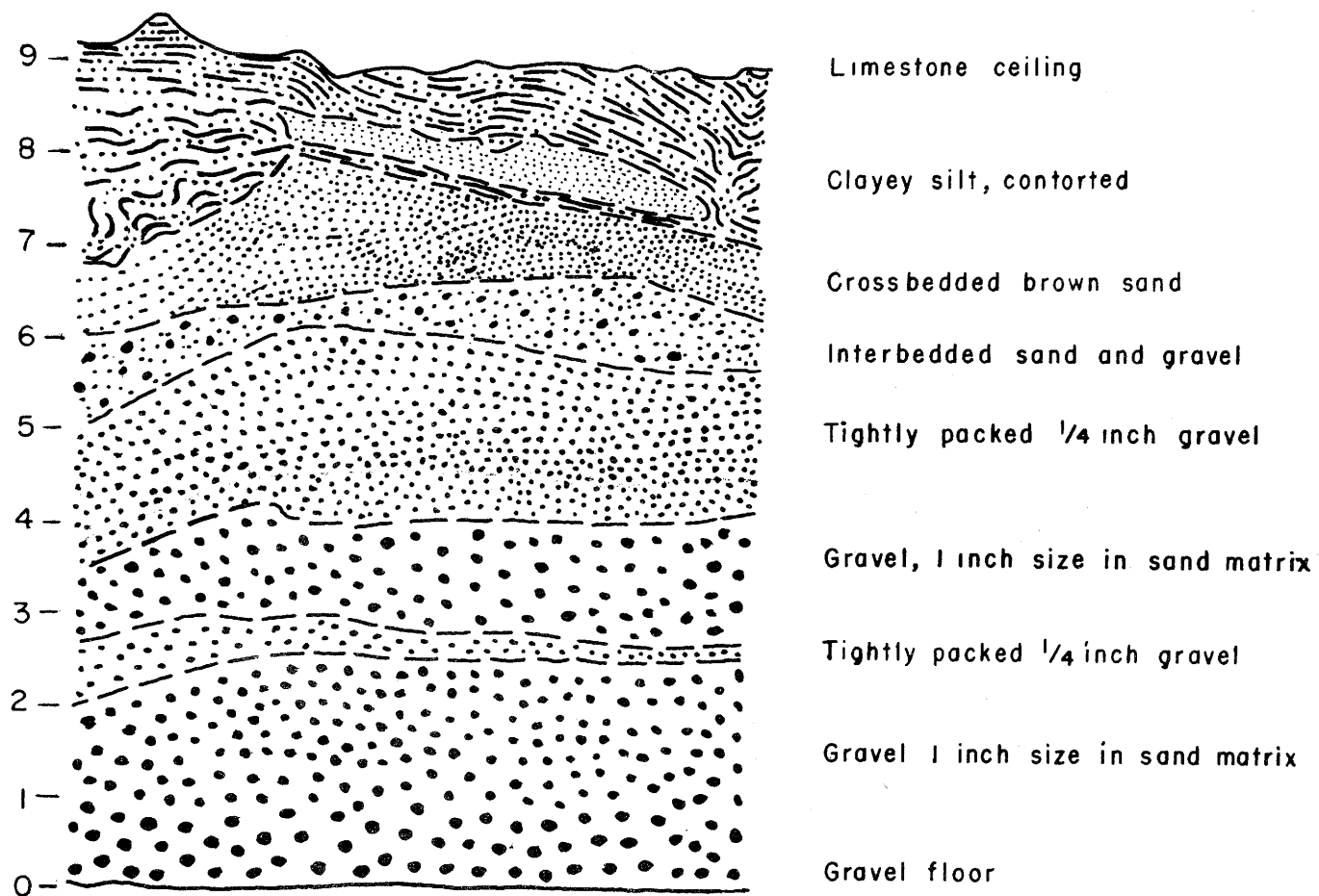


Figure 11. Section of fill at Ladies Room, River hall.

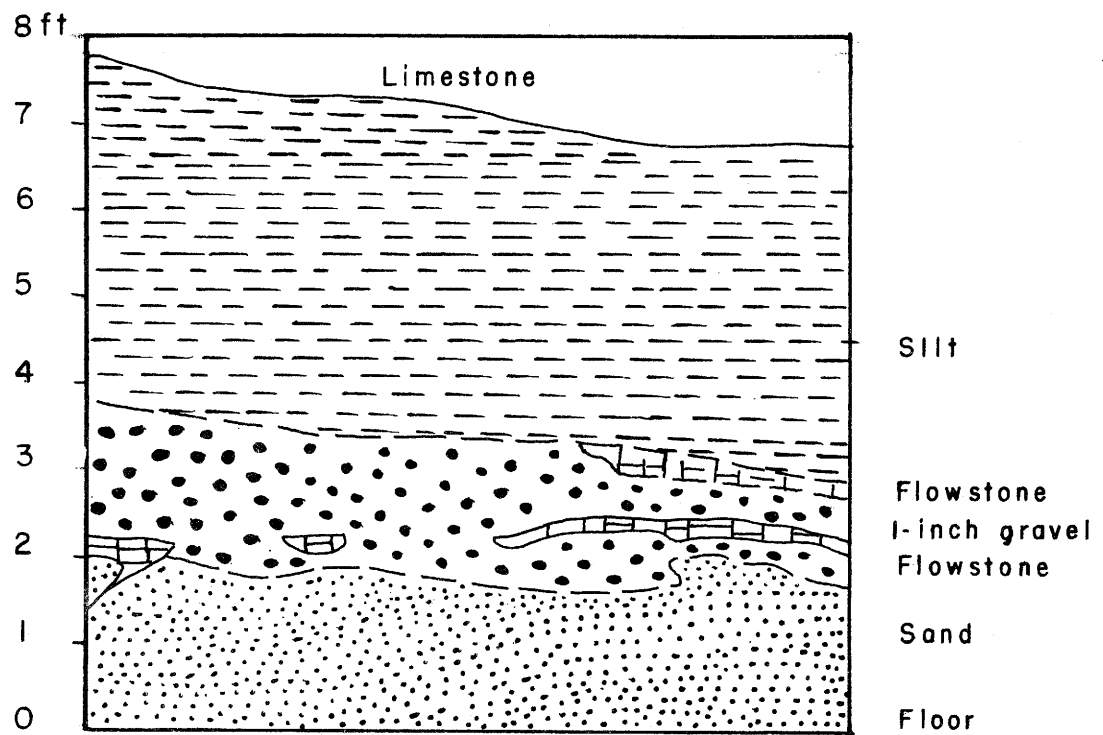


Figure 12. Section of fill at base of elevator shaft.

