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# Some engineering geology problems at Mammoth Cave National Park, Kentucky

by

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## INTRODUCTION

The U.S. Geological Survey, at the request of the National Park Service, participated in a field symposium May 22-26, 1967, at Mammoth Cave National Park, Kentucky. This symposium, held by the National Park Service, was to determine the applicability of the Wilderness Act of 1964 to underground and surface portions of the Park (W. Drew Chick, Jr., written communication, 1967). Scientific evidence bearing on the relationships between human surface activities and natural underground openings was examined and discussed at the symposium. This report discusses relations between various types of surface activities and physical damage to the cave openings and features. Additional interpretive material is taken from the literature and from limited laboratory information. Possible hydrologic and biologic effects are not considered here, but were investigated by other members of the symposium. Hydrologic effects are discussed in a companion report by Robert V. Cushman of the Geological Survey.

During the brief investigations on which this report is based, three factors bearing on possible physical damage to the caves were considered:

1. Possible damage to the Flint Ridge cave system from nearby highway construction (fig. 1).

2. Possible damage to the caves by use of heavy construction machinery, by vehicular traffic, and by other activities, at the Great Onyx Job Corps Training Center on Flint Ridge (fig. 1).

3. Deformational features in the caves which may have been caused by human activities or which may indicate potential hazards to cave visitors.

Three kinds of damage to the caves are considered to be possible:

