<u>Sandstone Talus Caves</u>

<u>of the Central Kentucky Karst</u>

Tomislav M. Gracanin

Presented in partial fulfillment of the

Bachelor of Science Degree in Geology,

June, 1978.

Advisor: Garry D McKenzie

(Dr. Garry McKenzie)

Contents

Introduction	page 1
Acknowledgements	3
Location of Study Area	4
Regional Geology	5
The Sandstone Talus Caves	7
Relation of Sandstone Talus Caves to Limestone Caves	10
Genesis of Sandstone Talus Caves	13
Evolution of Sandstone Talus Caves	19
Suggestions for Further Research	20
Summary and Conclusion	21
References	22
Appendix	23

List of Figures

Figure 1	Location of Mammoth Cave National Park.
Figure 2	Outline of Study Area within Mammoth Cave National Park.
Figure 3	Generalized Geologic Column of the Central Kentucky Karst.
Figure 4	Physiographic Divisions of the Central Kentucky Karst.
Figure 5a	Sandstone Talus Cave in Massive Sandstone.
Figure 5b	Sandstone Talus Cave with Collapsed Overhang and Internal Stream.
Figure 6	Sandstone Talus Cave in Less Competent Sandstone.
Figure 7	Antler Pit (Map).
Figure 8a	Sagging Sandstone in Ceiling of Antler Pit (Photo).
Figure 8b	Thin Bedded Sandstone Supporting Arched Ceiling of Passage to Lower Room in Antler Pit (Photo).
Figure 8c	Limestone Exposed in Floor of Antler Pit (Photo).
Figure 8d	Joint Seperation Between Slumped and In Situ Sandstone Beds, Antler Pit (Photo).
Figure 8e	Entrance of Antler Pit (Photo).
Figure 9	Cave #11 (Map).
Figure 10	Deer Park Avenue Hollow Cave (Map).
Figure 11	Rebel Rubble Cave (Map).
Figure 12a	Joint in Ceiling of Rebel Rubble Cave (Photo).
Figure 12b	Collapsed Sandstone in Ceiling and on Steep Slope in Rebel Rubble Cave (Photo).
Figure 12c	Shaft with Waterfall in Rebel Rubble Cave (Photo).
Figure 13	CCC Quarry Cave (Map).
Figure 14	Cave, in East End of Strawberry Valley (Map).
Figure 15	Slumped Sandstone Exposed in Wall of Talus Cave Above Cathedral Domes Entrance (Photo).
Figure 16	Cross Section of Sink with Associated "Fissure" Talus Cave.
Figure 17a-d	Evolution of a Sandstone Talus Cave.
Appendix	Cave Map Symbols.

Introduction

Features herein defined as sandstone talus caves are common geomorphic features at Mammoth Cave National Park and in the surrounding area. Their frequent occurrence, restriction to a narrow stratigraphic horizon, association with even more frequent depression, slumps and impassably small holes in the same horizon, and characteristic morphology led to this investigation into their genesis and how they might be related to the complex cave system developed below. It was determined empirically that lithology and hydrology are important principle factors in cave morphology and distribution. Sandstone talus caves heve been found in intimate association with shafts, particularly migrated shafts. In such cases their genesis seems to be intimately associated with the development of these shafts and other voids, indicating that they can form an integral part of the local vadose water inputs to the numerous vertical shafts in the cave systems. Sandstone talus caves in association with these shaft systems, constitute one of the principal mechanisms by which erosion and retreat of the sandstone cap take place.

Sandstone talus caves of the Central Kentucky Karst have been mentioned only once previously in literature. Wilson (1976), briefly describing them and associated holes blowing air above the sandstone-limestone contact, suggests that they are water input points for the vertical shafts and that they form by collapse of the Big Clifty Sandstone into solution voids in the Girkin Formation.

Several authors have discussed the distribution and significance of vertical shafts relative to the edge of the sandstone cap. Pohl (1935, 1955) first noted the close relationship of vertical shafts and the edge of the sandstone cap rock, especially at heads of valleys, developed in the ridge top. He said vertical shafts also aid in the headward erosion of these valleys, because the sandstone, a few feet above the shaft tops, weakens with weathering and collapses. Because of the rapid destruction occuring in them, shafts are very recent features. Rubble-filled sinkholes below the edge of the sandstone cap were interpreted to be filled shaft remnants.

Quinlan and Pohl (1967), state that vertical shaft development is restricted to an approximately two-hundred-foot wide zone at the edge of ridges by impermeable shale and sandstone cap rock. While shaft development may be especially strong near valley heads, it occurs along the entire perimeter of the ridges. The karstification below the sandstone-limestone contact can cause catastrophic collapse into the shafts, where the material is ground up and transported by water through the drains finally emerging as dissolved load and as sand and silt into springs along the Green River. Voids formed in this manner need not have surface expression as depressions or sinkholes.

Brucker et al. (1972) restates the views expressed by the authors discussed above, emphasizing the concentration of the shafts under reentrant valleys and the fact that they are young features associated with the present landscape. They also indicate vertical shafts are formed by one of two types of chemically distinct vadose water (discussed by Thrailkill, 1968): 1) vadose flows, undersaturated with respect to calcite, and 2) vadose seep, which are saturated with respect to carbonate and deposit tavertine.

Field work for this study has been carried out as part of the on-going Cave Research Foundation (CRF) surface reconnaisance project begun in 1974. Field notes and sketches of the sandstone talus caves and other features were prepared principally by William L. Wilson and Tomislav M. Gracanin. Surveys of some of the larger caves were completed by CRF field survey parties.

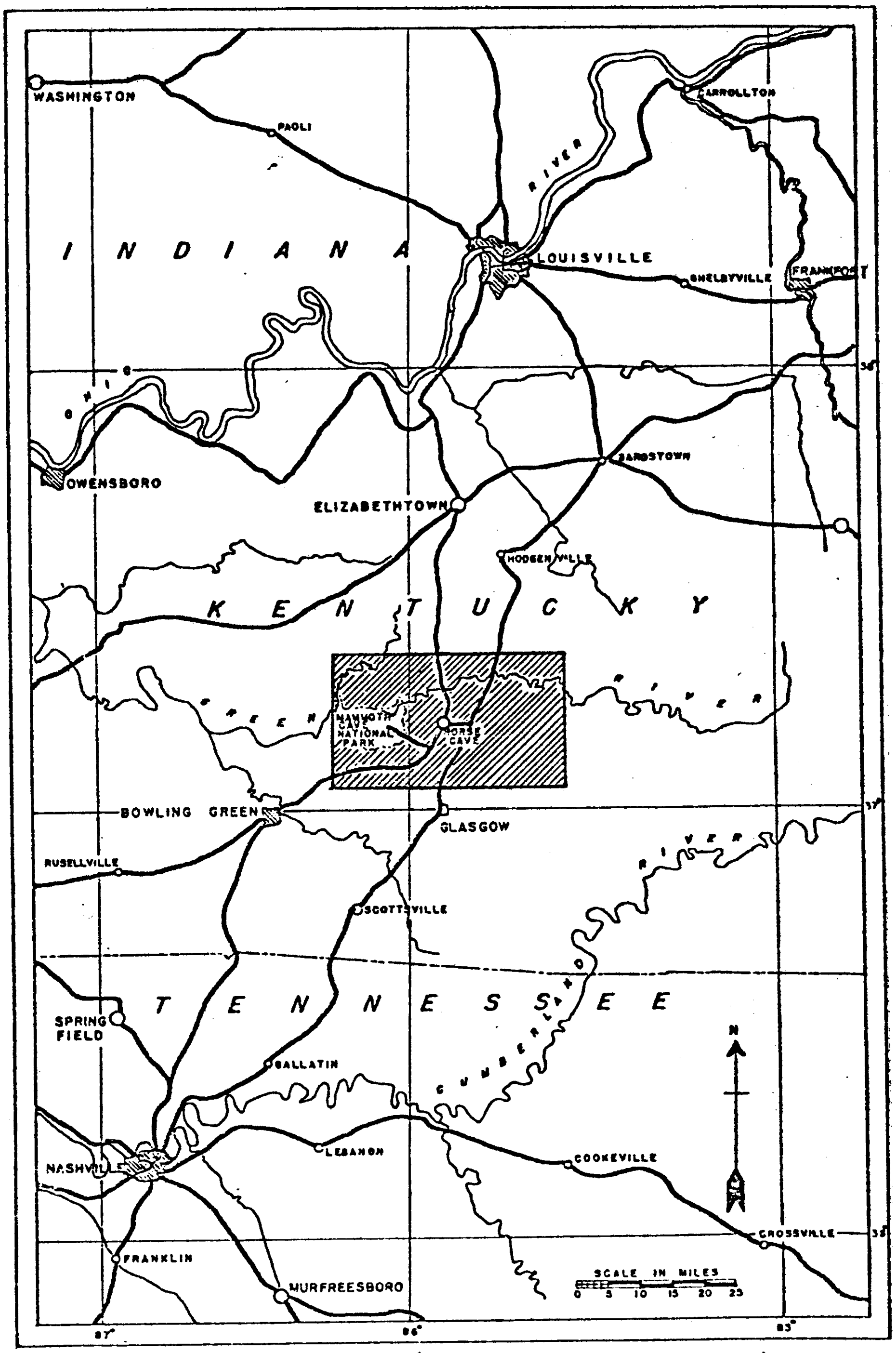
Field data compiled in the surface reconnaissance notes originally strongly reflected the principle purpose of finding new cave entrances, and evolved toward gathering data of more general geologic interest. Described features, principally sandstone talus caves and sinkholes, were located on ten-foot contour intervals 1:12000, one and one-half minute quadrangles enlarged fromt the 1933 "Mammoth Cave National Park" map by Monbeck et al. Detailed descriptions, plan and cross-section sketches of each feature were made. The data were then placed in the surface reconnaissance file for future reference.

Acknowledgments

Special thanks go to Stephen Wells for stimulating interest in the original project and to William L. Wilson, his wife Diane, and all the other people who helped with the field work. The support of the Cave Research Foundation and the use of their facilities at Mammoth Cave National Park is greatly appreciated and gratefully received.

Location of the Study Area

Research for this paper was carried out at Mammoth Cave National Park, Kentucky. The park is located approximately ninety miles south of Louisville, Kentucky and a hundred miles north of Nashville, Tennessee (Figure 1). The study area is located in Barren, Edmonson and Hart Counties, in the southeast portion of the national park (Figure 2). Field work was carried out chiefly on the eastern portion of Joppa Ridge, north flank of Pewee Ridge (unofficial name), and Strawberry Valley (including Strawberry Knob). Deer Park Avenue Hollow, the western end of Doyle Valley and part of Katy Pace Valley were also examined.



(from Pohl, 1955, p. 2)

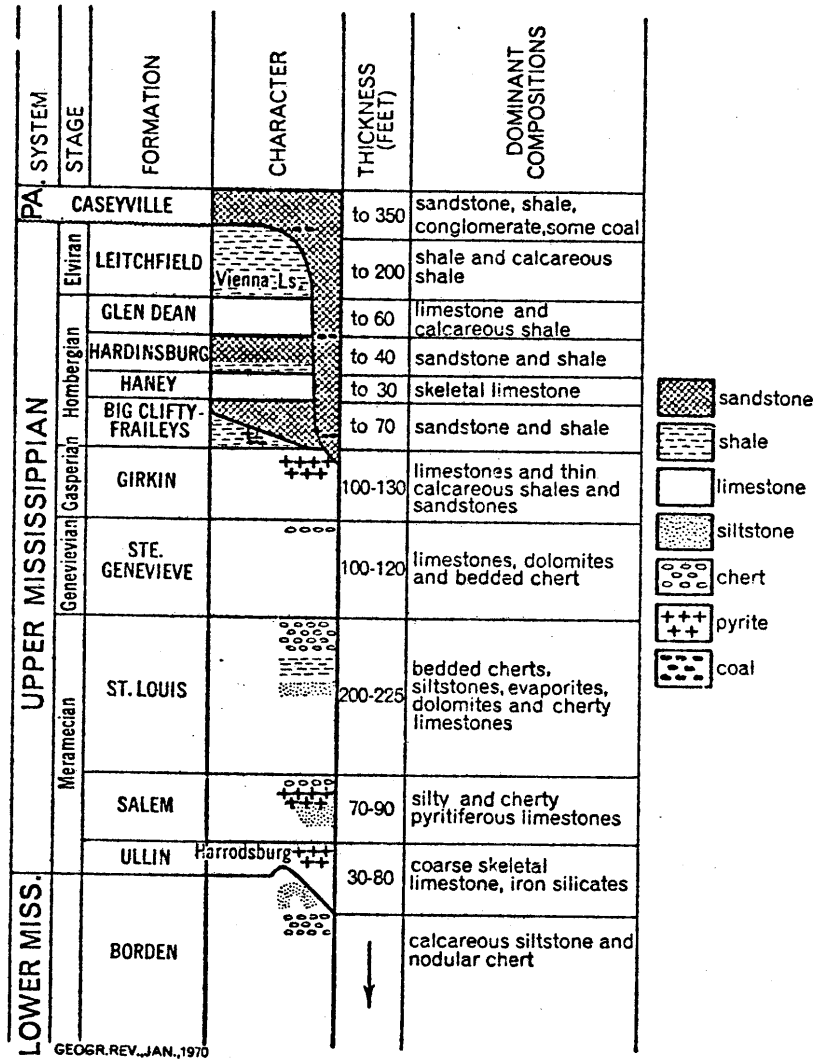
Figure 1

Regional Geology

Mammoth Cave National Park is situated in the Central Kentucky Karst on the western flank of the Cincinnati Arch and southeast edge of the Western Kentucky Coal Basin. The strata dip approximately thirty to seventy feet per mile to the northwest (Palmer, personal communication). Units of Late (Middle to Late) Mississippian and Early Pennsylvanian age crop out. In general the statigraphy consists of a thick carbonate sequence capped by clastic seciments (Figure 3). At the base of the sequence the Meramecian St. Louis and St. Genevieve Limestone crop out. The Mississippian Chester series overlies these. It includes the Girkin Formation, Big Clifty Sandstone and Haney Limestone members of the Golconda Formation, the Hardinsburg Sandstone and Glen Dean Limestone. A major interregional unconformity seperates the Mississippian and Pennsylvanian Systems (Sloss 1968). Only the lower part of the Pennsylvanian Caseyville Formation is still present in the study area's vicinity.