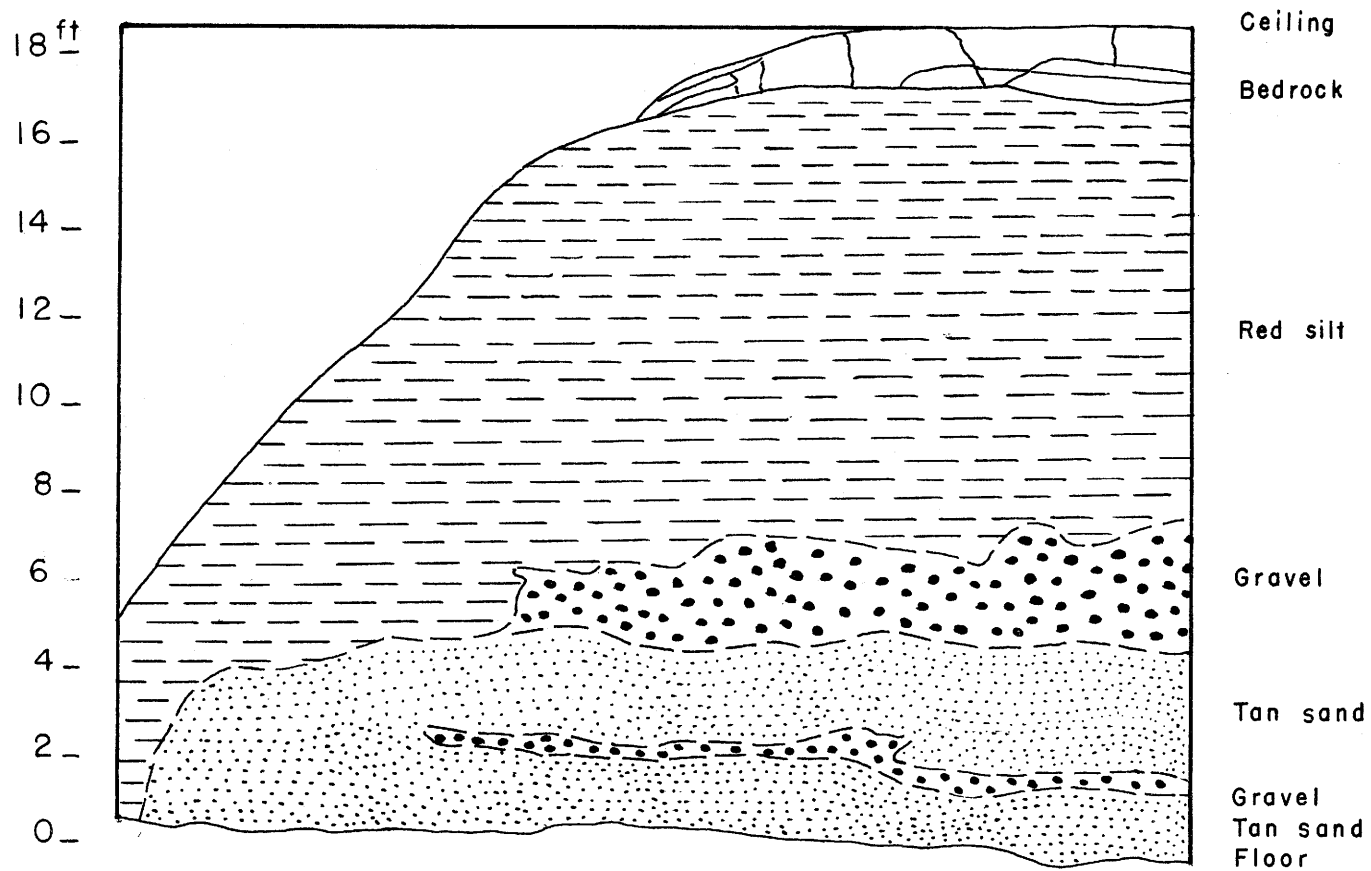


Figure 13. Section of fill at junction of Boone and Kentucky Avenues.

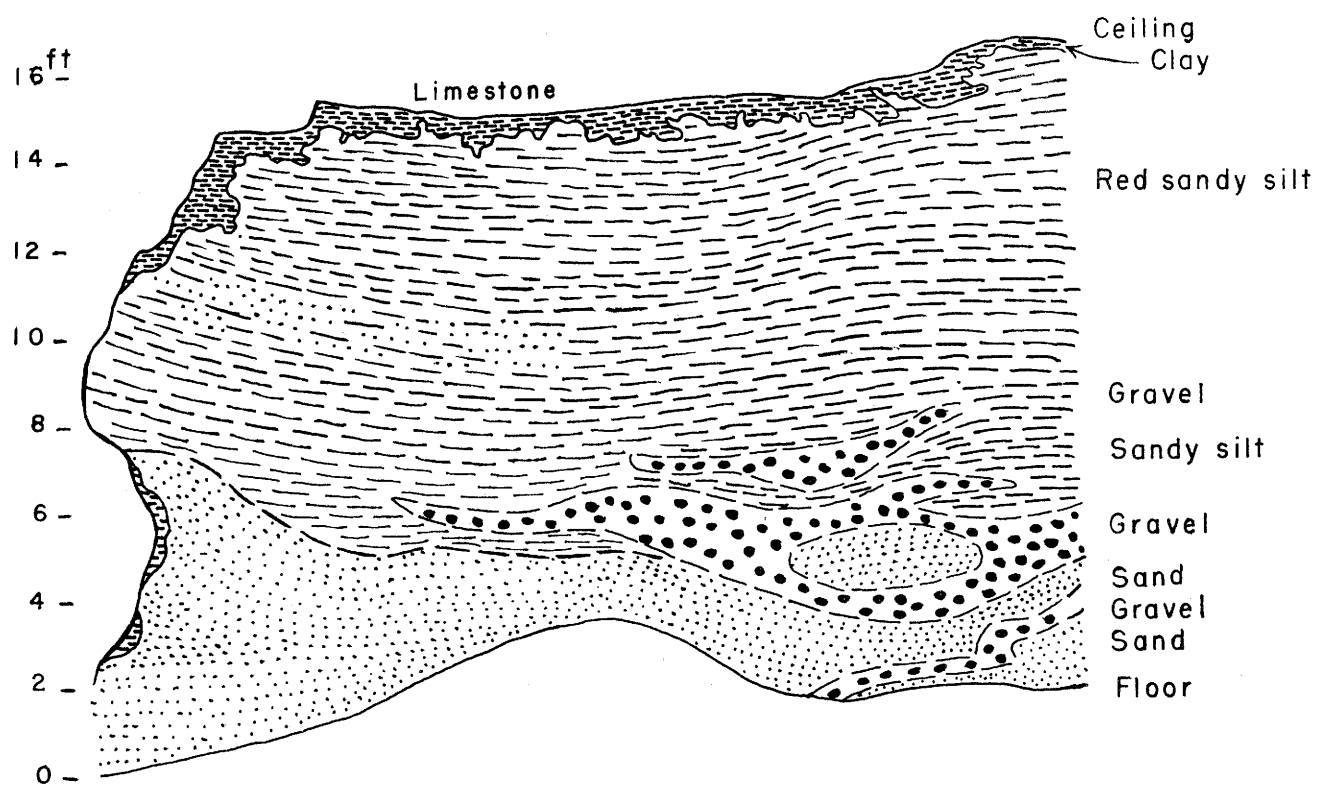


Figure 14. Section of fill at Dismal Valley, Salts Cave.



Figure 15. Cave fill at terminus of Dismal Valley, Salts Cave.



Figure 16. Clay and silt beds at top of section opposite entrance to Gothic Avenue.