1. Breaking of speleothems.

2. Failures of walls or roofs.

3. Dislodging of loose rock masses.

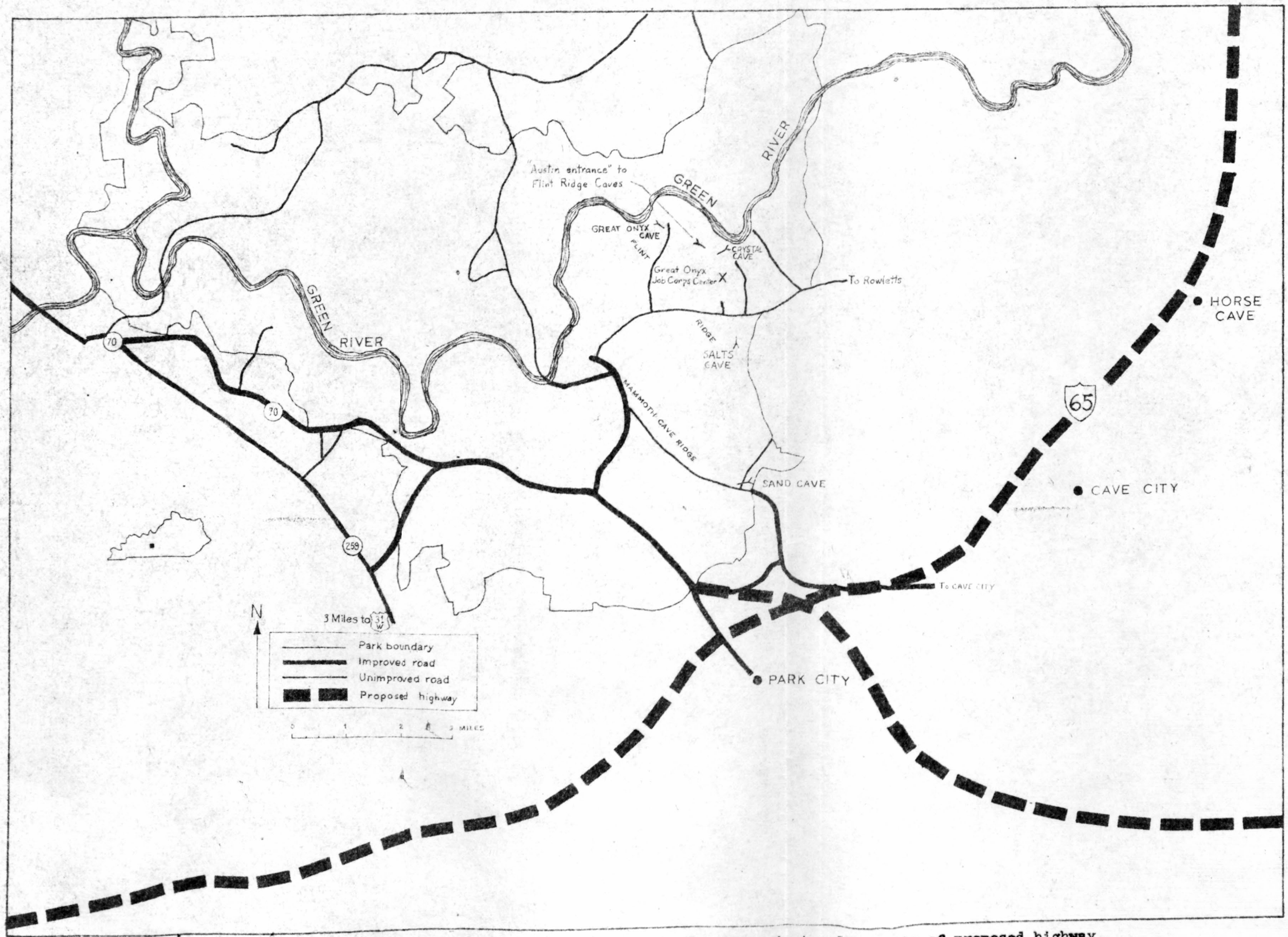


Figure 1.--Index map of Mammoth Cave National Park area, showing approximate alignments of proposed highway construction, and localities discussed in text. Modified from National Park Service map.

The surface geology of the Mammoth Cave area has been mapped in detail by Haynes (1964), and has been described by Lobeck (1929) and by Livesay (1962). In general, the cave openings are in limestones of the Girkin Formation and in the upper part of the Ste. Genevieve Limestone; both rock units are of Mississippian age. The cave openings are the result of solution along an extensive system of underground drainages, tributary to the Green River (Brown, 1966, p. 11-16; Cushman, Krieger, and McCabe, 1965, p. 610-613). Topographic ridges in the area, beneath which are located most of the known cave openings, are capped by the Big Clifty Sandstone Member of the Golconda Formation of Mississippian age. The Big Clifty is overlain by remnant patches of the Haney Limestone Member of the Golconda Formation and by remnants of the Mississippian Hardinsburg Sandstone (Haynes, 1964).

## POSSIBLE CAVE DAMAGE FROM HIGHWAY CONSTRUCTION

Two large highway projects are in progress south and east of Mammoth Cave National Park (fig. 1). To investigate possible blasting damage to the cave systems, field examinations at the Park were supplemented by literature and laboratory investigations pertaining to the propagation in limestones of elastic waves from quarry blasts.

Limestones vary widely in elastic properties which govern the transmission and attenuation of elastic waves (Wuerker, 1956, table 3). Velocities of compressional and transverse waves in cores of the Girkin Formation were measured in the laboratory (table 1).

Quarry blasts generate large amounts of energy in seismic (elastic) waves, but are commonly attenuated in short distances from the blast point. Most of the energy from nearby quarry blasts is transmitted by elastic waves that vibrate at frequencies averaging near 25 cps (cycles per second) and ranging from 5 to 50 cps (fig. 2).