The geomorphic features in this part of Kentucky are strongly influenced by the lithology and differential erosion underlying rock units. The Central Kentucky Karst, in which the study area lies, extends from Munfordville west to the Barren River, and lies between the Green River and the Glasgow Upland to the south. It encompasses three regional physiographic divisions, the Pennyroyal Plateau, Dripping Springs Escarpment, and the Mammoth Cave Plateau (Livesay 1953) (Figure 4). The Mammoth Cave Plateau was called Chester Cuesta by Brucker et al. (1972). Chester Cuesta will be used here.

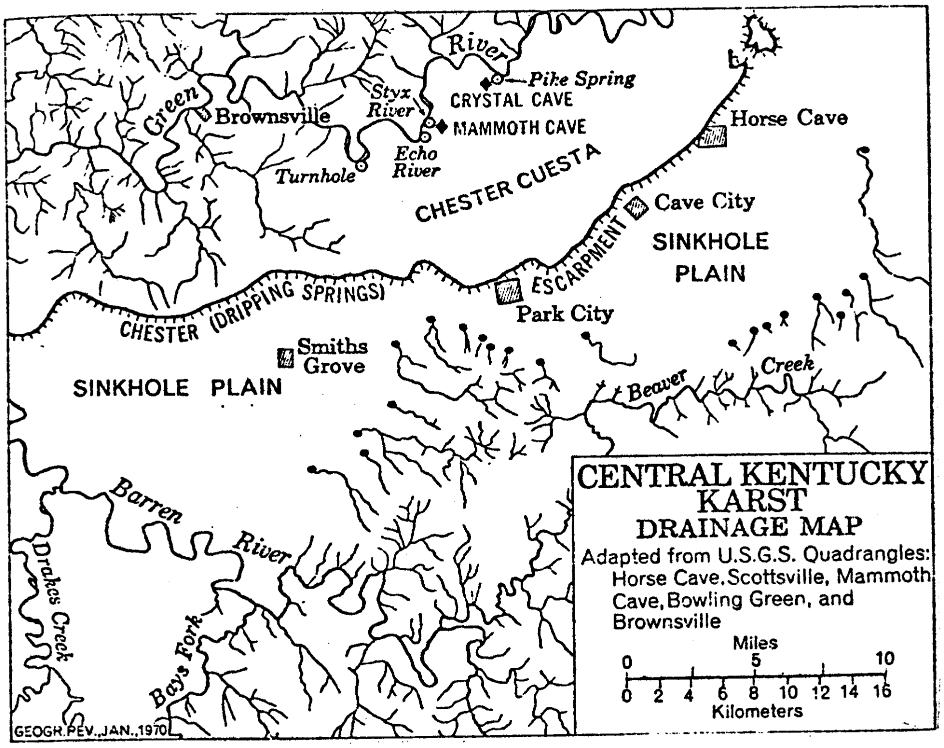
Stratigraphy of the Central Kentucky Karst Area



(from White, et al., 1970, p 93)

Figure 3

Physiographic Units Of The Central Kentucky Karst



(from White, et al., 1970, p 95)

Figure 4

In the Central Kentucky Karst, the Pennyroyal Plateau is developed on the St. Louis and St. Genevieve Limestones. Due to extensive karstification of the soluble limestone, a high sinkhole density and a well integrated underground drainage network had been developed. The plateau is locally known as the Sinkhole Plain..

The rugged Dripping Springs Escarpment to the north and west separates the Sinkhole Plain from the Mammoth Cave Plateau. The Chester Cuesta is developed on upper Chester units, and is principally supported by the resistant Big Clifty Sandstone. The steep erosional scarp to the Sinkhole Plain ranges from two hundred to three hundred fifty feet high. Behind the main escarpment the Big Clifty Sandstone capping the Mammoth Cave Plateau south of the deeply entrenched Green River has been extensively breached.

Wide sinkhole valleys have developed in the (soluble) Girkin Formation and St. Genevieve Limestone, leaving behind long often narrow plateau remnants known as ridges. The degree of dissection of the plateau corresponds approximately with Lobeck's (1928) mature stage for a limestone plateau. Drainage on the Chester Cuesta is principally surficial near the ridgetop perimeters and entirely subterranean in the valleys. Surface streams and perched vadose flow sink immediately, or soon after flowing from the sandstone cap, into the valleys. Water descends to near baselevel in cylindrical or migrated shafts, joins phreatic streams and rises again in springs along the Green River.(Pohl, 1955; Quinlan and Pohl, 1967; Brucker et al., 1972).

The Sandstone Talus Caves

Sandstone talus caves are cavities enterable by man formed by collapse and slumping of sandstone bedrock. They are common geomorphic features in Mammoth Cave National Park, and spot checks indicate they are common on ridges with underground drainage throughout the Central Kentucky Karst. Their distribution is limited to a narrow stratigraphic horizon near the Big Clifty-Girkin (sandstone-limestone) contact. This horizon occurs within the shoulder slope zone (Ruhe and Walker's 1968 classification of slopes in Ruhe, 1975) at the ridge top perimeter where erosion of the sandstone cap is rapidly proceeding. Their zone of occurrence has been found to be about one-hundred feet wide. In this zone they are associated with even more numerous subsidence including shallow depression and sandstone-colluvium filled sinkholes. Hydrology controls their distribution insofar as enough surface runnoff or vadose ground water from the Haney Limestone or Big Clifty Sandstone must be available to excavate a void below the sandstone-limestone contact for the sandstone to cave into. As a result, though they do occur on toe slopes, they are concentrated at heads of reentrant valleys where water flow ofer the edge of the sanstone cap is concentrated (Pohl, 1955; Brucker et al., 1972). Pohl (1955) states the positions of the reentrant valleys represent former stream positions on the Chester Cuesta.

Lithology and local competence of the sandstone has some control over the distribution of the talus caves. Where the sandstone is massive competent, talus caves tend to have a wide entrance with an overhanging sandstone face exposed. The entrance slope generally angles down at seventy-five to forty-five degrees away from the hill slope (Figure 5a, b). Where more weathered or less competent sandstones outcrop, entrances are smaller, often barely enterable (Figure 6), and descend at angles up to ninety degrees as in the case of Antler Pit (Figure 7, 8a). Generally the entrance is flush with the ground surface or in a small (five-foot diameter or less) depression. Where the sandstone is extremely weathered or incompetent it is possible that no entrances would ever form, yet depressions or sinks could.

The caves consist essentially of a single room at the base of the entrance slope which contains a drain or is floored with breakdown. The room can be up to fifteen feet high and forty feet wide. Often they are partially filled with sandstone talus. Commonly the upper few feet of the Girkin Formation are exposed in the bottom walls of the room.

Total passage length in all examined talus caves is very short; most do not have a true dark zone. Typically a cave ranges from ten to twenty feet long. Passage length of seventy feet in Antler Pit [illegible] (Figure 7, 8a-e), the longest true sandstone talus cave discovered to date, is unusually long.

Walls and ceiling are composed of sandstone bedrock except near the bottom of the cave. The bedrock shows signs of slumping and the ceiling sags into the cavity beneath it. Frequently slumped blocks are propped in precarious positions in the walls and ceilings. The entrance slope and drain are covered with sandstone breakdown, usually cobbles, derived from ceiling and walls. These cobbles and surface debris input in the entrance, are transported down to the drain or breakdown.. Evidently the sediment and breakdown are internally consumed, in- [illegible] the presence of [illegible] to handle the influx of material.