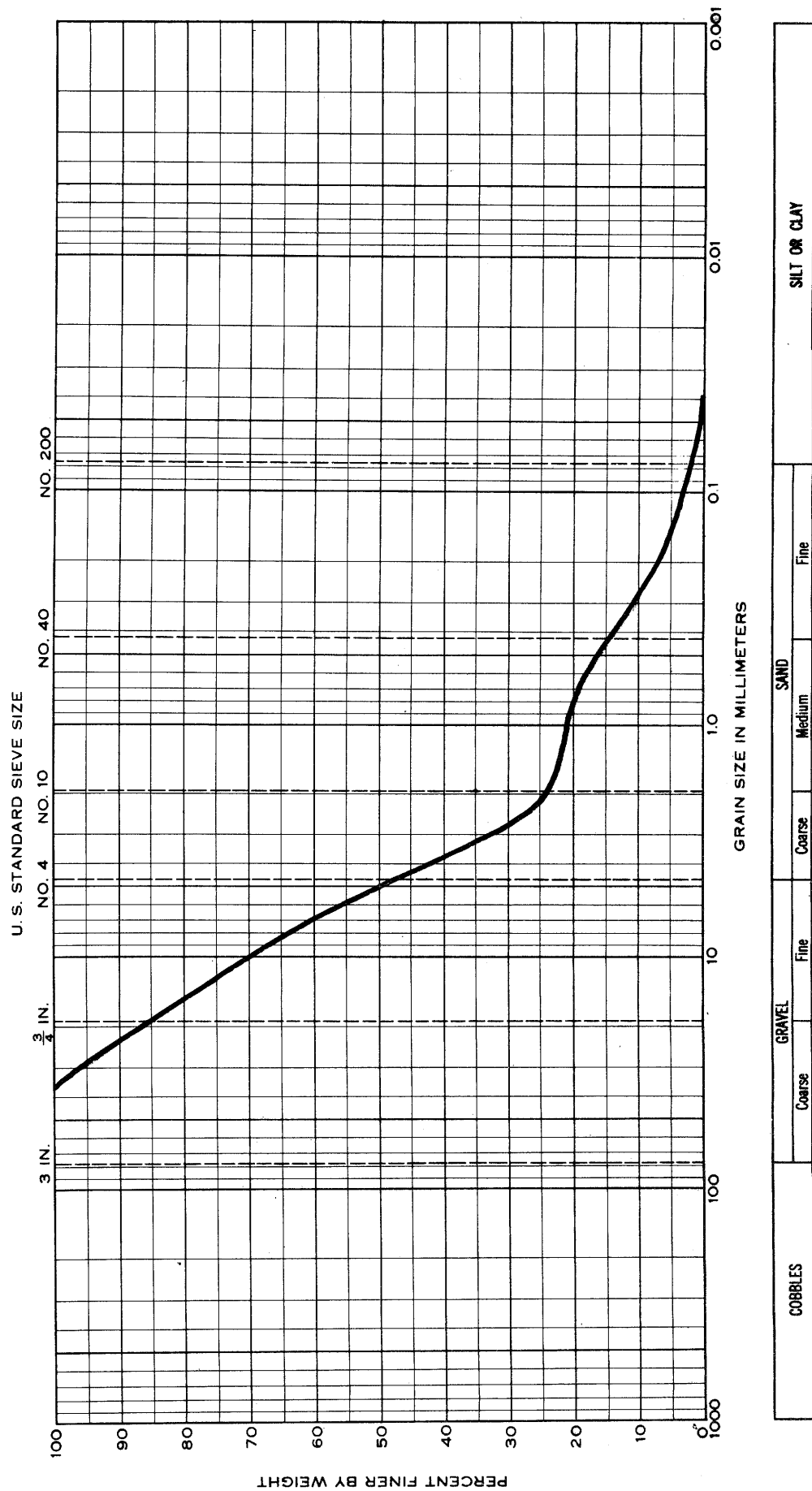


Figure 17. Gradation curve for gravel fill. (sample 46)

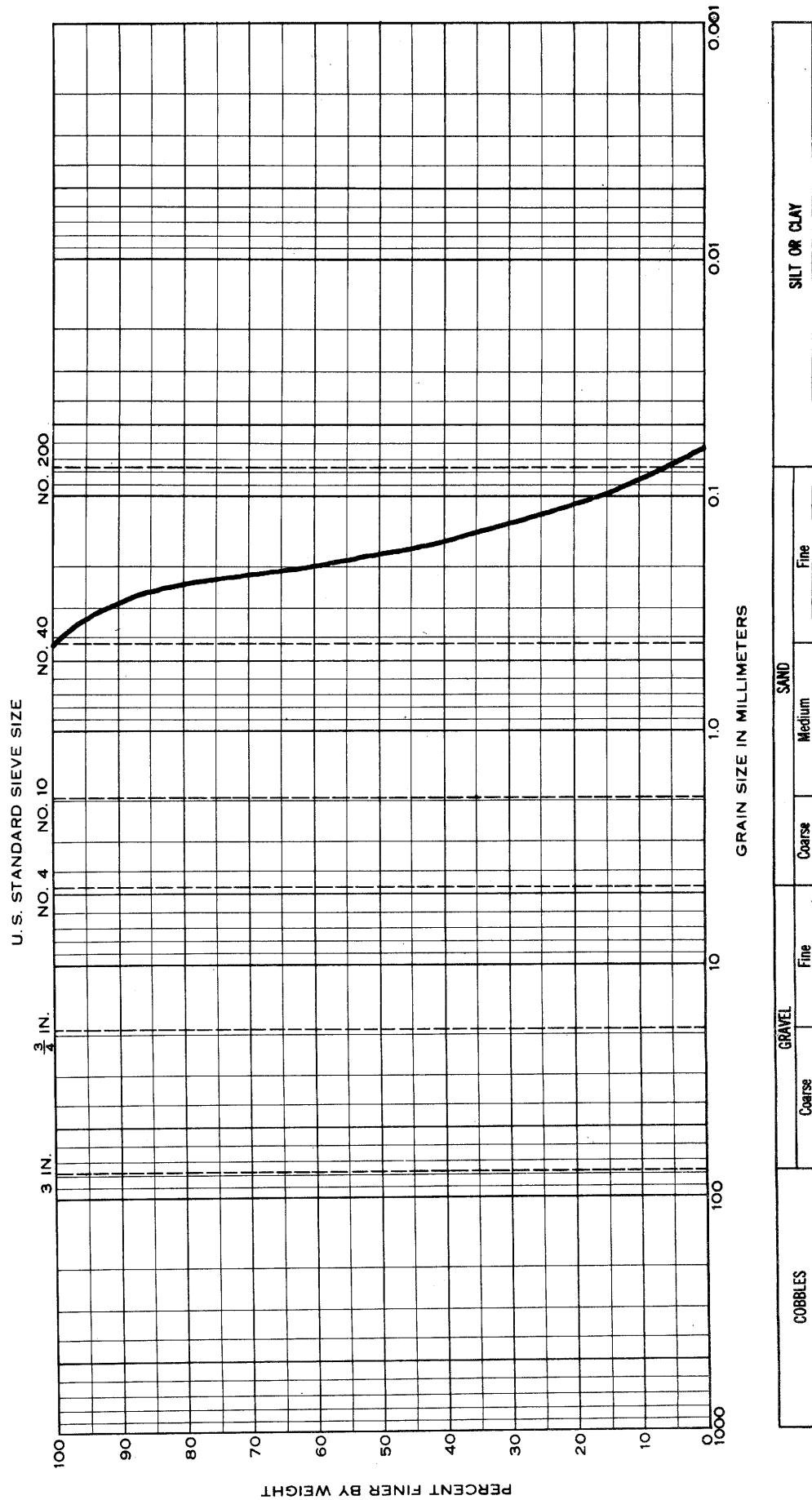
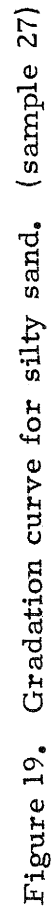


Figure 18. Gradation curve for sand fill. (sample 33)