Table 1.--Engineering properties of selected rocks from Mammoth Cave National Park, Kentucky

[Analyst: A. F. Chleborad, U.S. Geological Survey]

| ratory No. 02- | Rock name | Compressional velocity (ft/sec) | Compressional velocity (km/sec) | Shear velocity (ft/sec) | Poisson's ratio | Young's modulus ($10^6$ psi) | Shear modulus ($10^6$ psi) | Bulk modulus ($10^6$ psi) | Whole core: Dry bulk density 1/ (g/cc) | Whole core: Porosity [calculated total] (percent) | Grain density 2/ (g/cc) | Saturated bulk density 3/ (g/cc) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5X | Big Clifty Sandstone Member, Golconda Formation, parallel to bedding. | 8,931 | 2.72 | 4,948 | 0.28 | 1.30 | 0.50 | 0.98 | 1.75 | 33.96 | 2.65 | 2.09 |
| 5Y | Big Clifty Sandstone Member, Golconda Formation, normal to bedding. | 10,263 | 3.13 | 5,482 | .30 | 1.84 | .71 | 1.54 | ----- | ----- | ----- | ----- |
| 6X | Limestone of Girkin Formation (calcarenite), parallel to bedding. | 20,829 | 6.35 | 10,616 | .32 | 8.29 | 3.14 | 7.68 | 2.07 | 23.33 | 2.70 | 2.30 |
| 6Y | Limestone of Girkin Formation (calcarenite) normal to bedding. | 21,892 | 6.68 | 11,866 | .32 | 9.38 | 3.55 | 8.69 | ----- | ----- | ----- | ------ |
| 7X | Hardinsburg Sandstone, parallel to bedding. | 8,882 | 2.69 | 5,234 | .24 | 1.69 | .68 | 1.09 | 1.85 | 30.19 | 2.65 | 2.15 |
| 7Y | Hardinsburg Sandstone, normal to bedding. | 8,455 | 2.58 | 5,172 | .20 | 1.60 | .67 | .89 | ----- | ----- | ----- | ----- |
| 8 | Stalactite, Mammoth Cave. | 25,107 | 7.65 | 12,928 | .32 | 15.81 | 5.99 | 14.63 | 2.66 | .02 | 2.72 | 2.68 |

1/ Calipered method.
2/ Powdered grains in kerosene.
3/ Calculated fractional porosity plus dry bulk density.

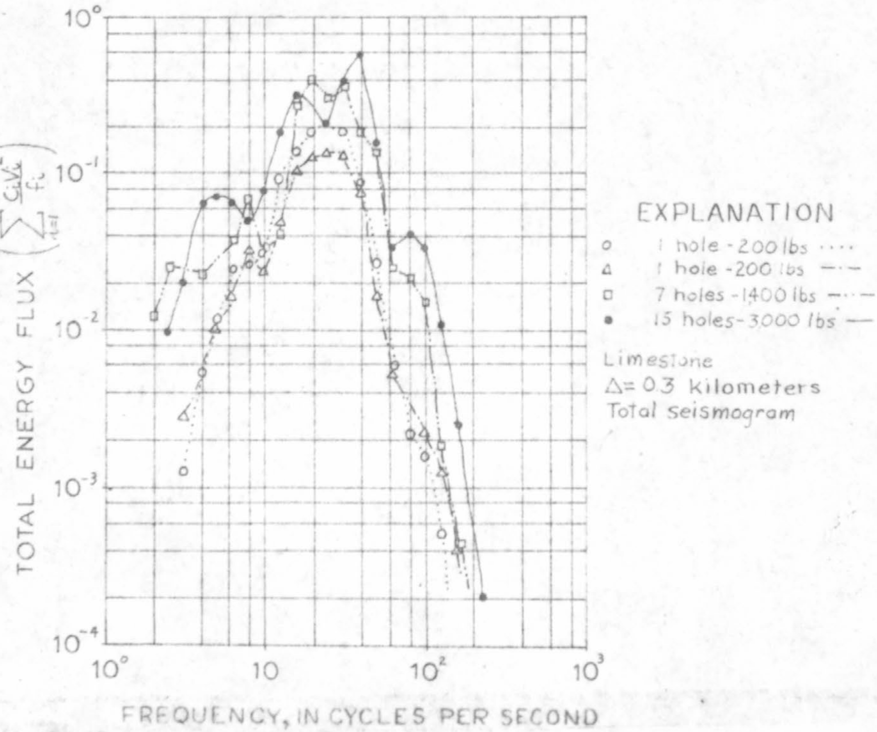


Figure 2.--Energy spectra from nearby quarry blasts, after Frantti (1963a). ($C_i$ = propagation velocity, $V_i$ = ground particle velocity, $f_i$ = frequency).