TYPICAL SANDSTONE TALUS CAVES

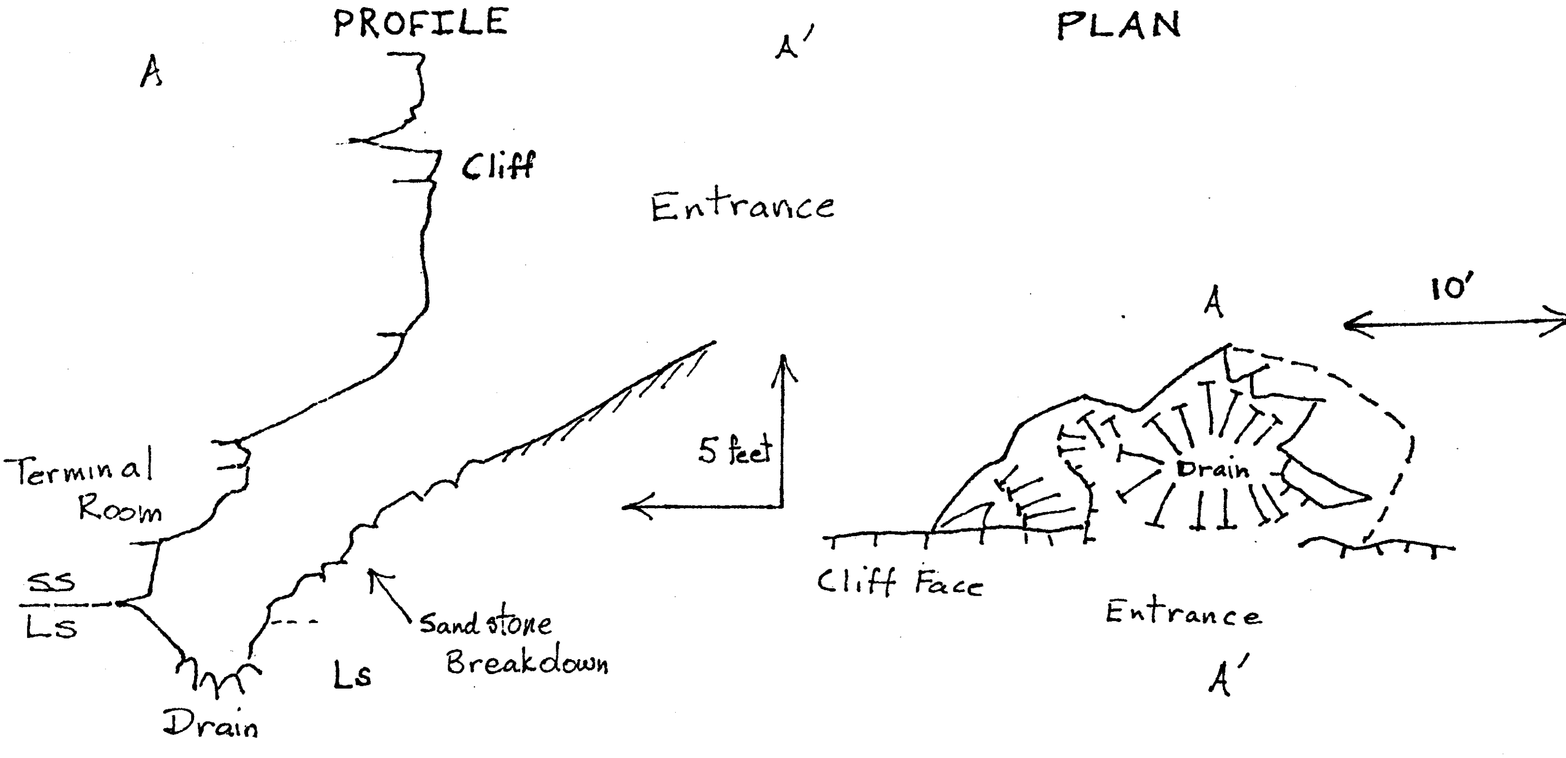


Figure 5a

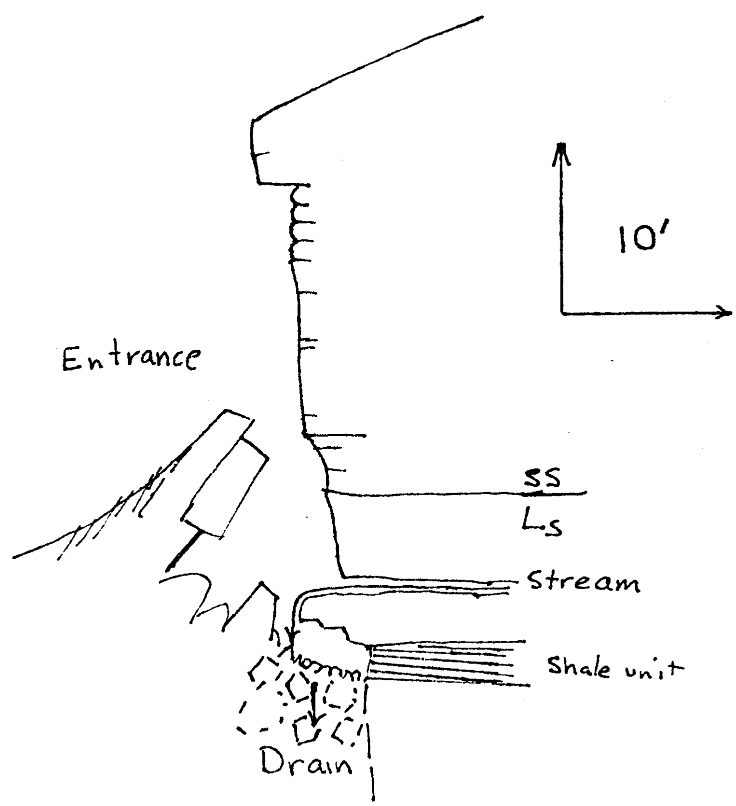


Figure 5b

TALUS CAVE IN THIN BEDDED SANDSTONE

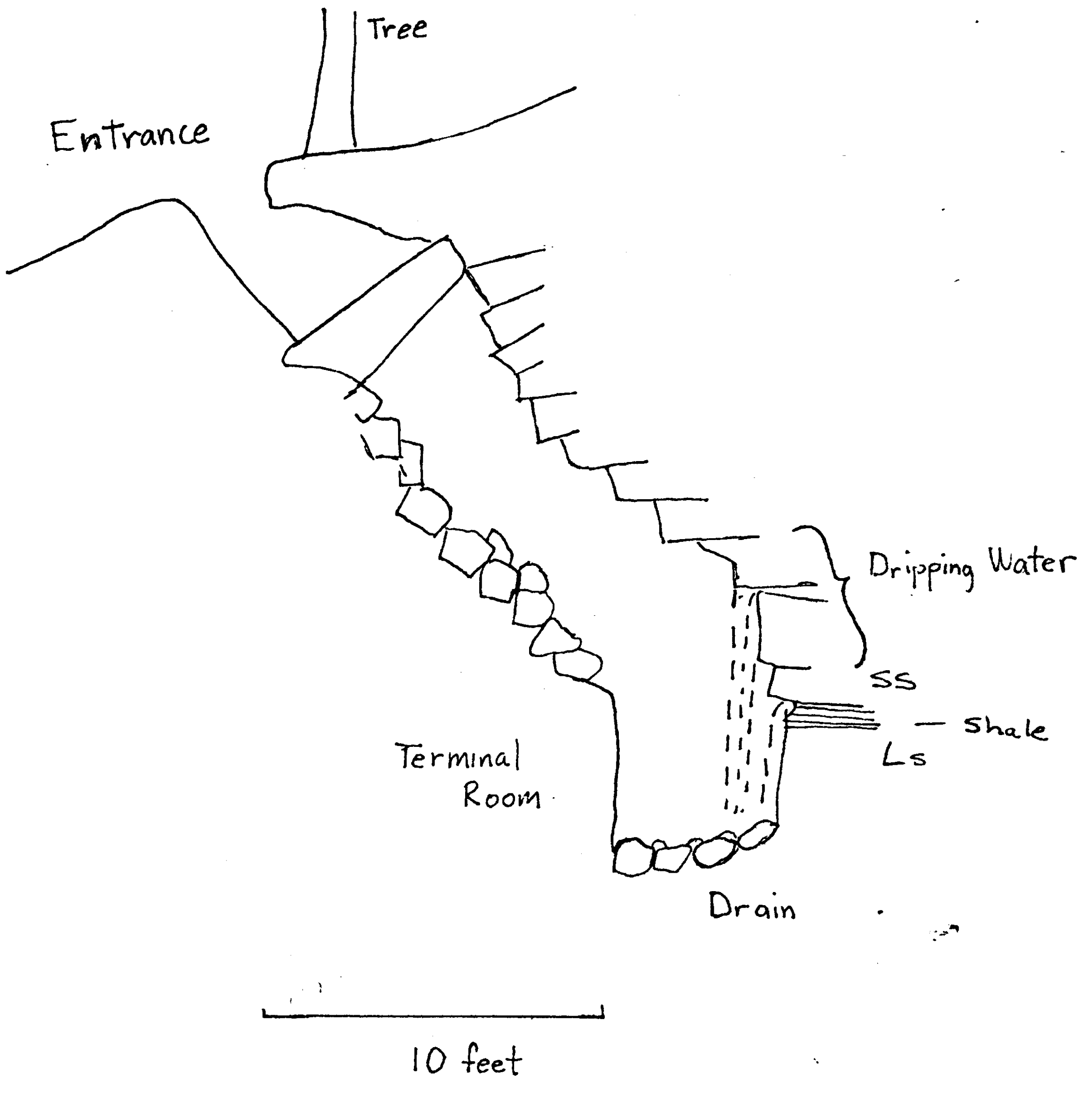


Figure 6

ANTLER PIT

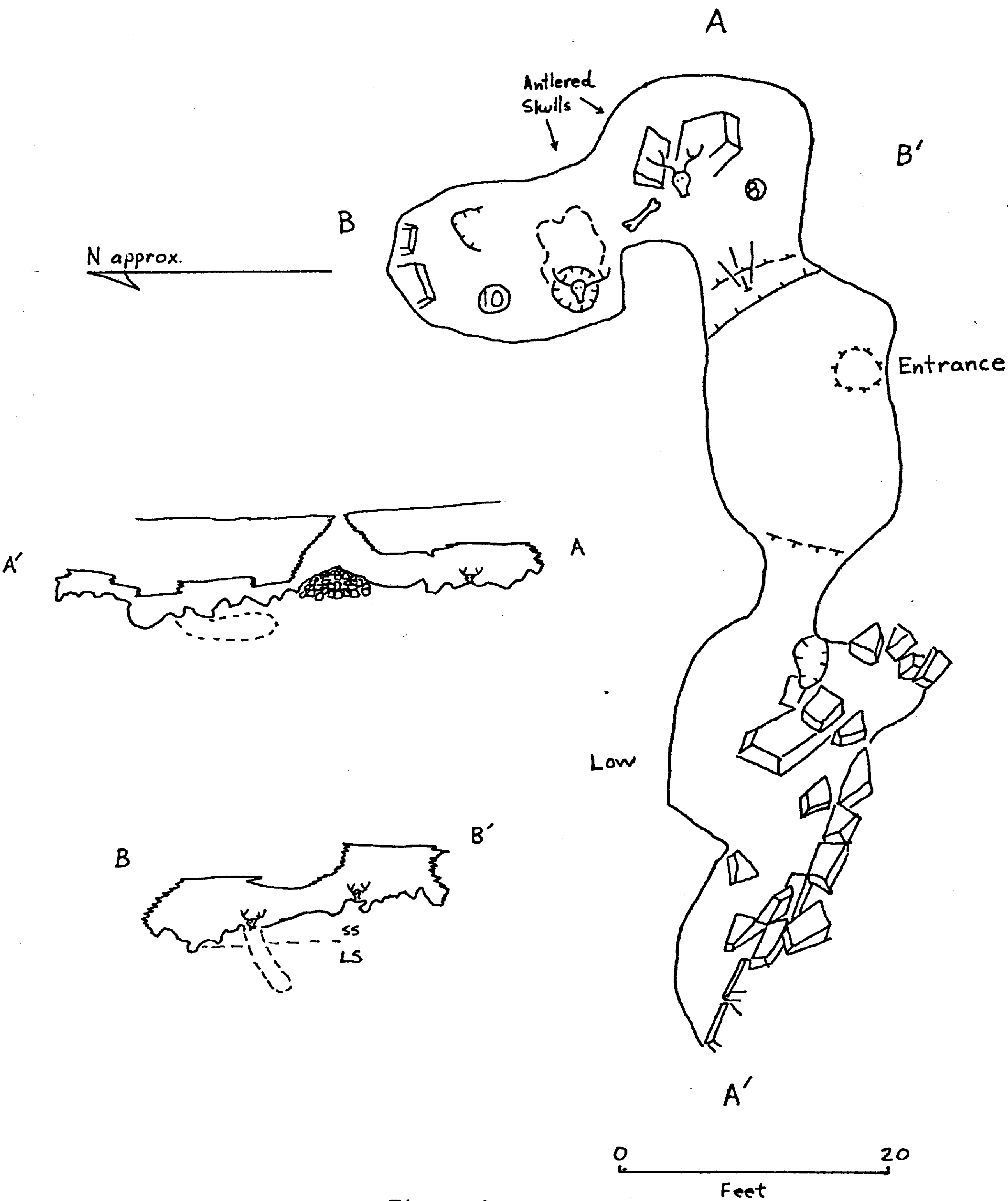


Figure 7
See Appendix for explanation of symbols.

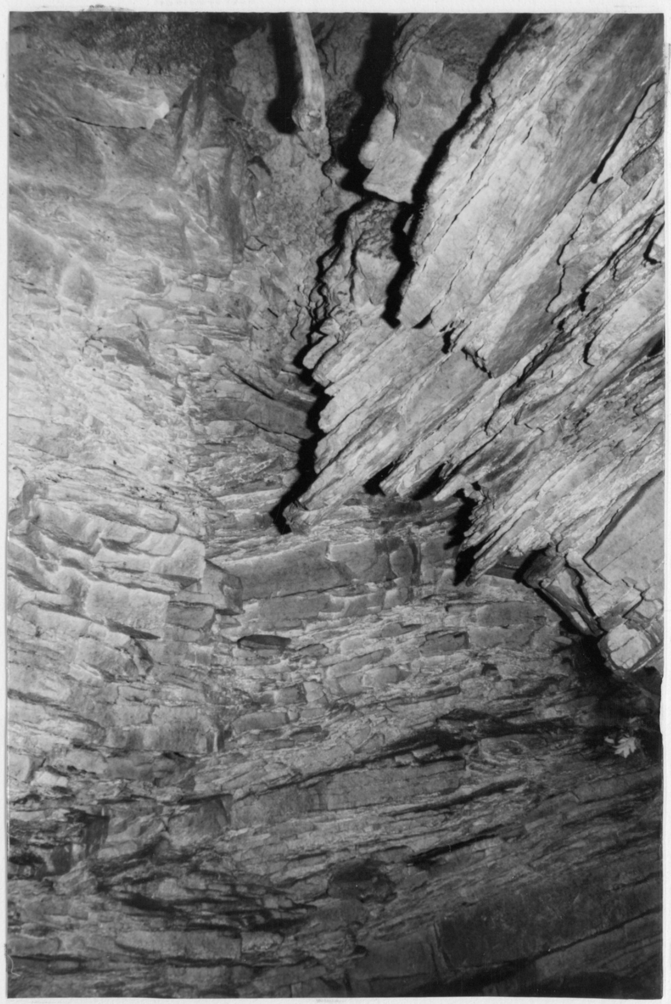


Figure 8a. Antler Pit. Sagging sandstone in ceiling.