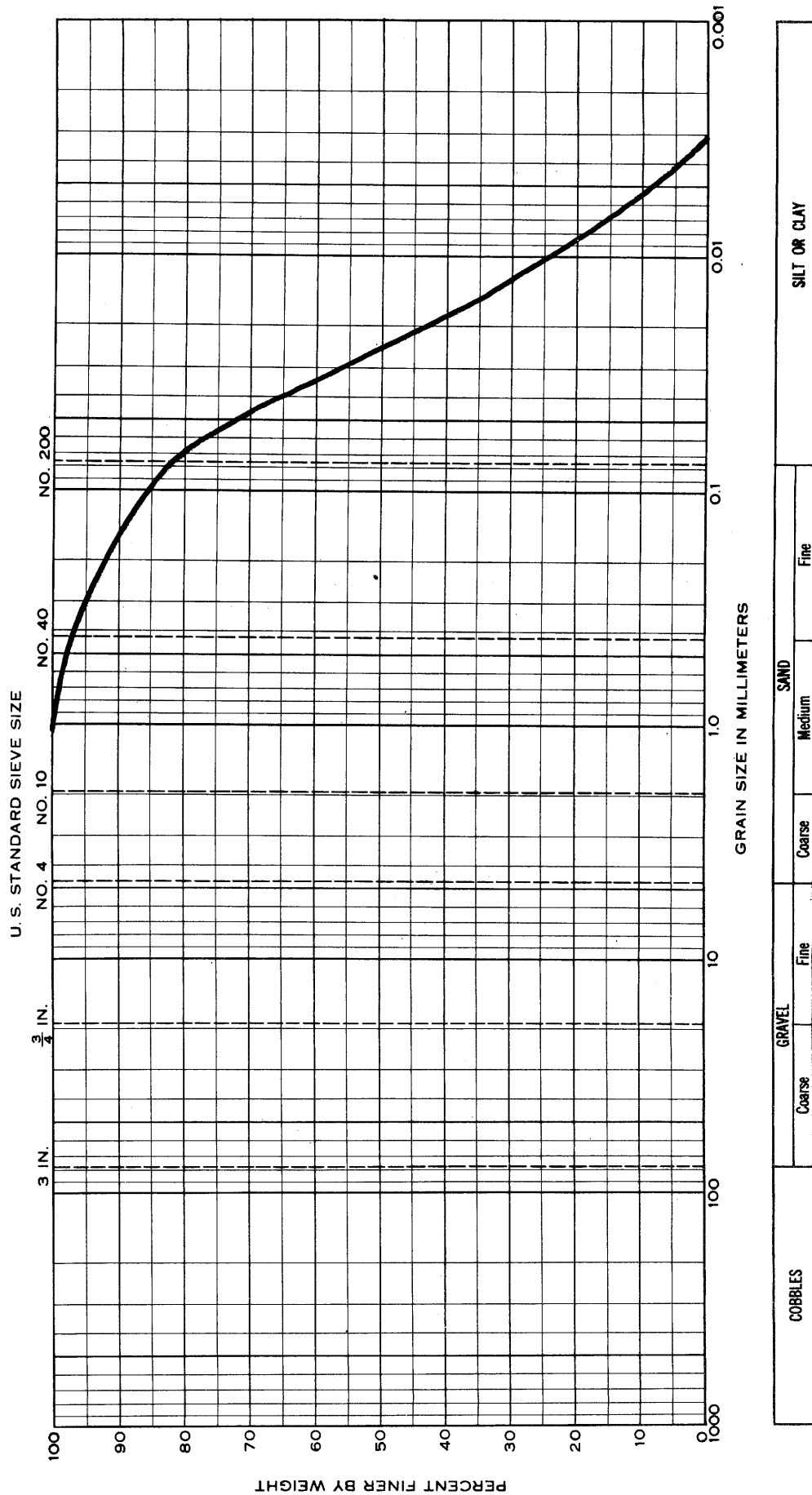
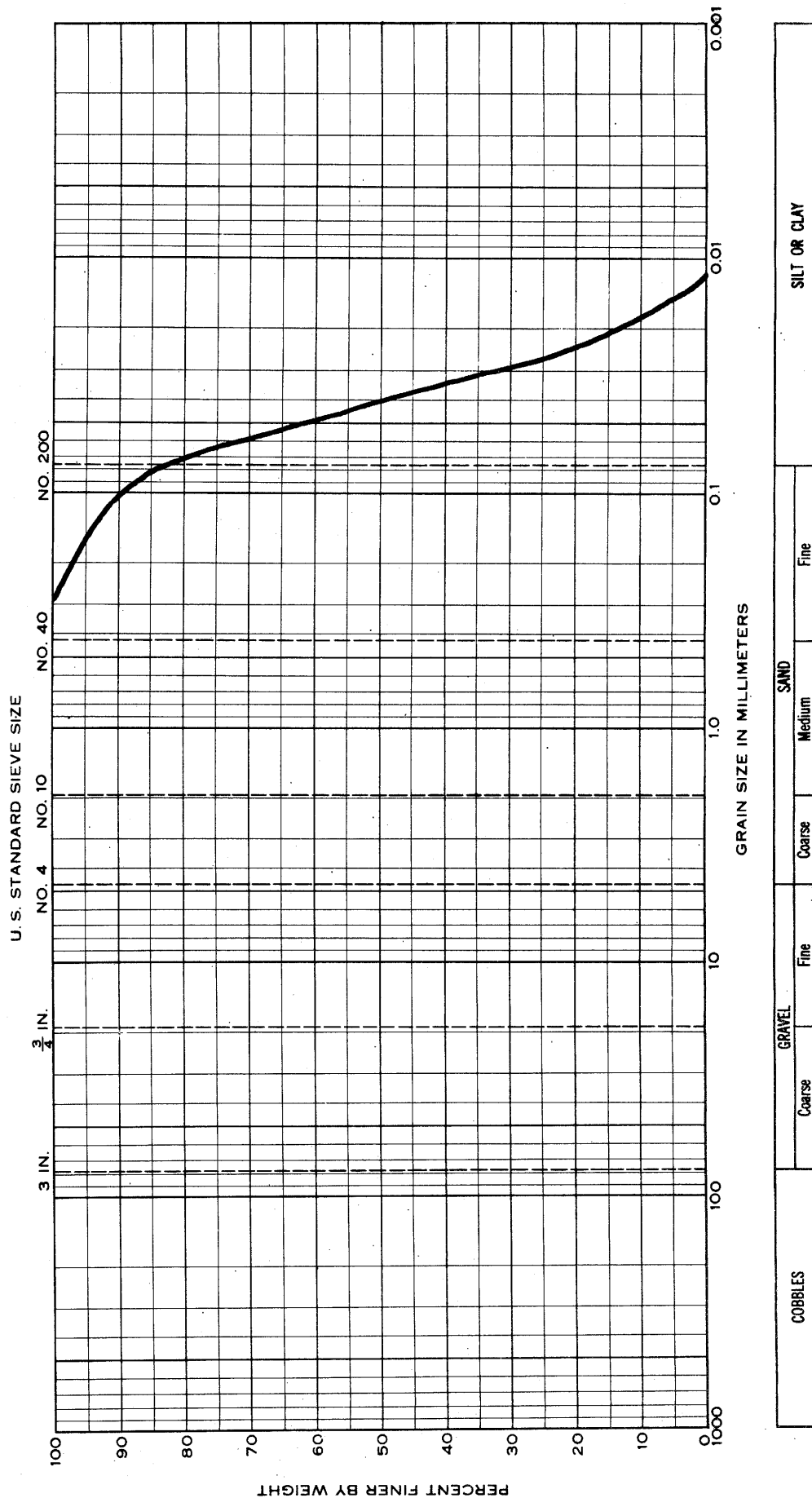


Figure 20. Gratation curve for sandy silt. (sample 313)