Studies made by Hudson, Alford, and Iwan (1961, p. 199) indicate that a blast of about 300 tons of explosive will yield a probable ground acceleration of only 0.03 g at a distance of 5,000 feet from the shotpoint and that a blast generated by approximately 2,000 tons of explosive will yield a ground acceleration of only 0.03 g at a distance of 10,000 feet from the shotpoint (fig. 3). The nearest expected major construction in the Mammoth Cave National Park area is about 3 miles from the Flint Ridge cave system (fig. 1). Hudson, Alford, and Iwan found that the measured ground accelerations from 3 large quarry blasts were less than the predicted accelerations (fig. 3). Such blasts are generally larger than those used in highway construction. Furthermore, Frantti (1963b, p. 996) and Willis (1963), who studied the energy spectra from ripple-fired quarry blasts, concluded that it might be possible partly to control the seismic energy levels from such blasts by regulating the time duration between the individual shots in the blast, relative to the expectable wave velocities and wavelengths. This suggests that ground accelerations in the caves might be further reduced by proper design of the blast delay patterns, if the elastic properties and wave velocities of the Girkin Formation and Ste. Genevieve Limestone are measured in the field.

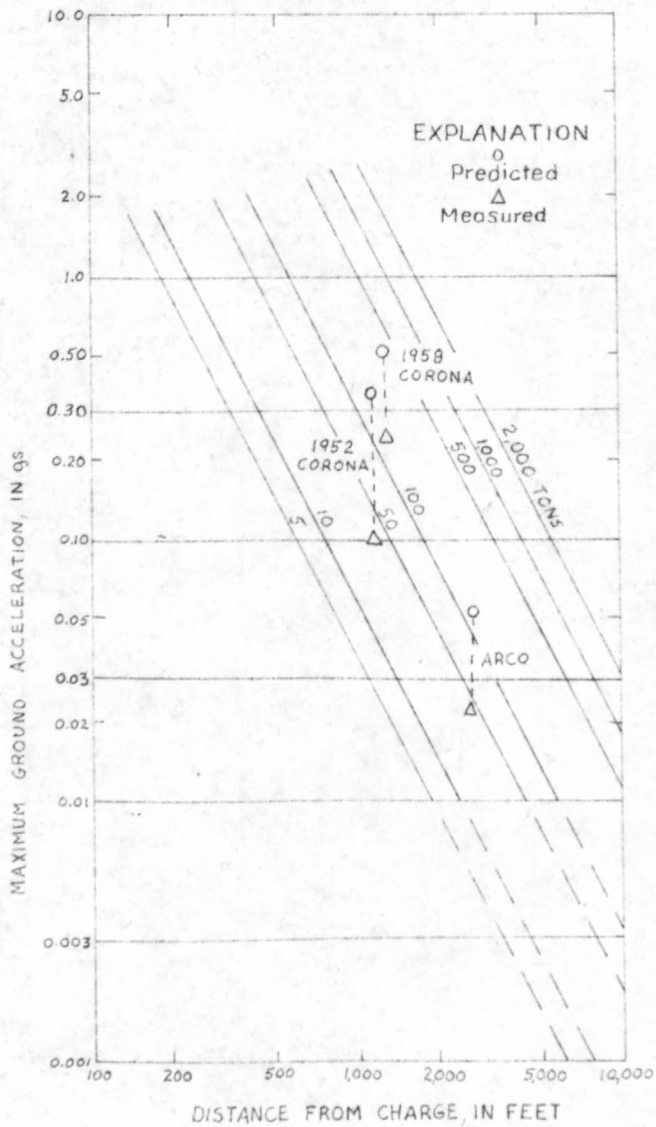


**Figure 3.--Graph showing relationship between ground acceleration, distance from shot location, and charge weight for large blasts, extended from Hudson, Alford, and Iwan (1961, fig. 9).**