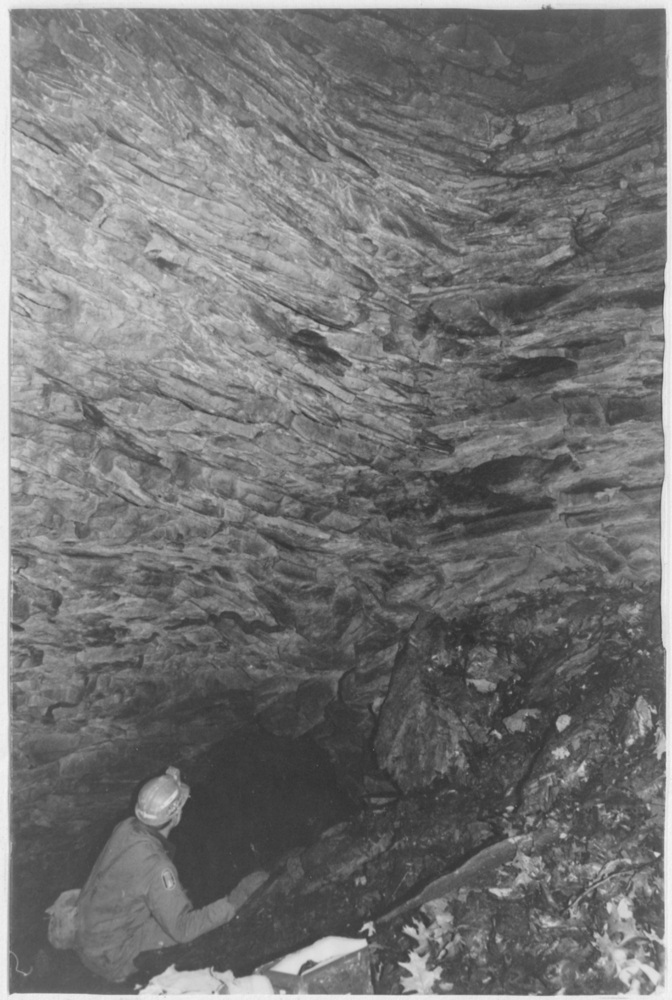


Figure 8b. Antler Pit. Arched ceiling of passage to lower room developed in sagging, thin-bedded sandstone.

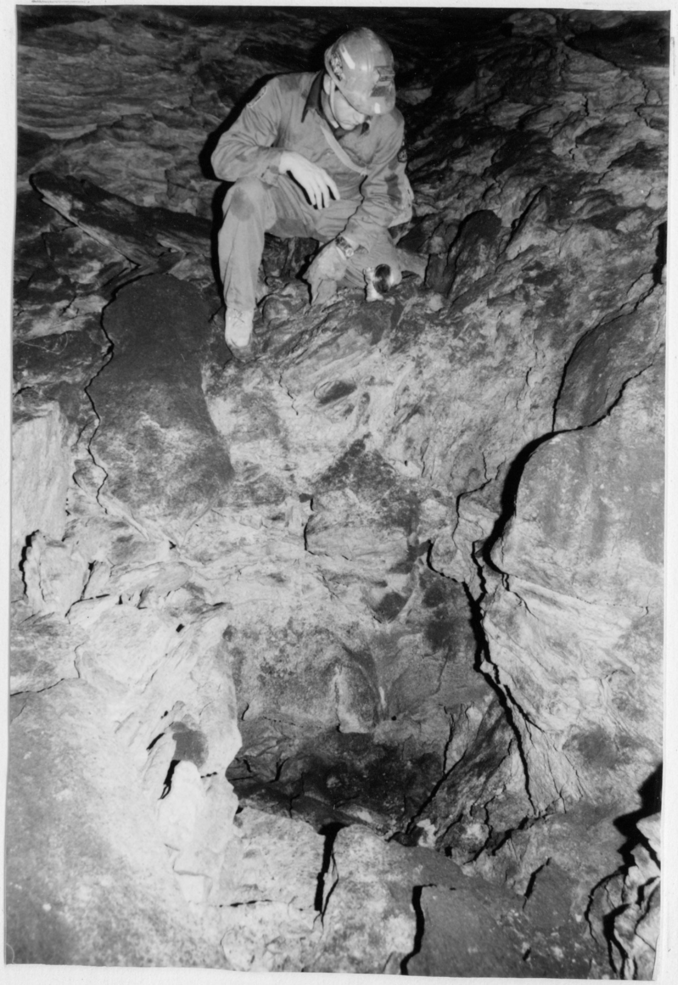


Figure 8c. Antler Pit. Limestone exposed in floor.

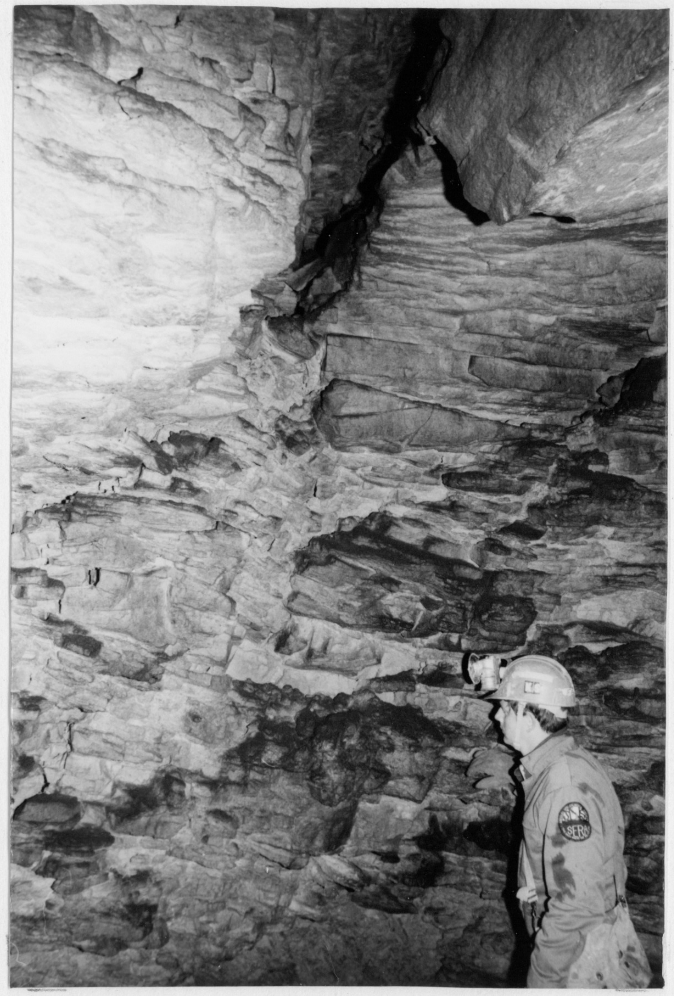


Figure 8d. Antler Pit. Joint seperation between slumped (on right) and in situ sandstone beds.

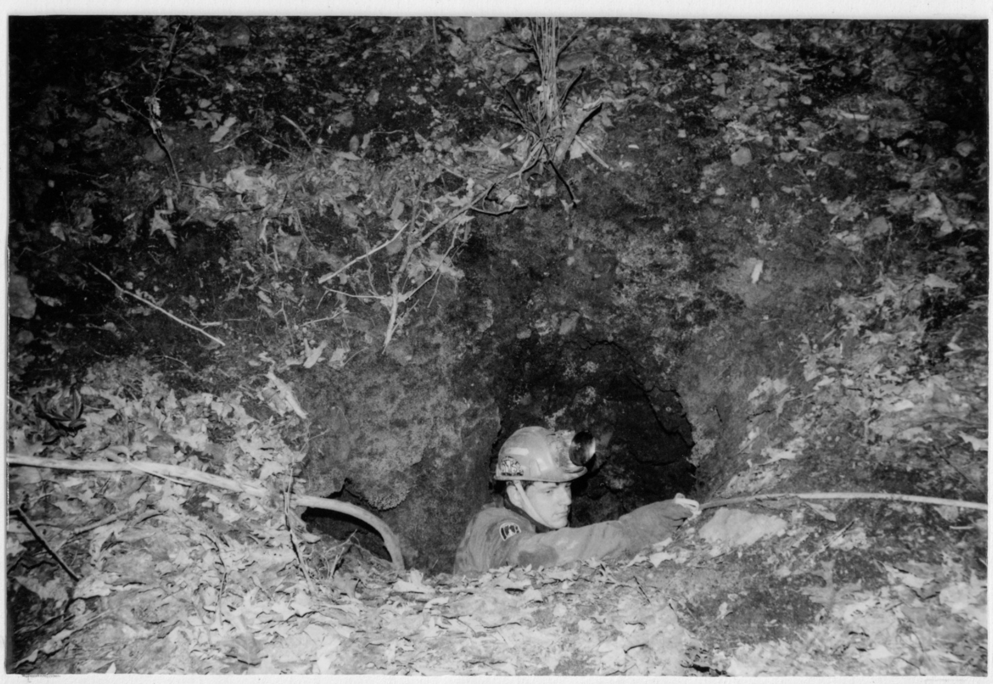


Figure 8e. Antler Pit. The entrance.

indicating the presence of cavities large enough to handle the influx of material.

While some talus caves are dry, most have some significant amounts of water passing through. The wetter talus caves are generally located on headslopes, where water flow into valleys is concentrated.

The amount of water flowing into talus caves after seeping through the porous sandstone or along fractures and joints can be quite voluminous after rains or snowmelts. Seven talus caves have small rivulets or streams entering them at or immediately below the sandstone-limestone contact. These streams appear to represent seepage along joints through the porous Big Clifty Sandstone which has become perched on shale units in the lower part of the Big Clifty or the upper few feet of the Girkin and are flowing to the edge of the ridge on these shales (Figure 5b). Nearly all but the driest talus caves at least have some seepage entering the cave at this horizon.

Relation of Sandstone Talus Caves to Limestone Caves

Five sandstone talus caves discovered to date connect with underlying caves developed in limestone, providing a unique opportunity to examine the interstratal karstification processes contributing to talus cave and vertical shaft genesis and therefore, to retreat of the sandstone cap. All five talus caves open initially into horizontal passages developed at or immediately below the sandstone-limestone contact. From four talus caves at least one vertical shaft is accessible. In Deer Park Avenue Hollow Cave (Figure 10), Cave #11 east of Long's Cave (Figure 9), and Rebel Rubble Cave (Figure 11), the passages, ranging from one to seven feet high and two to three feet wide, have vertically fluted limestone walls, a sandstone ceiling, and floors littered with dissolutioned limestone fragments and sandstone blocks derived from the ceiling. Little debris from the entrance is found. A joint in the sandstone ceiling appears to control the passage direction in Rebel Rubble (Figure 12a) and Deer Park Avenue Hollow Cave. Water seeping through the joint constantly drips from the ceiling.

No vertical shafts are accessible in Deer Park Avenue Hollow Cave or Cave #11. In Rebel Rubble Cave, however, two vertical shaft systems are accessible. Shaft #1 (Figure 11) is reached by climbing down a twelve foot shaft which has a two-foot shale unit at its top. The room at the bottom is half filled with sandstone boulders of up to roughly fifteen cubic feet which have caved in from the left and above. A window on the right drops into a forty-five foot shaft whose floor and drain are covered with sandstone cobbles resting at the angle of repose. The

Cave No. 11

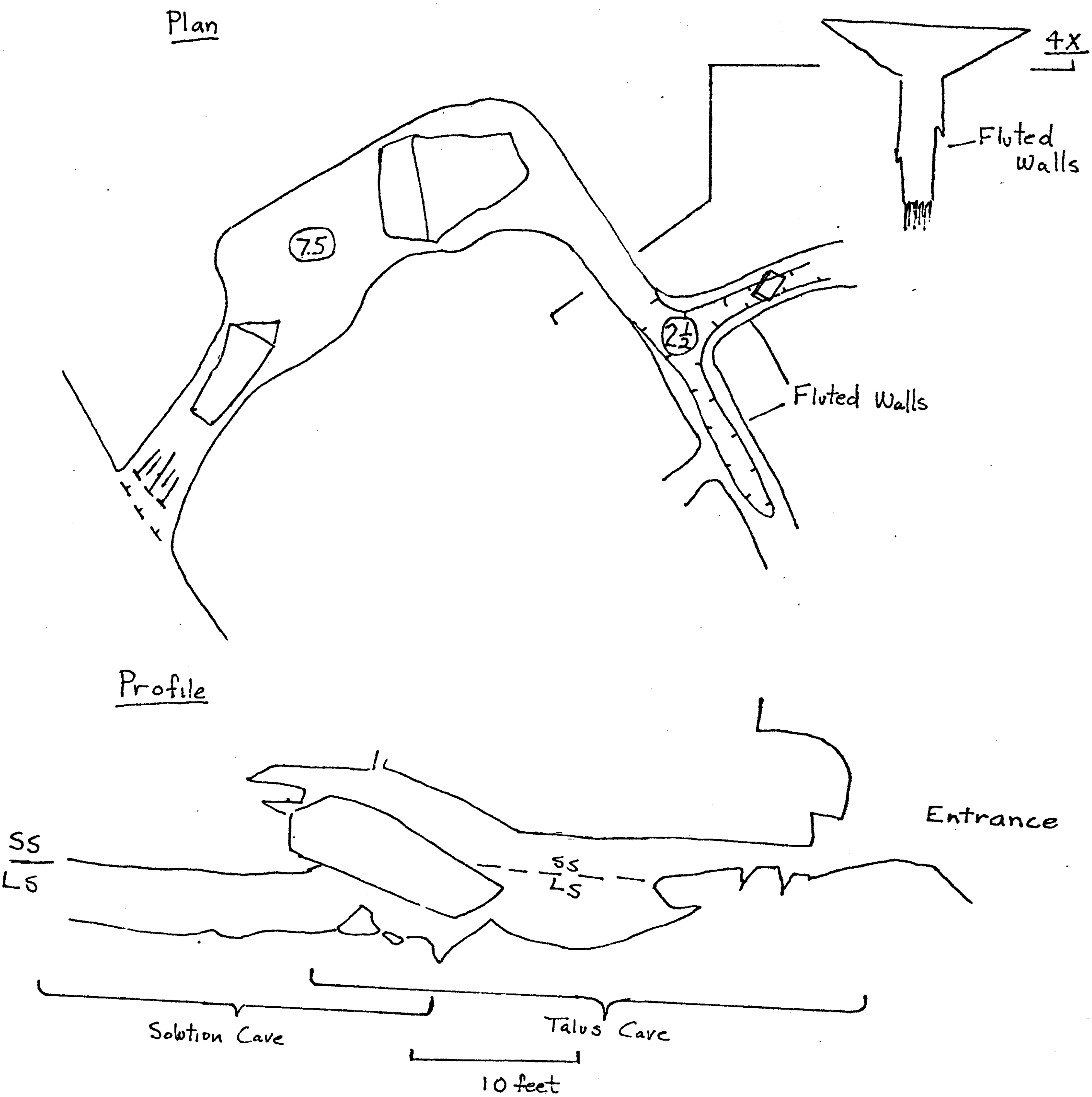


Figure 9
See Appendix for explanation of symbols.