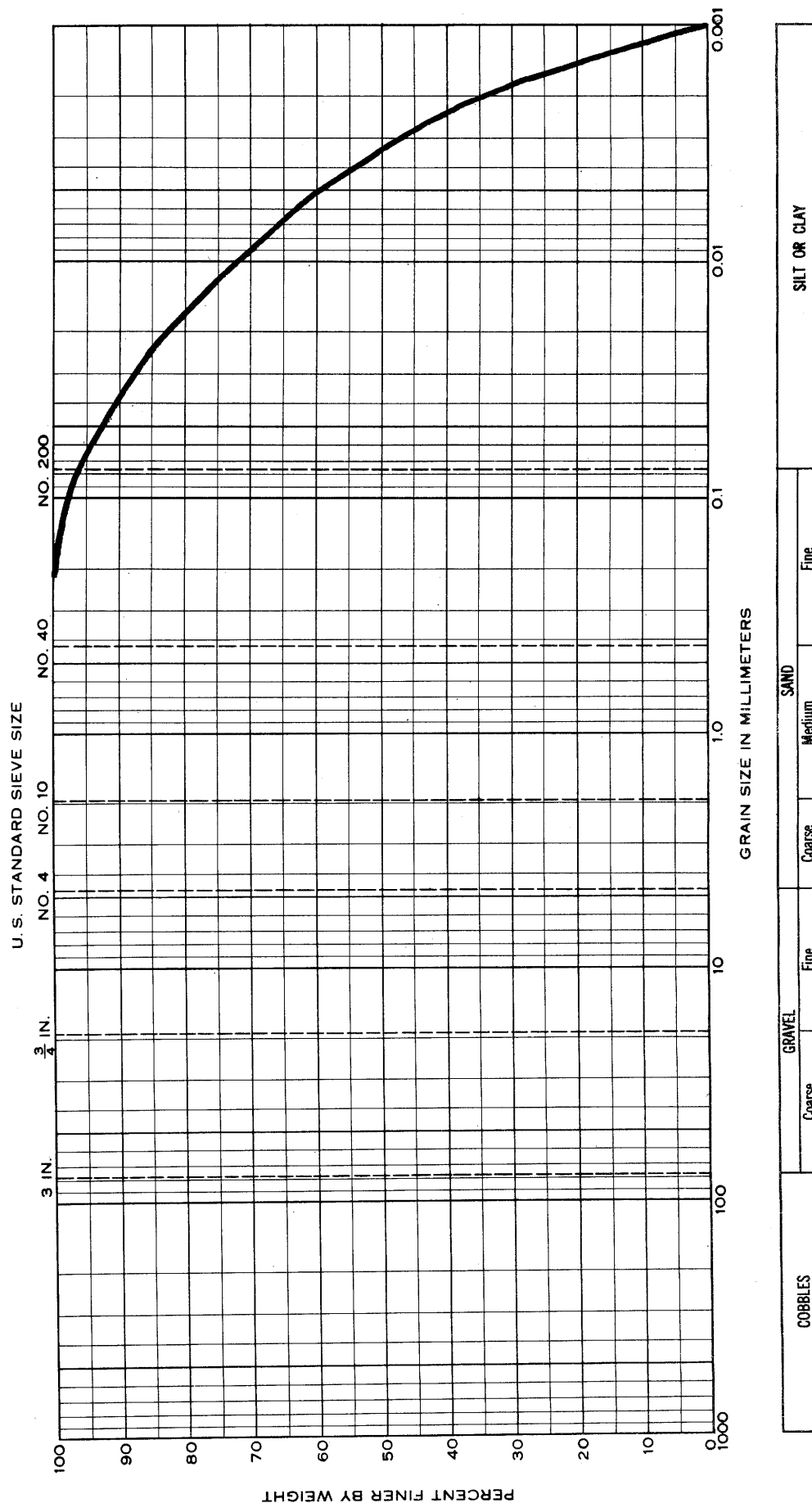


Figure 22. Gradation curve for silty clay. (sample 13)

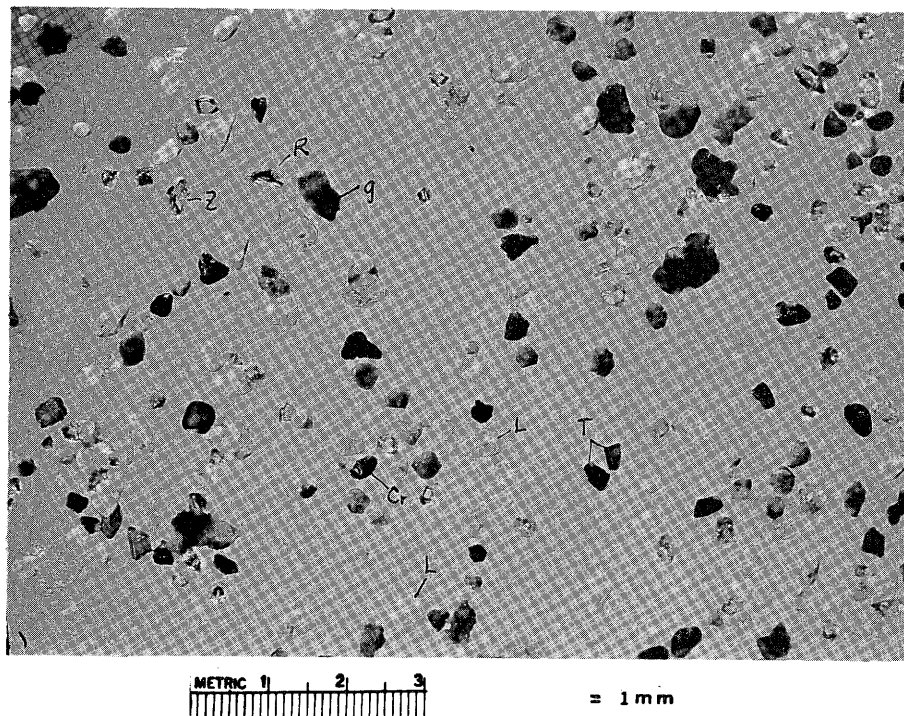


Figure 23. Photomicrograph of heavy minerals from Monroe Sink, sample no. 56. Z-zircon, T-tourmaline, R-rutile, g-goethite, L-leucoxene, and Cr-chromite.

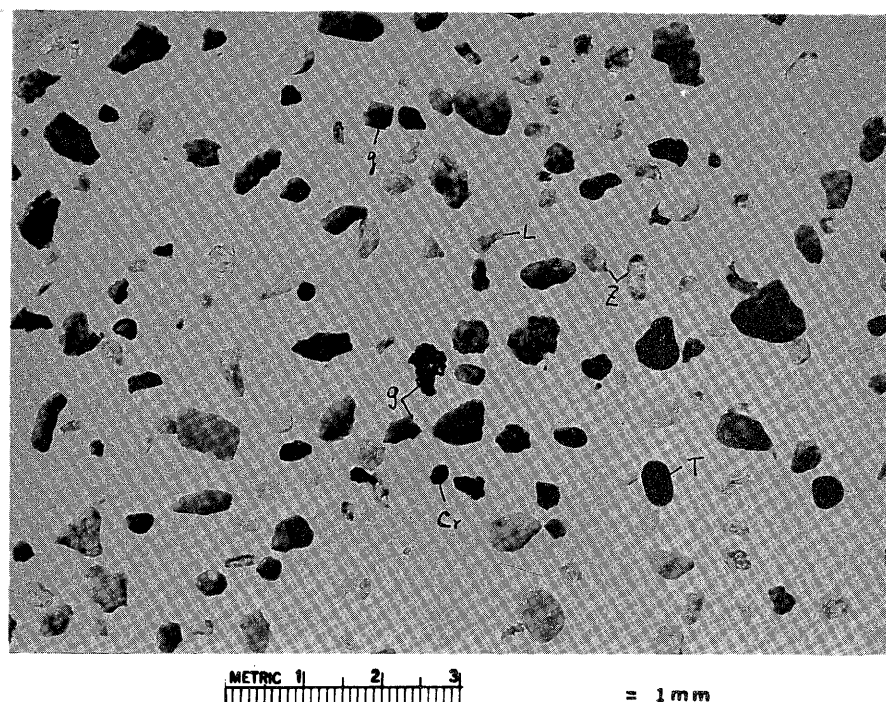


Figure 24. Photomicrograph of heavy minerals from flood-plain alluvium, junction of River Styx and Green River, sample no. 100. Z-zircon, T-tourmaline, g-goethite, L-leucoxene, and Cr-chromite.

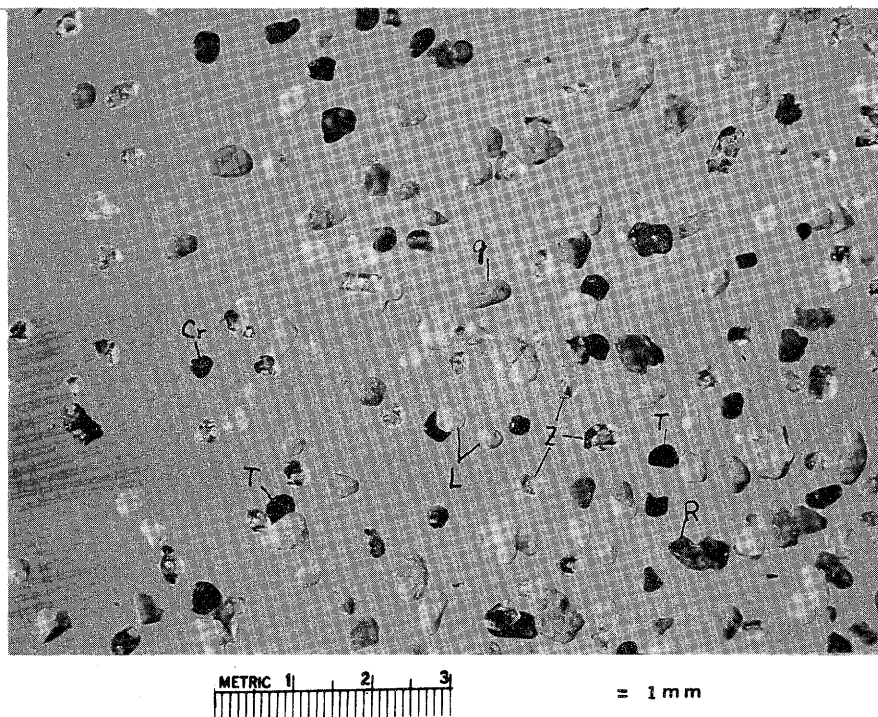


Figure 25. Photomicrograph of heavy minerals of the Big Clifty sandstone, sample no. 200. Z-zircon, T-tourmaline, R-rutile, g-goethite, L-leucoxene, and Cr-chromite.