The caves of Mammoth Cave National Park probably have, in the past, been subjected to earthquake-generated natural accelerations much larger than those expected from the proposed highway blasting (table 2). Accelerations from earthquakes can be estimated by the following empirical formula (Richter, 1958, p. 140):

$$\log a = \frac{I}{3} - 1/2$$

a = acceleration in cm/sec$^2$

I = Modified Mercalli earthquake intensity, 1956 version

For an earthquake of intensity VI (in which weak plaster and weak masonry will crack) (Richter, 1958, p. 137):

$$\log a = \frac{VI}{3} - 1/2 = \frac{6}{3} - 1/2 = 1.5$$

$$a = 31.6 \text{ cm/sec}^2 \quad \text{or about } 0.032 \text{ g.}$$

As shown in table 2, several earthquakes have been of sufficient intensity to have produced accelerations of 0.03 g or more in Mammoth Cave National Park. Therefore, the attenuated elastic waves from blasting during proposed highway construction will be unlikely to cause damage to the caves.

One possible exception to this conclusion might be damage from resonance effects, to the few long and slender speliothems that are present. Elastic waves impinging on speliothems at even low energy levels, but vibrating at their natural frequency, could cause structural damage or breakage. The phenomenon is complex and could only be adequately evaluated by proper field instrumentation of the longest stalactites and stalagmites during blasting or during other vibration-generating activity to study their response.

Table 2.--Some earthquakes that produced effects of intensity VI or more in the Mammoth Cave area

[after U.S. Coast and Geodetic Survey, 1965, p. 36-48]

| Date | | Epicenter | Remarks |
|---|---|---|---|
| 1811 | December 16 ) | New Madrid, Mo. | Damage to buildings in Tennessee, Kentucky, Missouri. Felt from Canada to New Orleans. Intensity XII |
| 1812 | (January 23, ) | | |
| | (February 7 ) | | |
| 1843 | January 4 | Near Memphis, Tenn. | Felt in Ohio, North and South Carolina |
| 1895 | October 31 | Charleston, Mo. | Felt from Canada to Mississippi, Virginia to South Dakota, Wisconsin, Illinois, Ontario. |

To estimate the possible longitudinal resonance effects of blast-produced seismic waves on stalactites and stalagmites, these cave features were considered as if they were bars, clamped at one end, and vibrating at an average blast vibration frequency of 25 cps (fig. 2). Estimates were then made, using probable elastic properties for a stalactite from Mammoth Cave, to find the length of speliothem necessary to resonate and possibly break (table 1). According to White (1965, p. 86) in order for a bar to resonate longitudinally, the following equation must be satisfied:

$$\text{If } f_n = \frac{nCy}{2L},$$

$$2L = \frac{nCy}{f_n},$$

$$\text{and } L = \frac{nCy}{2f_n}$$

Where

$f_n$ = natural frequency

$n$ = number of wave lengths in the bar

$C_y$ = speed of compressional wave propagation governed by Young's modulus

$L$ = length of the bar.

If $n = 1$ (for the shortest possible bar) and

$Cy = 7.65$ kilometers/second ($Cy$ is assumed to be close to velocity of compressional waves) and

$f_n = 25$ cps,

Then $$L = \frac{(1)\ (7{,}650 \text{ m/sec}}{(2)\ (25 \text{ cps})} = 153 \text{ meters}$$

$L = 153$ m, the minimum length for a calcium carbonate speliothem to resonate longitudinally at 25 cps.