Deer Park Avenue Hollow Cave

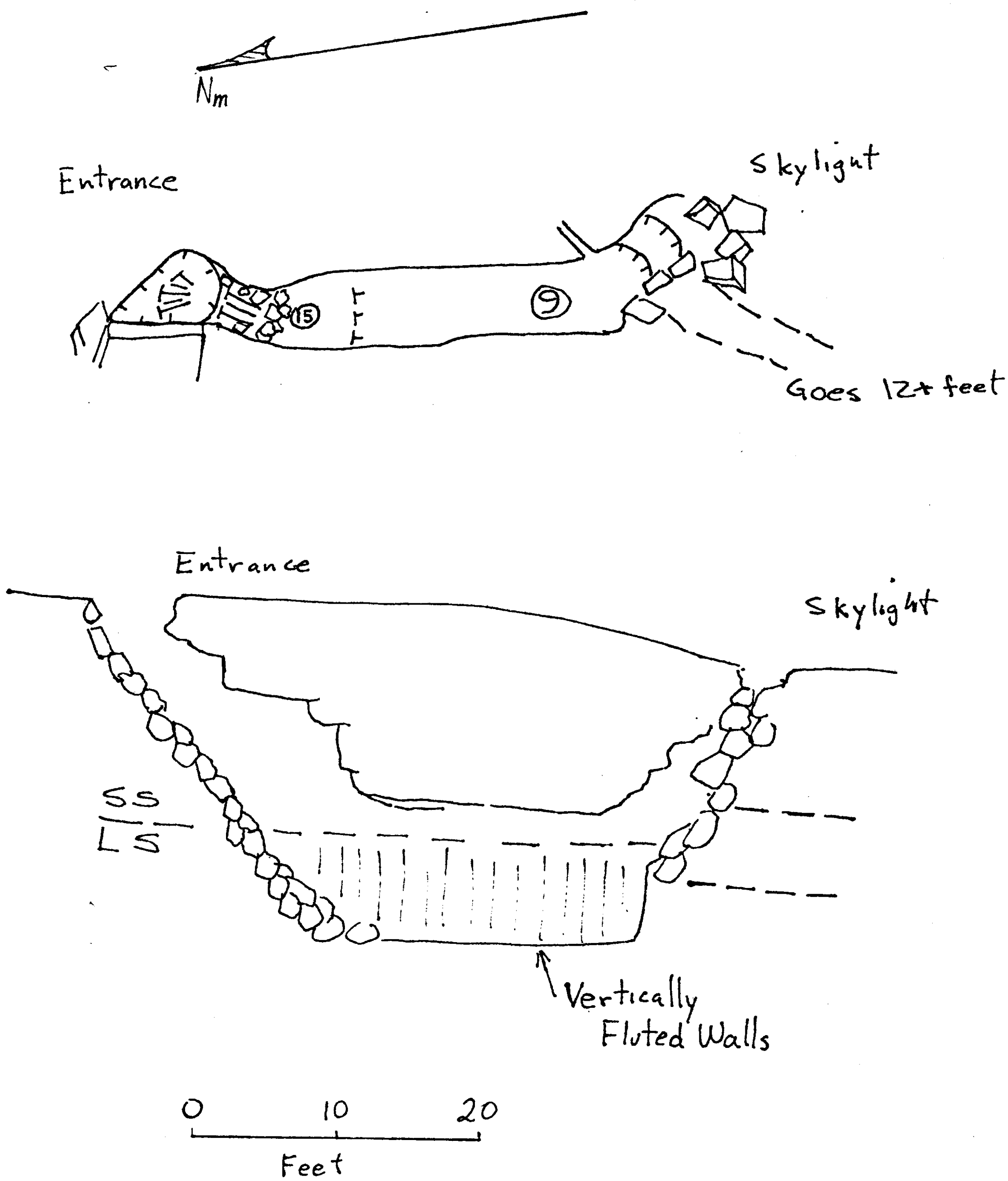


Figure 10

See Appendix for explanation of symbols.

REBBLE RUBBLE CAVE

MAMMOTH CAVE NATIONAL PARK, KENTUCKY

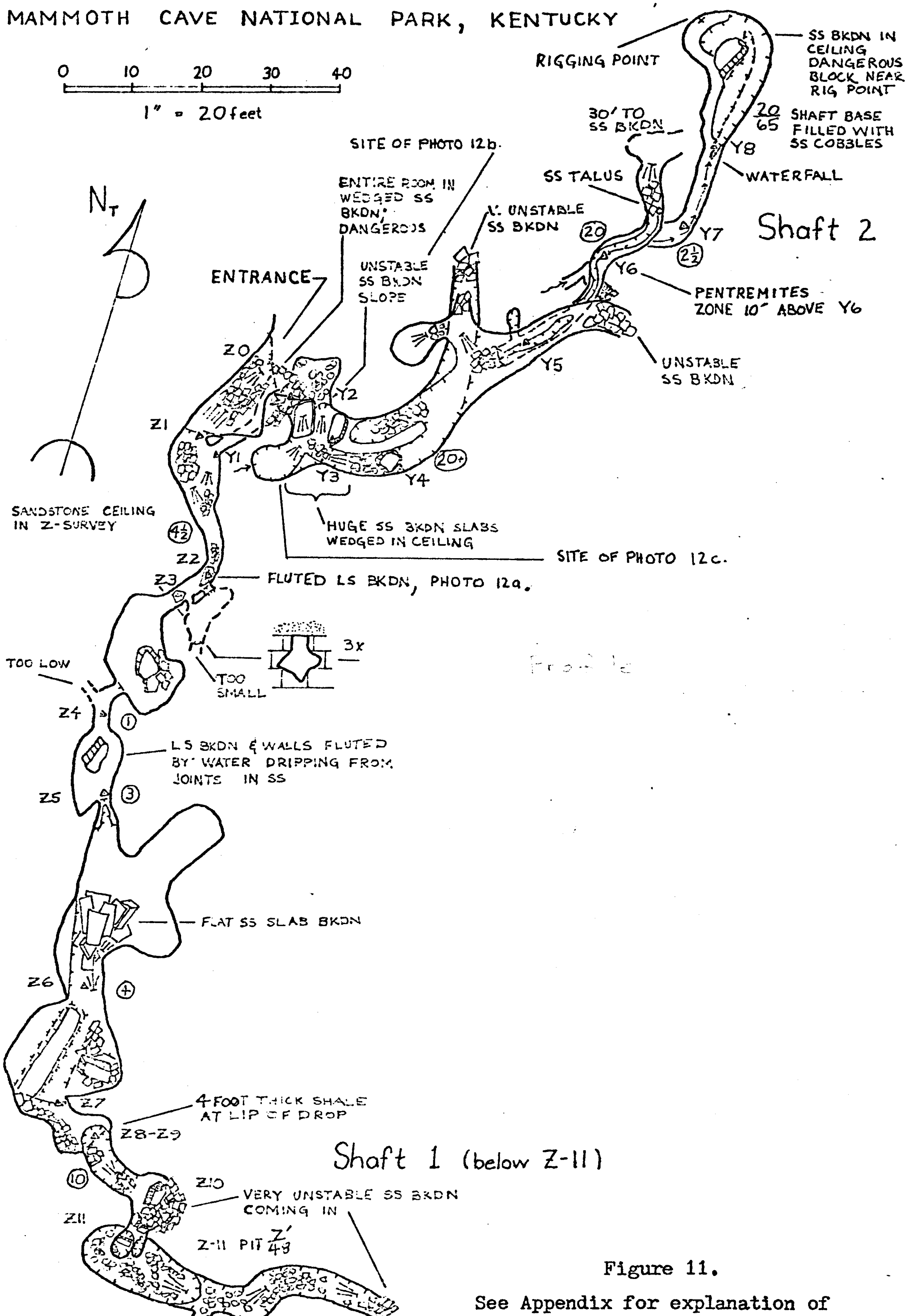


Figure 11.

See Appendix for explanation of map symbols.

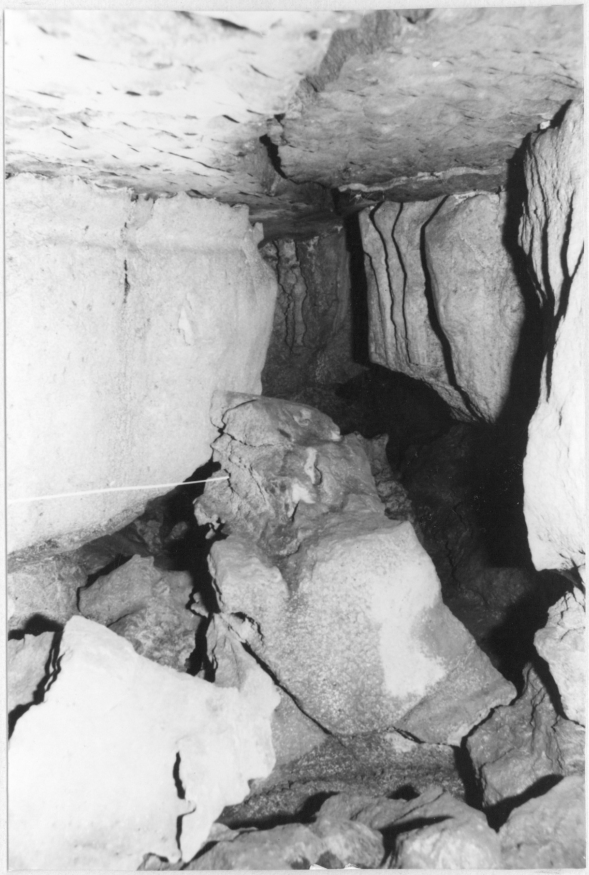


Figure 12a. Rebble Rubble Cave. Passage ($3\frac{1}{2}$ feet high x 3 feet wide) developed below the sandstone-limestone contact under a joint in the sandstone ceiling.

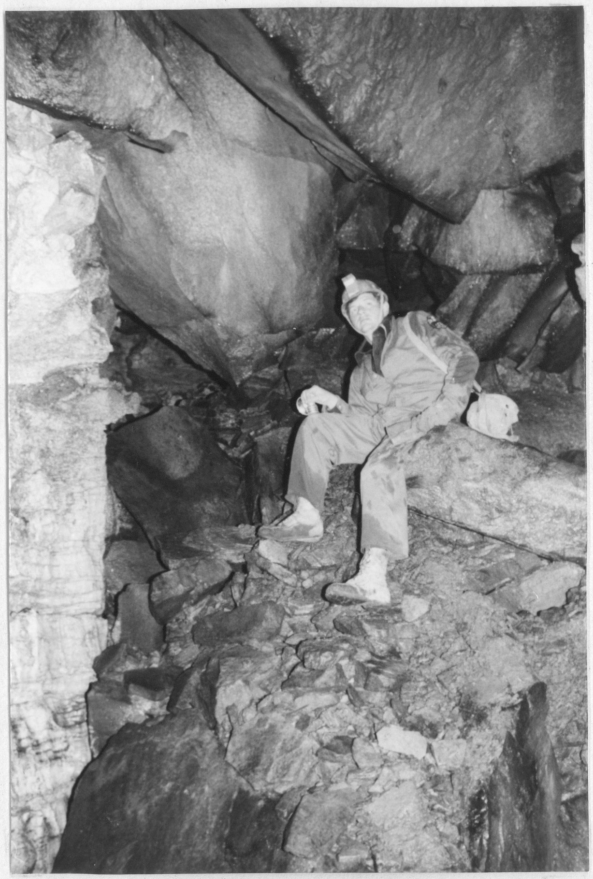


Figure 12b. Rebble Rubble Cave. Slumped sandstone suspended in ceiling of a migrated shaft system. Sandstone boulder slope is at angle of repose.