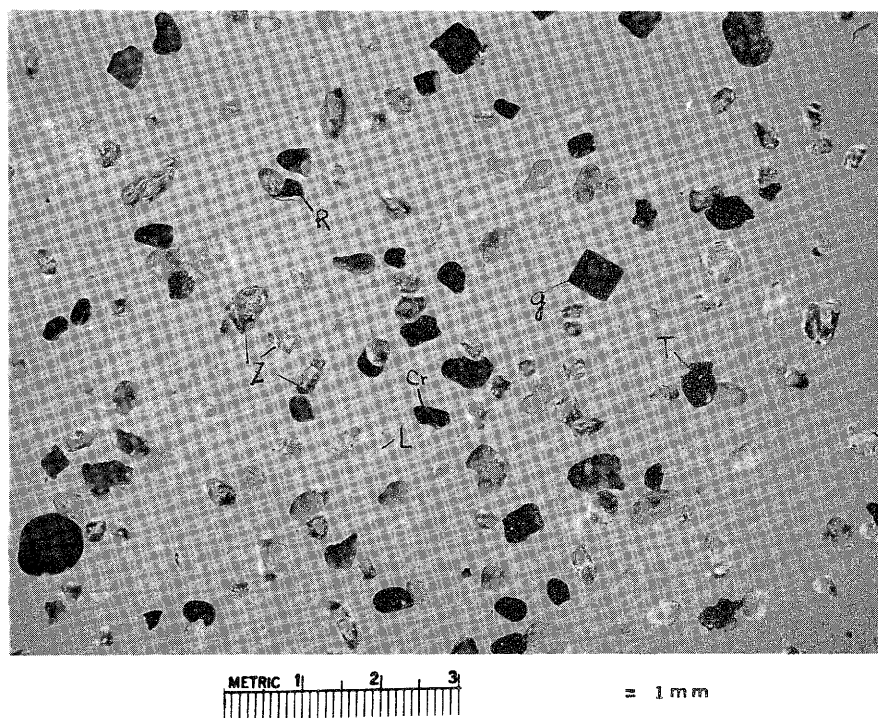


Figure 26. Photomicrograph of heavy minerals of low level cave fill, sample no. 316, Echo River, Minnehaha Island. Z-zircon, T-tourmaline, R-rutile, G-goethite, L-leucoxene, and Cr-chromite.

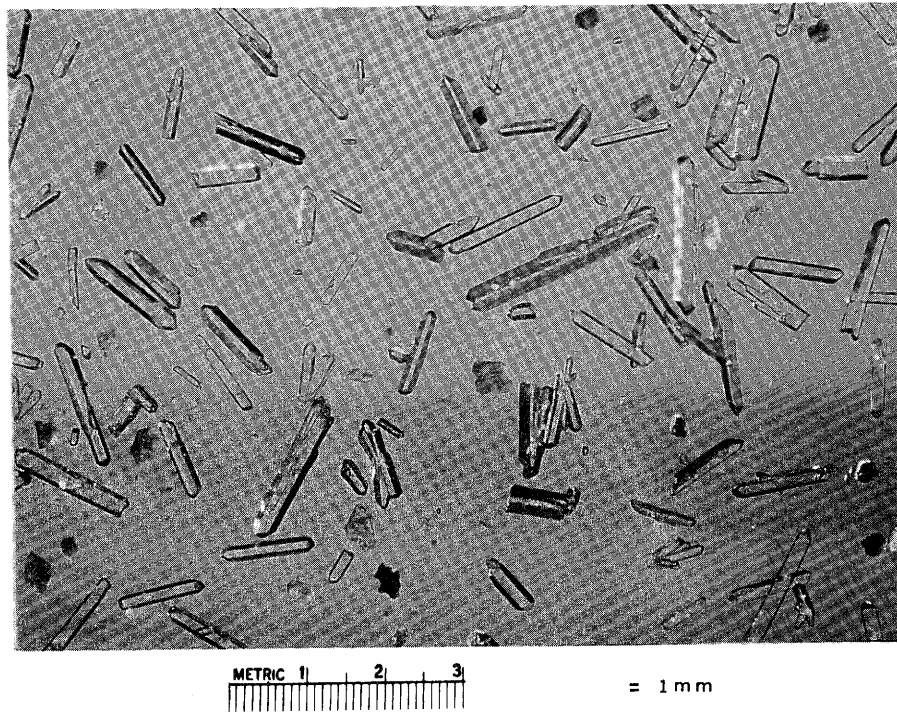


Figure 27. Photomicrograph of heavy mineral fraction of cave fill sample 36 showing the predominance of authigenic celestite.

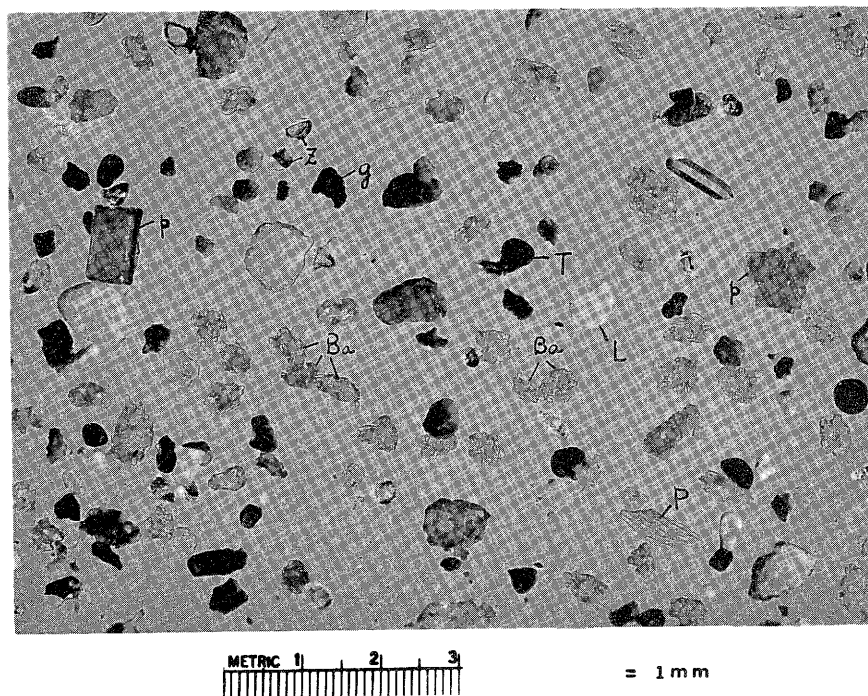


Figure 28. Photomicrograph of heavy minerals of high level cave sediments, sample no. 19, Methodist Church. Z-zircon, T-tourmaline, Ba-authigenic barite, p-collophane, g-goethite, and L-leucoxene.