It is not possible, at present, to estimate the amount of base acceleration or torque necessary to break a stalactite or stalagmite by mechanisms of cavity surface vibration or angular resonance (pendulum resonance) because of the complex and partially unknown relationship between the torque exerted on a speliothem and the type and degree of polarization of the wave, shape of the wave, and the moment of inertia of the speliothems. As shown in table 1, however, measured properties of a stalactite from Mammoth Cave indicate that it is stronger than Girkin limestone.

## POSSIBLE CAVE DAMAGE FROM MACHINERY OPERATION

Some activities at the Great Onyx Job Corps Training Center (fig. 1) were observed briefly to determine whether such activities might cause damage to the Flint Ridge cave system. These activities consisted of vehicular traffic, operation of construction machinery, and construction of two sewage lagoons. The vehicular traffic is mostly passage of cars, light to medium trucks, and small buses, along roads that probably were established before 1942. A vehicle park, equipment yard, and shop are also located at the center. At the time of the examination, a trainee was using a small, tracked, front-end loader pulling a sheep's foot roller to compact an area near the shops for a ball field. Heavier equipment and heavy-construction training activities are located outside the Park boundaries (Charles F. Riebe, oral communication, 1967). The construction of the sewage lagoons is described briefly later in the report.

Vibrations caused by operation of construction machinery are characteristically of higher frequency than those caused by blasting. Research in deep Canadian mines in crystalline metamorphic rocks "...indicated that bursts and blasts each generate a wide spectrum of seismic frequencies, the former up to 200 to 400 cps (cycles per second) and the latter 40 to 60 cps. Other mine noises, except drills, were found to generate frequencies of about 100 cps. The frequency for drills was about 200 cps..." (Hodgson, 1958, p. 237). Vibrations in the sandstones and limestones of Flint Ridge probably would be slightly lower than those reported by Hodgson.

Attenuation of seismic waves is a function of frequency of vibration (White, 1965, p. 110-113); waves of high frequency are attenuated in shorter distances than waves of low frequency. Therefore, waves generated by machinery probably will be attenuated within shorter distances than waves caused by blasting. Without direct field measurements of amplitudes of waves from specific machines, and of the attentuation of these waves in Flint Ridge, no precise distances can be given in which these waves will be reduced to an insignificant amplitude. The attenuation of transverse (shear) waves, however, which in limestones are probably of greater amplitude than compressional waves, is nearly 20 db or 100 times as great for waves vibrating at 50 cps as it is for waves vibrating at 25 cps (fig. 4B). Longitudinal (compressional) waves will be attenuated much less rapidly than shear waves (fig. 4A). If, however, the maximum acceleration due to elastic waves from a large machine is allowed to be one tenth (0.1) as large as the acceleration due to waves generated by a 100 ton quarry blast, and if the blast is attenuated to a safe value within 5,000 feet, then the machine-produced vibrations should be safe at about 500 feet in limestone. Vibrations from machines and vehicles on Mammoth Cave Ridge and on Flint Ridge, however, will pass down through about 70 feet of Hardinsburg Sandstone and as much as 110 feet of Golconda Formation (sandstone, with lesser amounts of limestone and shale) (Haynes, 1964), to reach the top limestone of the Girkin Formation, in which the caves are located. Because the velocities are lower in these sandstones (table 1), the attenuation probably will be greater at these relatively high frequencies.

Unpublished results obtained by the author and C. R. Dunrud in the coal mines in Utah indicate that the 500-foot distance for safe attenuation of machine-produced waves is conservative. Vibrations from a large, continuous-mining machine were not even recorded by a seismometer located 800 feet away. Furthermore, some of the elastic energy in the waves probably will be refracted or reflected at the base of the Hardinsburg and at other rock contacts before it reaches the caves; this would further reduce the amplitude of vibration.