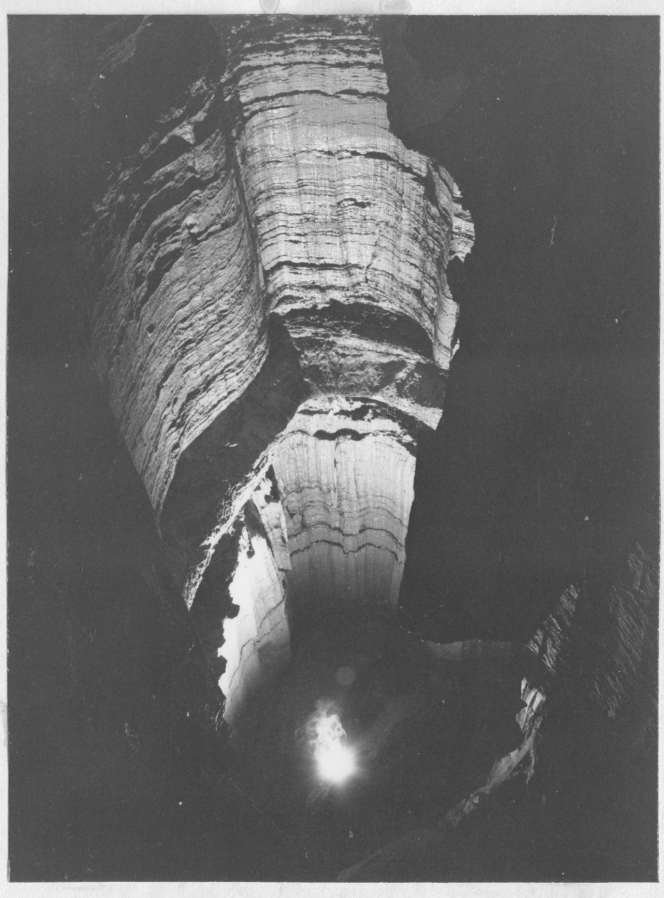


Figure 12c. Rebble Rubble Cave. Active headward portion of a migrated shaft being enlarged by a waterfall.

sandstone breakdown is extremely unstable; even slight disturbances set it moving downslope en masse.

The second shaft system is of note because of the great depth to which it descends. Directly under the sandstone entrance of the cave is a small room entirely of sandstone boulders and blocks wedging themselves up to form a dome. A hole between blocks on the floor leads down to a forty degree slope of sandstone boulders, supported by blocks with dimensions up to fifteen by six by three feet (Figure 12b). This slope descends into the fity-foot high migrated shaft. Similarly, the ceiling and wall above the slope are composed of sandstone blocks of equal size wedged together. The shaft has been cut back from the hillside under the sandstone cap by a stream (Figures 12b and c) and sandstone is now caving into the shaft. The points of the shaft near the hillslope are filling principally with sandstone colluvium. The shaft system can be descended to a depth of seventy feet below the sandstone-limestone contact through passages free of sandstone colluvium to the edge of a seventy foot vertical shaft. Instead of being free of sandstone colluvium as expected, large sandstone blocks are wedged in the ceiling of this shaft and the entire floor area is covered with cobbles, which slope steeply to the apparent drain. The cobbles slump into a buried cavity near the drain after being agitated by digging, indicating the sandstone is being moved deeper into the cave.

The passage in CCC Quarry Cave (Figure 13) is an abandoned horizontal stream passage which intersects the pit pirating the water fifty feet from the entrance. The stream, which still occupies the upstream portion of the passage across the pit, flows from the main body of Mammoth Cave Ridge toward the ridge perimeter perched on a shale unit three feet below

CCC QUARRY CAVE

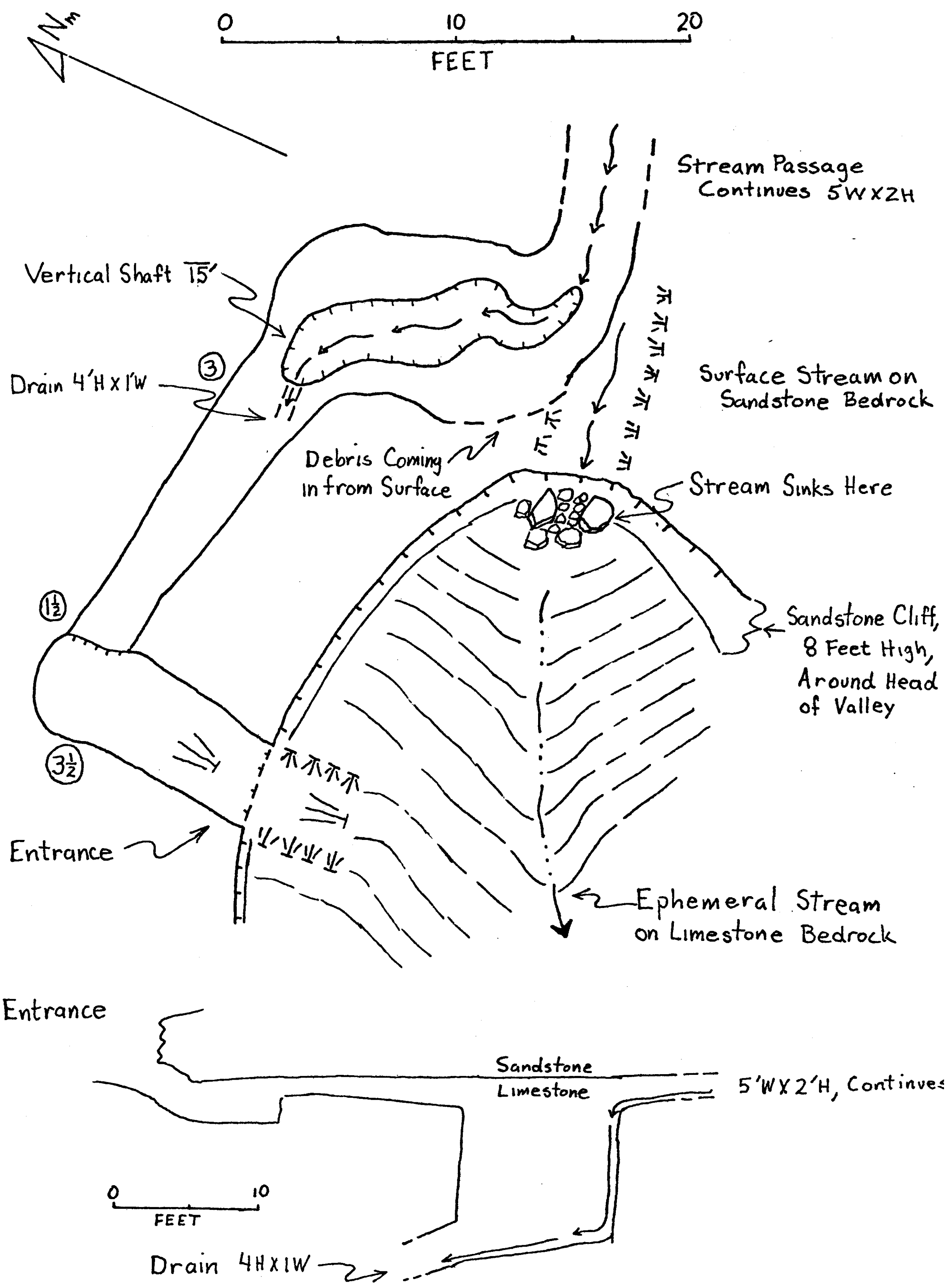


Figure 13
See Appendix for explanation of symbols.

the Big Clifty Sandstone. The shale has been breached a few feet short of the edge of the sandstone cap, and a fifteen-foot migrated shaft with a tall narrow drain has developed. Presumably, the stream flowed out of the present entrance toward a now destroyed shaft during a former position of the sandstone cap. Sandstone cobbles and surface debris slope toward the shaft from the edge of the sandstone cap, and also are present in the shaft bottom. The cave on the east end of Strawberry Valley (Figure 14) has a dry but impassable horizontal passage, which has been heavily modified by breakdown at the top of a migrated shaft to create a low wide room. Water feeding the shaft flows toward the edge of the sandstone cap; the shaft has migrated away from the edge toward the interior of the ridge. The end of the shaft proximal to the sandstone cap edge is filling with sandstone colluvium and limestone fragments. The drain is buried by debris, and is also the lowest point on the floor of the shaft, suggesting removal of debris from the shaft through the drain.

CAVE, IN EAST STRAWBERRY VALLEY

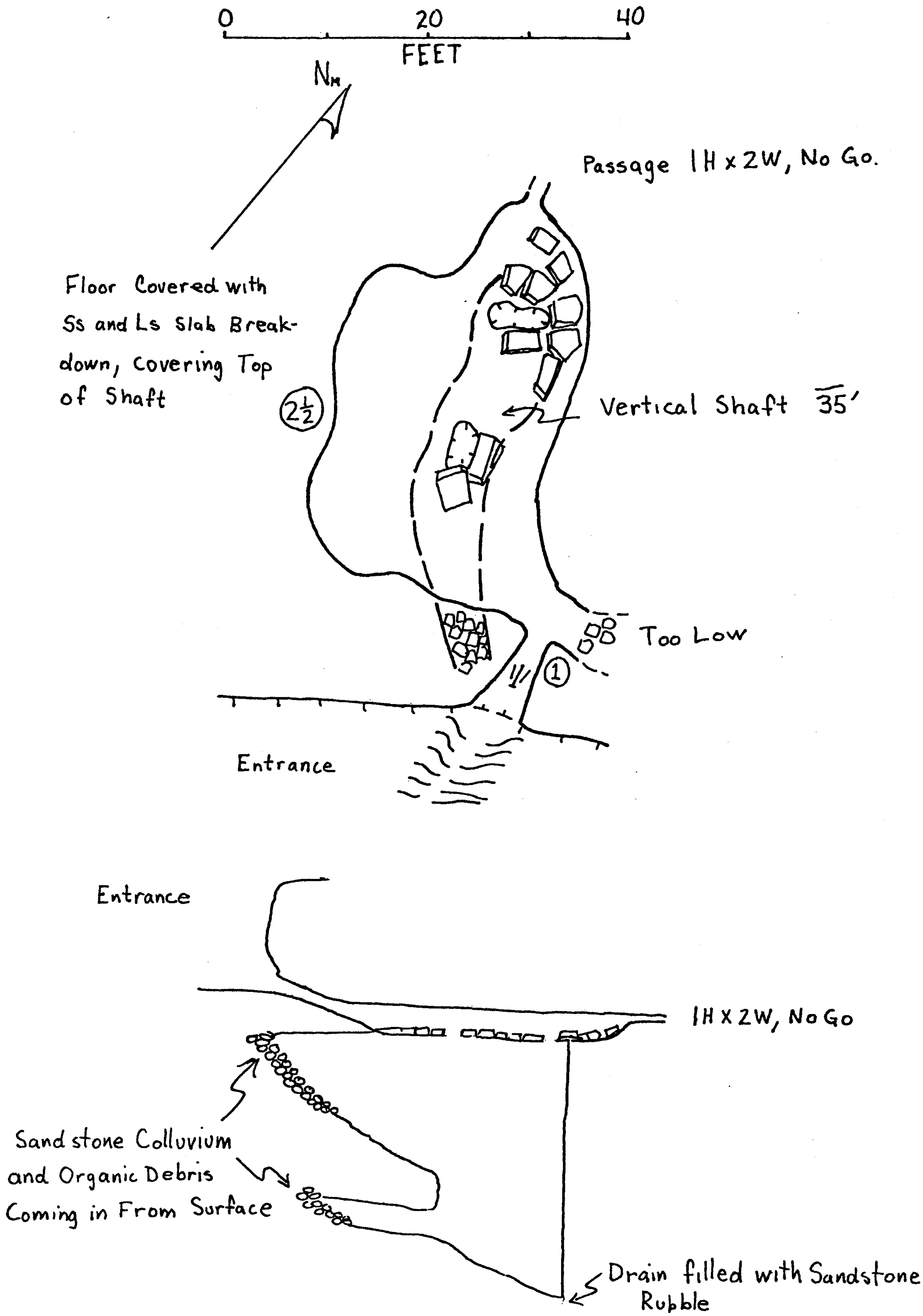


Figure 14
See appendix for explanation of symbols.