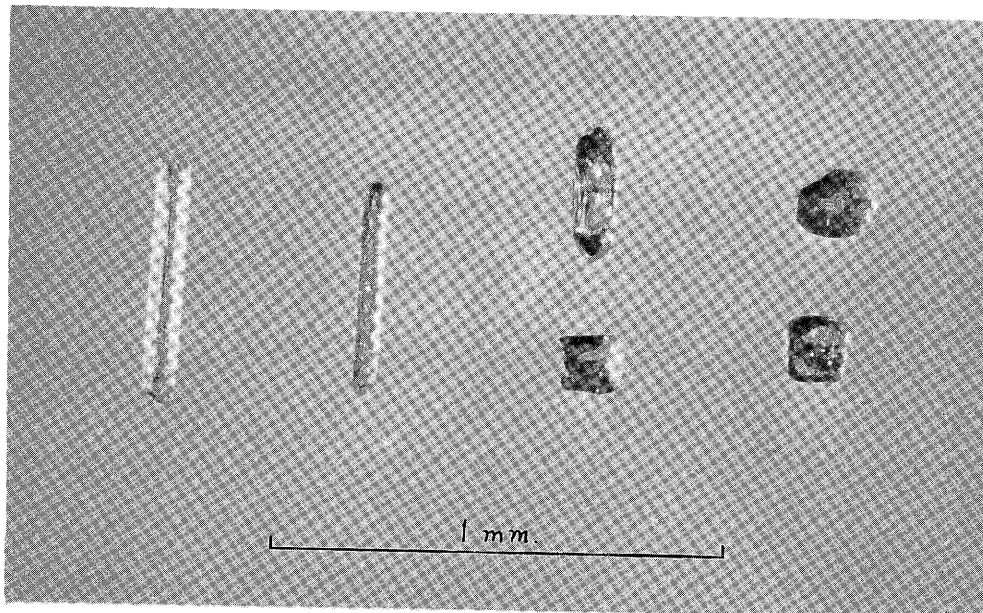


Figure 29. Zircon.

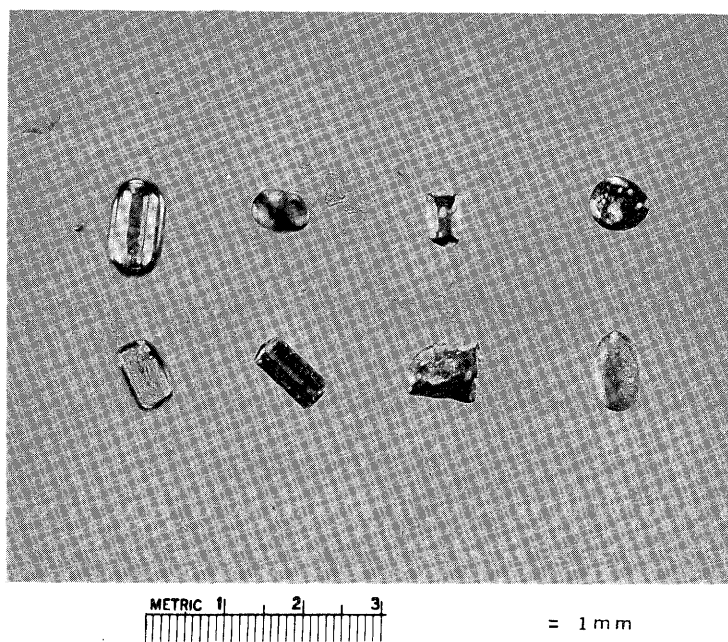


Figure 30. Tourmaline.

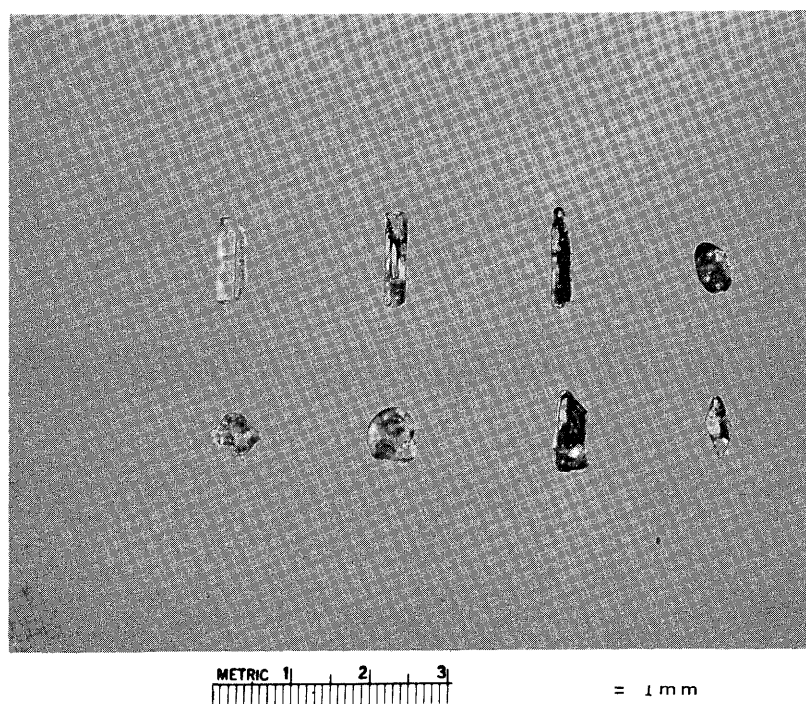


Figure 31. Rutile.

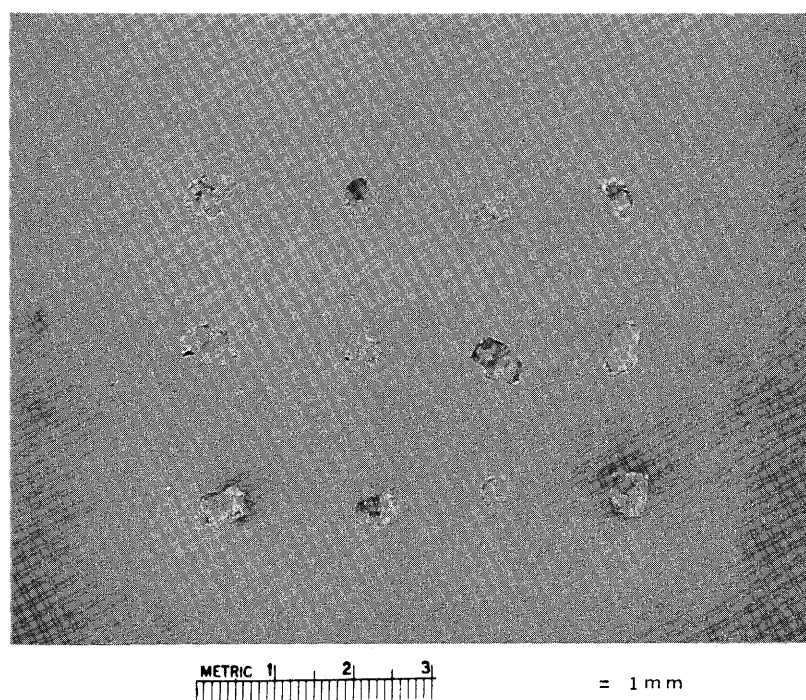


Figure 32. Authigenic brookite.

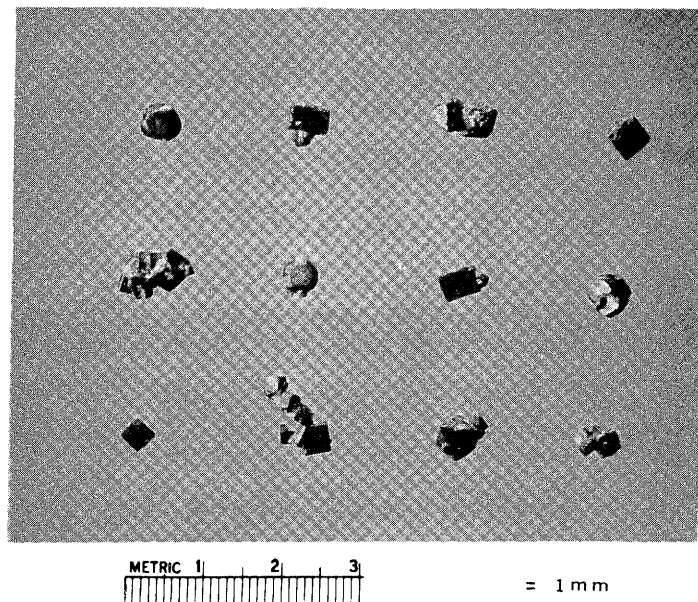


Figure 40. Goethite, pseudomorph after pyrite.