Genesis of the Sandstone Talus Caves

The genesis of sandstone talus caves is directly related to interstratal karstification processes described in abstract by Quinlan and Pohl (1967). Three factors necessary for the formation of these talus caves are: 1) a karst region with well integrated drainage; 2) a resistant, competent rock unit such as the Big Clifty Sandstone overlying a soluble rock unit such as the Girkin Formation; 3) a mechanism to concentrate flow of vadose water at specific points along the sandstone-limestone contact peripheral to ridge tops, so that dissolution voids form in limestone.

Interstratal karstification at the Big Clifty-Girkin contact forms voids in the limestone into which the sandstone slumps. The four major void types include: 1) horizontal canyon-like passages with vertically fluted walls formed by dripping water from joints in the overlying sandstone; 2) horizontal-tube stream passages developed by streams perched on shale units in the upper few feet of the Girkin; 3) vertical shafts (described by Brucker et al., 1972; Quinlan and Pohl, 1967; and Pohl, 1955); 4) migrated shafts, whose sinuous, canyon-like appearance is due to headward erosion by the streams that feed them. Of these voids, vertical and migrated shafts constitute the greatest volume and number.

The Big Clifty Sandstone, weakend by removal of the supporting Girkin, settles into these shaft systems catastrophically or at about the same rate as solution takes place (Quinlan and Pohl, 1967). Sandstone talus caves form when cavities in the sandstone resulting from such collapse open to the surface. Where such slumping of the sandstone occurs breaching and retreat of the sandstone cap takes place. The frequently catastrophic nature of the settling is clearly shown by the shafts with sandstone coluvium wedged in the ceilings or forming steep unstable slopes on the floors at the angle of repose. (Figures 8a, 8d, 12a).

The distribution and morphology of the talus caves are controlled principally by lithologic and hydrologic factors. The control of vadose ground water flow by the stratigraphic succession limits the occurrence of talus caves to the one-hundred foot wide zone along the ridge perimeter.

While the sandstone cap is resistant to weathering, it does not present an impermeable barrier to vadose ground water. Four other impermeable horizons occurring in or near the sandstone cap can by identified. The Haney Limestone, about forty feet thick in the study area, is extremely soluble and extensively channeled by solution cavities (Brown, 1966). At its base a thin shale occurs on which water in the Haney perches. Many springs, some of which are used for the Mammoth Cave water supply, occur at this horizon. Recent hammer seismic work by Palmer (personal communication, 1978) indicates the Haney has been largely removed by interstratal karstification on Flint Ridge (Figure 2) leaving a residual clay layer about ten feet thick between Hardinsburg and Big Clifty Sandstones. This clay apparently exists on all the ridge tops and persists as part of the soil horizon where the Haney has been eroded. Its presence accounts for most of the perched vadose water which forms ridge top swamps. A third impermeable layer occurs as a discontinuous shale layer within the Big Clifty (Brown, 1966). While it does present a barrier to vadose water it is rarely seen in outcrop and its exact distribution is not known. One or more shale layers in the upper two to ten feet of the Girkin present a fourth impermeable barrier. This layer is frequently encountered in some of the deeper talus caves and in in limestone caves intersected by them such as Rebel Rubble Cave. Due to the presence of these impermeable units most of the surficial and vadose water moves laterally to the ridge perimeters where these units have been breached. Vadose water penetrating the Big Clifty may form small horizontal passages above the shale layer in the uppermost Girkin. Such passages formed principally by dripping water from joints in the sandstone ceiling are canyon-like with vertically fluted walls (Figure 12a), while those formed by perched stream flow are typically low and tubular. Vadose flow concentrated at ridge top perimeters in this manner, particularly at the heads of reentrant valleys, traverses vertical joints in the now exposed limestone and carves vertical shaft systems (Pohl, 1955; Quinlan and Pohl, 1967; Brucker et al., 1972). These active shaft systems are therefore concentrated in a one-hundred foot wide zone at the edge of the sandstone cap, particularly at the heads of reentrant valleys. Unsupported sandstone collapses into the voids, frequently forming sandstone talus caves.

Local lithology and extent of weathering of the Big Clifty influences to some degree the size and morphology of talus caves. Caves developed in massive, well-indurated sandstone tend to have wide entrances at the base of cliffs five to twenty feet high. Entrance slopes generally range from twenty-five to forty degrees. In situ sandstone bedrock supports the ceiling and walls. Ceilings step down through individual sandstone beds which span the entire width of the cave and can form flat ceilings in the terminal rooms (Figure 5a). The cave floor consists of breakdown derived from the ceiling, and surface debris. The breakdown fills a former void in the underlying limestone. In some cases small streams entering near the sandstone-limestone contact still actively enlarge the solution void and actively transport material downward (Figure 5b). Deeply undercut entrance overhangs eventually weaken and collapse (Figure 5b).

Thin bedded, less competent sandstone in which talus caves may occur are frequently slumped. The ceilings and walls of such talus caves are arched (Figure 8b). The weak sandstone beds sag into the underlying void. In several talus caves the break between the in situ and slumped beds is clearly visible and may be indicated by a prominent fracture (Figures 8d, 15). Slumping frequently disturbs bedding to such a degree that ceiling and walls are supported by a pressure arch of sandstone blocks and cobbles wedged together. The tops of limestone dissolution voids are sometimes accessible through the breakdown on the floor (Figure 8c), or are exposed in the terminal room. The arches supporting the cave approach the surface as sandstone progressively caves into underlying solution voids and eventually intersect the surface. Since these entrances tend to be near the arch's apex, entrance slopes are steep generally ranging from forty to ninety degrees. Entrances also tend to be flush with the ground surface and small (Figure 8e).

Several talus caves of both morphologic types occur on the uphill edges of sinks developed in sandstone bedrock or colluvium. Such sinks are unroofed sites of solution voids which still actively ingest sandstone colluvium. The resulting talus caves are essentially fissures, which form as sandstone creeps downhill into a sink and separates from in situ bedrock or well compacted colluvium at the sink edge (Figure 16).

Cavities in sandstone formed when slumping into solution voids occurs need not have entrances or be easily detectable. Quinlan and Pohl (1967)

Figure 15. Slumped sandstone exposed in a wall of a talus cave above the Cathedral Domes Entrance. Flashlight is $8\frac{1}{4}$ inches long.

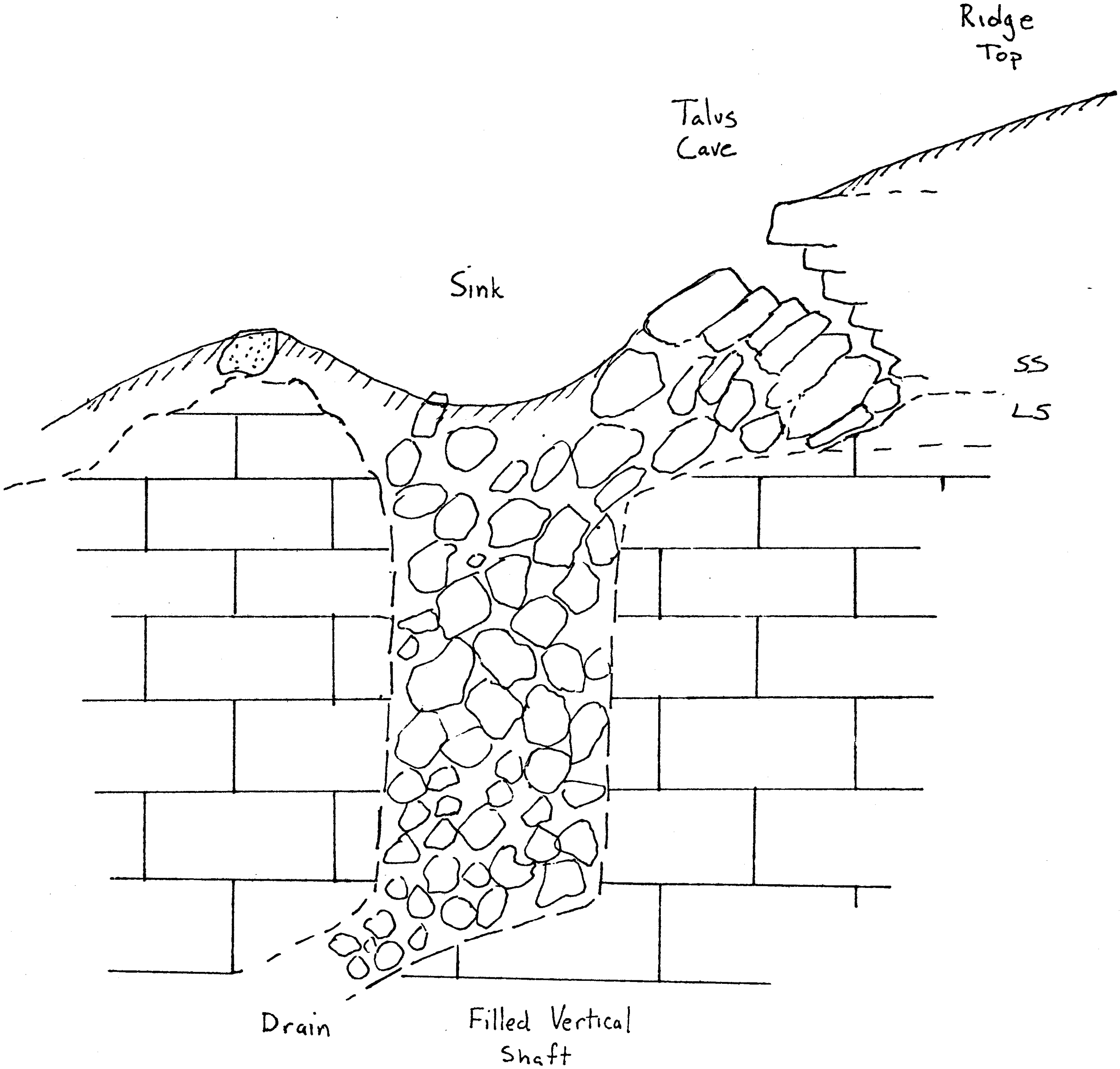


Figure 16

recognize such cavities exist and call them "structural sinks." Their existence, location and connection with underlying shaft systems is often indicated by detectable airflow filtering through small holes and colluvium along ridge perimeters.

The average volume of water passing through talus caves and aiding in the enlargement of underlying solution voids in limestone affects their size and rate of formation. Volume of water passing through talus caves ranged from essentially none to a few cubic feet per minute (visual estimates) during heavy rains; most flow volumes ranged from a few hundredths to a few tenths cfm. Where catchment areas for surficial and vadose flow to talus caves are small (often less than an acre) such as on toe and many side slopes, the talus caves are small. Signs of recent collapse are rare and the interior of the caves are relatively dry and stable. Where moderate to large flow through talus caves occurs, such as reentrants on headslopes, talus caves tend to be more voluminous, wet, and unstable.

Large surface streams which run over the edge of the sandstone cap at the heads of major reentrant valleys and sink at the sandstone-limestone contact erode the sandstone very rapidly and prevent the formation of large talus caves. When present the talus caves are small and extremely unstable. They are transient features because underlying shaft systems enlarge rapidly and much water is available to aid in the downward transportation of collapsed material. During high flow conditions much sandstone colluvium is transported down into the valleys in high gradient stream channels.