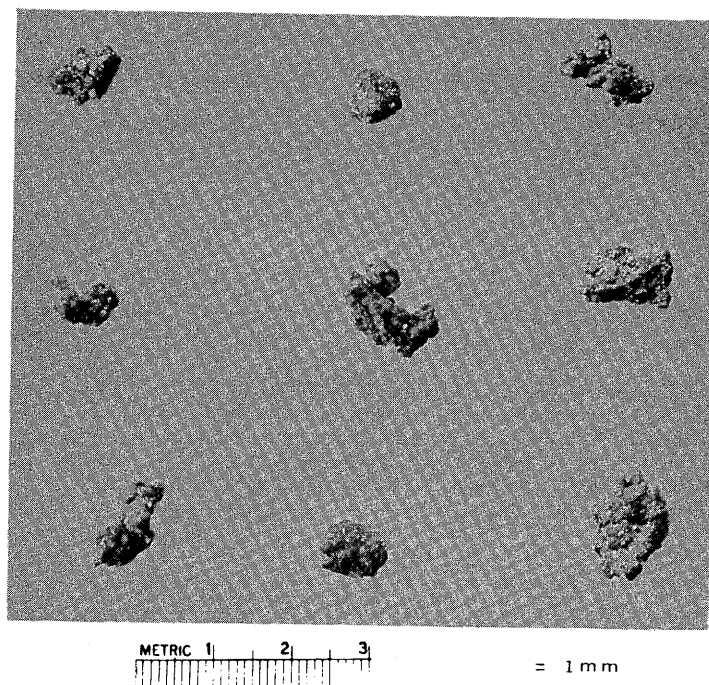


Figure 41. Manganese mineral aggregate containing rancieite (?).

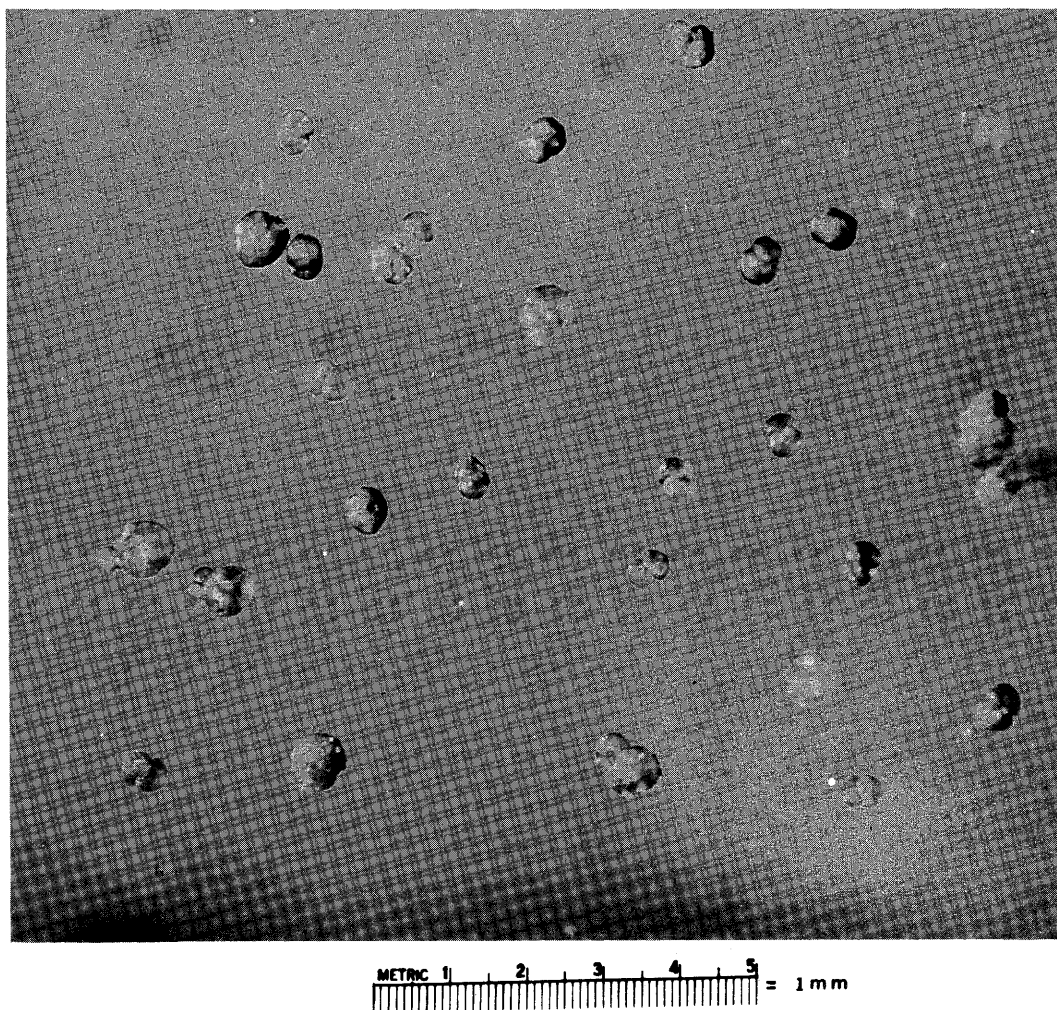
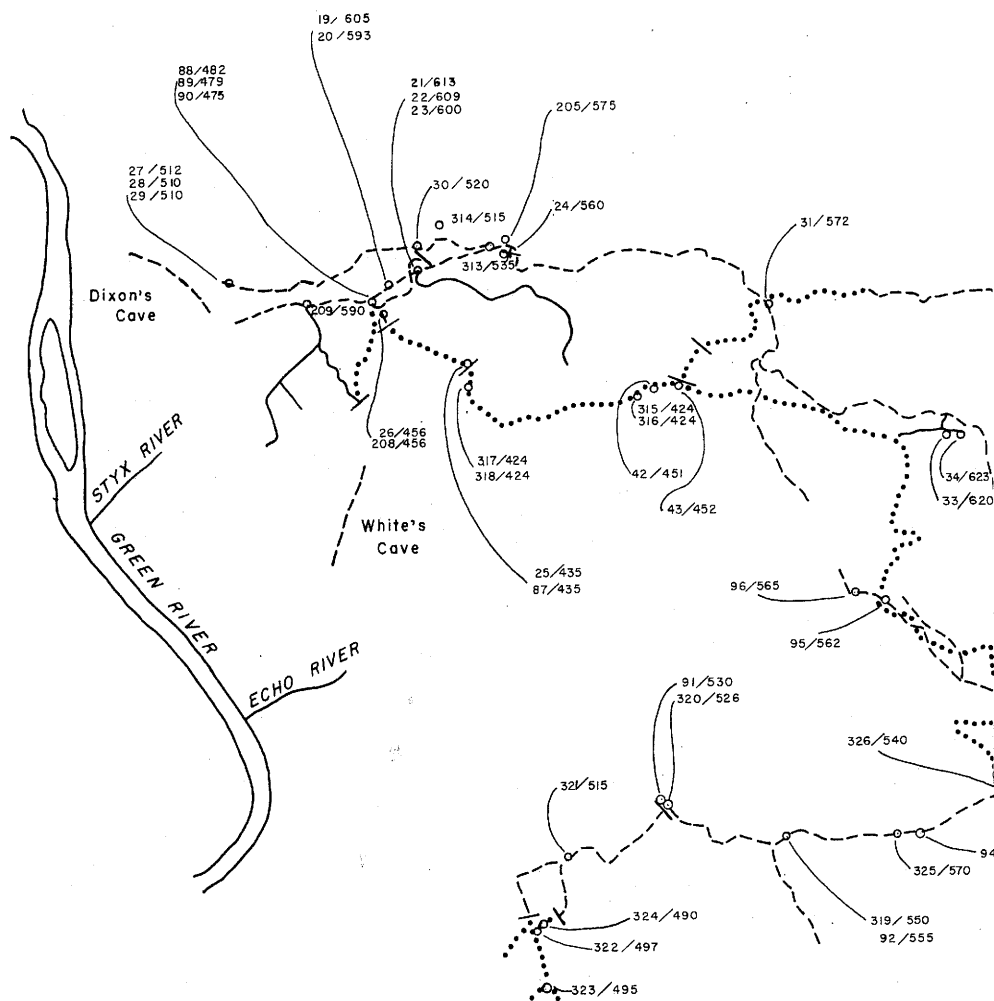


Figure 42. Spherulitic rhodochrosite.

MAMMO

PASSA



MAMMOTH CAVE

GE LEVELS