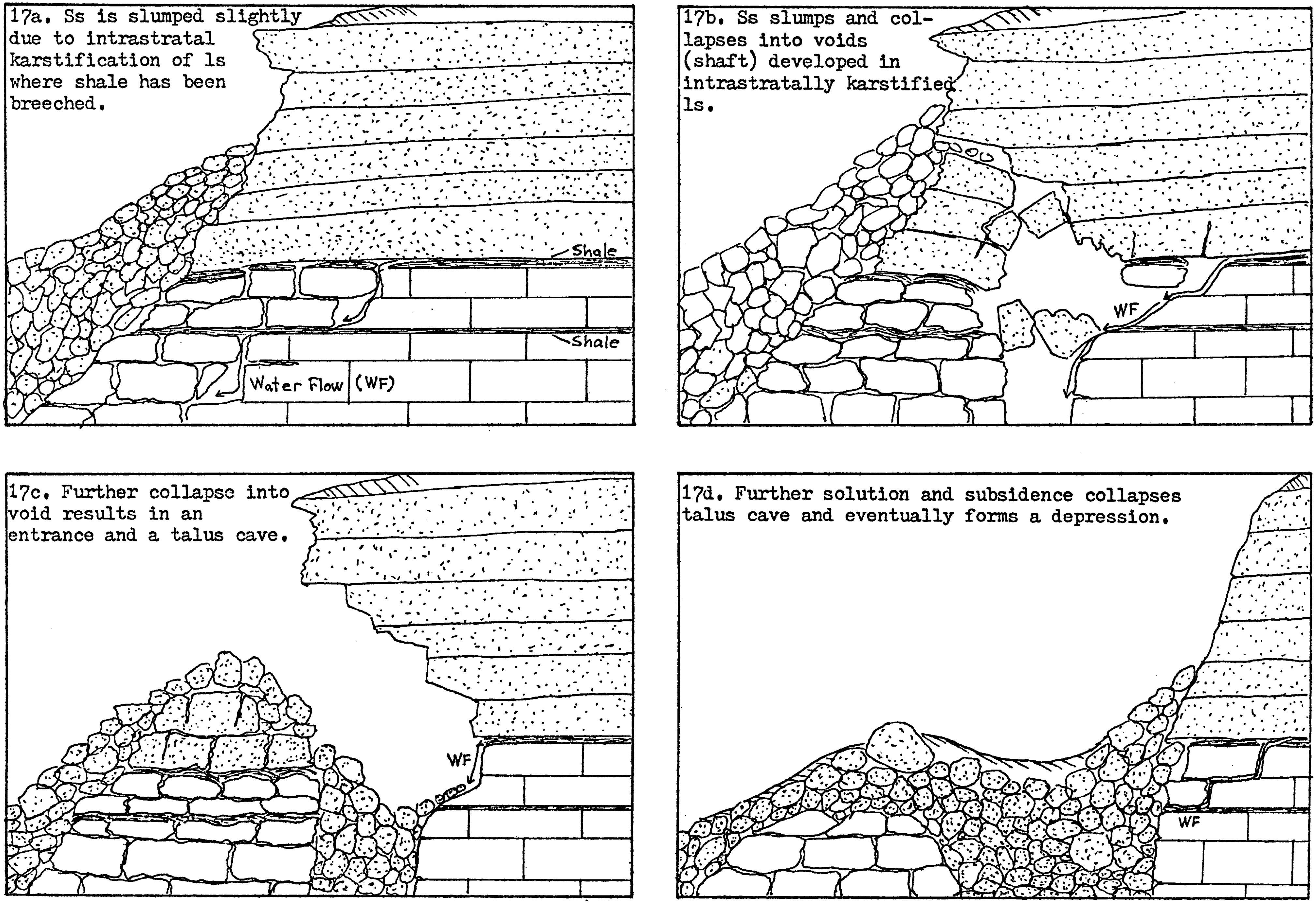
Some large relatively dry talus caves such as Antler Pit (Figure 7) occur on toe slopes. Water flowing through such caves has apparently been pirated away. No signs of very recent collapse are evident in such caves. Subsidence into underlying solution voids has ceased and the caves are relatively stable. Such talus may be preserved for relatively long periods of time.

Evolution of Sandstone Talus Caves

The association of sandstone talus caves with sinks and breathing holes near the sandstone-limestone contact suggests they may represent one phase of a dynamic evolutionary cycle. This postulated cycle is to be viewed as a general dynamic process of which some phases may not apply to all talus caves. The evolution of the talus caves is a destructive process causing retreat of the sandstone cap.

The evolutionary cycle involves four general phases. First, inter-stratal solution creates a void in the limestone under but near the edge of the sandstone cap (Figure 17a). Second, unsupported sandstone begins to cave into the void (Figure 17b). Such voids may be completely undetectable or their presence may be indicated by air filtering through fractures in the sandstone. Third, progressive collapse of sandstone into the enlarging solution void creates an entrance, forming a sandstone talus cave (Figure 17c). The collapsing sandstone and accompanying subsoil solution of limestone contribute to a general lowering of the ground surface. Finally, further enlargement of solution cavity causes the talus cave's ceiling to weaken and collapse, and forms a sink (Figure 17d). Such sinks are frequently filled with sandstone colluvium. Colluvium may continue to be transported down into the underlying solution void for some time.

The resistant sandstone cap has been breached and its edge moved back several tens of feet. The vertical shaft system below the sandstone talus cave has been filled with colluvium and alluvium. Continued karsti-fication below the sandstone-limestone contact creates new vertical shaft systems and the cycle repeats.



17a. Ss is slumped slightly due to intrastratal karstification of ls where shale has been breeched.

17b. Ss slumps and collapses into voids (shaft) developed in intrastratally karstified ls.

17c. Further collapse into void results in an entrance and a talus cave.

17d. Further solution and subsidence collapses talus cave and eventually forms a depression.

Figure 17

Suggestions for Further Research

This study of sandstone talus caves suggests several interesting problems on which further research could be conducted. Such problems include detecting cavities, determining ages for some talus caves, and determining a relationship between groundwater chemistry and evolution of talus caves.

The detection of entranceless cavities in sandstone is of considerable interest to construction projects. The existence of such cavities is shown by the fact that a large collapse occurred under the main highway into the park 300 yards north of Sloans Crossing in 1974. Methods which might be used to detect these cavities include seismic (methods), electrical resistivity, microgravity, and subsurface radar.

Further work may uncover a relationship between the evolution rate and size of talus caves and the chemistry of the water passing through them. Water trickling through small stable talus caves may have a composition approaching Thrailkill's (1960) vadose seeps, while larger talus caves may have water composition approaching vadose flows. The changes in water chemistry as it passes down from the sandstone cap through the vertical shaft systems could be studied in a few talus caves and their associated shaft systems.

Minimum age determinations of some talus caves my be possible. Skeletal remains of animals occurring in some of the drier talus caves may be dateable with radiocarbon techniques. Some of the remains may be of extinct animals whose time of extinction is known. Further work may also uncover dateable Indian artifacts.

Summary and Conclusions

Sandstone talus caves are common features of the Chester Cuesta in the Central Kentucky Karst. They are enterable cavities which form in sandstone when sandstone collapses into solution voids, principally shaft systems, in the underlying limestone. Collapse of the sandstone into the shaft systems contributes significantly to the retreat of the sandstone cap.

Three factors are prerequisite for the formation of these talus caves: 1) a karst area with well developed underground drainage; 2) a resistant rock unit such as sandstone capping ridges of soluble limestone; 3) one or more impermeable horizons on ridge tops which shed water toward ridge perimeters and thereby concentrate its flow there. These lithologic and hydrologic factors control the location, distribution, and morphology of the talus caves.

A general evolutionary cycle can be applied to the sandstone talus Caves. 1) A solution void, usually a vertical shaft system, developes near the edge of the sandstone cap. 2) Unsupported sandstone begins to collapse into the void. 3) With further collapse of sandstone into the enlarging void an entrance developes, forming a sandstone talus cave. 4) Collapse of the talus caves forms a sink filled with sandstone colluvium.

References

Brown, Richmond F., 1966, Hydrology of the Cavernous Limestones of the Mammoth Cave Area, Kentucky; USGS Water Supply Paper 1837, 64p.

Brucker, Roger W.; Hess, John W.; and White, William B.; 1972, Role of Vertical Shafts in the Movement of Ground Water in Carbonate Aquifers, Ground Water, vol. 10, no. 6, p 5-13.

Livesay, Ann, 1953, Geology of the Mammoth Cave National Park Area, Kentucky Geological Survey Special Publication, series 9, no. 2, 40p.

Lobeck, A. K., 1928,The Geology and Physiography of the Mammoth Cave National Park, Kentucky, Ky. Geol. Surv., series 6, no. 21, 69 p.

Monbeck et al., 1930, Topographic Map of the Mammoth Cave National Park, Kentucky, US Geological Survey.

Palmer, Arthur, 1978, personnal communication.

Pohl, E. R., 1935, Developement of Vertical Shafts in Limestone Caves, GSA Proceedings for 1935, p 96.

Pohl, E. R., 1955, Vertical Shafts in Limestone Caves, National Speleological Society Ocasional Paper No. 2, 24p.

Quinlan, James F.; and Pohl, E. R.; Vertical Shafts Actively Promote Slope Retreat and Dissection of the Solution Escarpment and the Chester Cuesta in the Central Kentucky Karst, National Speleological Society Bulletin vol. 29, p 109.

Ruhe, Robert V., 1975, Geomorphology, Houghton Mifflin Co., Boston.

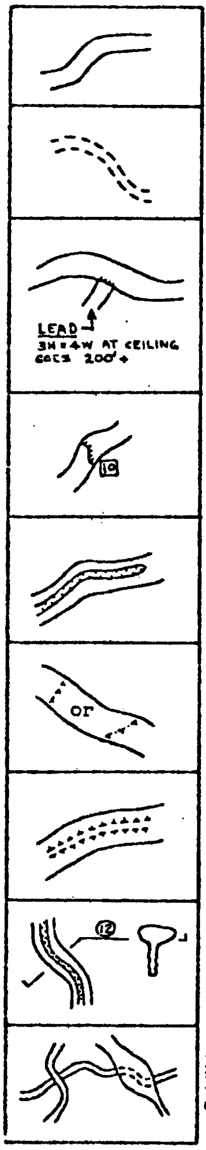
Sloss, L. L., 1963, Seqences in the Cratonic Interior of North America, GSA vol. 74, p 93-114.

Thrailkill, John, 1968, Chemical and Hydrologic Factors in the Excavation of Limestone Caves, GSA vol. 79, p 19-46.

White, William B.; Watson, Richard A.; Pohl, E. R.; and Brucker, Roger W.; 1970, The Central Kentucky Karst, Geographical Review, vol. 60, no. 1, p 88-115.

Wilson, William L., 1976, Surface Reconnaisance at Mammoth Cave National Park, Cave Research Foundation Annual Report, 1976, p 22-25.

Appendix



Surveyed cave passage.

Unsurveyed cave passage.

Unexplored passage. Always include dimensions, vertical relationship to survey passage, and distance explored.

Abrupt drop in floor. Hatchures on downward side. Give distance of drop in feet.

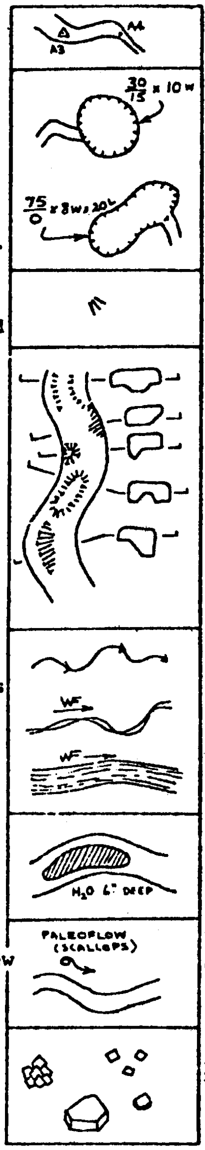
Canyon in floor.

Sudden drop in ceiling. Hatchures point toward lower ceiling.

Ceiling channel.

Cross section. Short lines point in direction of view and up. Passage height in feet.

Passages crossing. Lower level is dashed or omitted.



Survey stations.

Vertical shafts. Label with $\frac{\text{height}}{\text{depth}}$ x diameter at level of survey.

Slope. Lines diverge downhill.

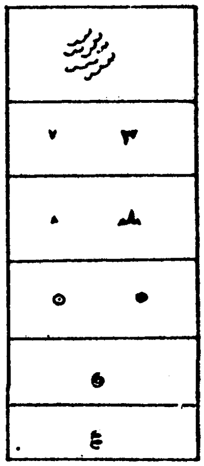
Slope. A more versatile notation. Lines trend straight down the slope. Short dashes show break at top of slope.

Streams, showing direction of water flow.

Ponded water.

Paleoflow direction. From scallops, rimstone dams, waterfall ledges. (Scallops work like this.)

Breakdown.



Formations.

Flowstone.

Stalactites.

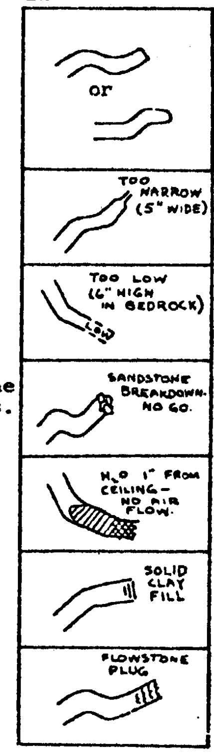
Stalagmites.

Column. (Ambiguou Define this symbol when you use it.)

Gypsum flower.

Helictite.

Passage Terminations. Always write down cause of termination in detail.



Use this symbol only if the passage ends in a solid rock wall.

Too narrow. Sometimes helps to note for whom it was too narrow!

Too low.

Breakdown.

Siphon.

Passage fills to ceiling. Note type of fill.

Flowstone.

(from the Cave Research Foundation Personnel Manual, 1975, p 79)