The Great Onyx Job Corps Center, when plotted on maps by reference to surface topographic features, is not above any cave openings shown on 1967 underground maps of the Cave Research Foundation, and probably is not within 600 feet of any known openings. The operation of vehicular equipment or machinery at the Center is not likely to cause any physical damage to the Flint Ridge cave system. This conclusion, however, should be checked, either by accurate surface and underground survey or by geophysical investigations or by both.

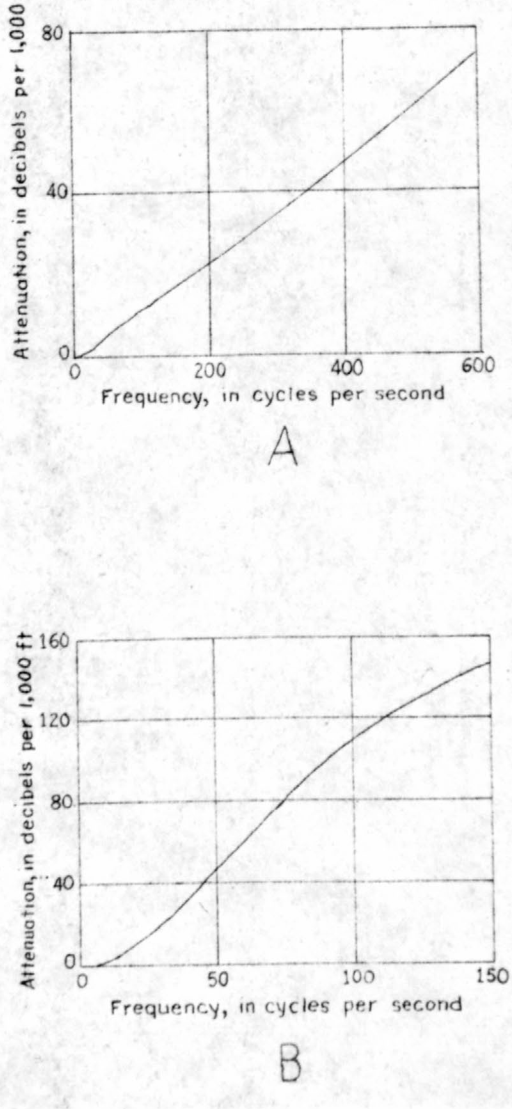


Figure 4.--Attenuation of seismic (elastic) waves as a function of frequency. After Horton (1959). Decibels (db) = Logarithm of the ratio of power transmitted to power received.

A. Attenuation of compressional waves.

B. Attenuation of transverse waves.

Two recently constructed sewage lagoons are designed to be operated in a cascade manner with an existing lagoon. The new lagoons were constructed of local soil mixed with clay, and the floors were compacted for 80 hours with the tracked loader and sheep's foot roller to give an impervious floor (Charles F. Riebe, oral communication, 1967). According to Mr. Riebe, the sheep's foot exerts a downward pressure of 250 psi on each "sheep's foot," and the tracked loader considerably less pressure. These pressures are much less than the compressive strengths of the rocks (table 1) and are not considered to be great enough to have an effect on subjacent cave openings. The walls of the new lagoons were examined closely but no evidence of leakage was found although the lower lagoon contained several feet of water from rain that had fallen 2 weeks previously. No evidence was seen indicating that the construction and compaction of these lagoons had any physical effect on the cave system. That the local soil derived mostly from weathering of sandstones had to be mixed with clay to construct impervious compacted floors suggests that normal vehicular traffic along the few roads and within the vehicle yard at the Center will not prevent downward percolation of surface water into the caves by excessive local compaction of the soil.

## CAVE FEATURES IN RELATION TO HUMAN ACTIVITIES

Some features in the caves may affect or be related to various human activities. These include deformational structures in the cave openings, mineral zoning and growth in the caves, and features that constitute potential hazards to persons in the caves.

### Deformational features

Deformational features are geologic structures that are of more recent age than the cave openings. They result from response of the rocks near openings to external stresses, aided in part by solution along joints and bedding planes and by undercutting by cave streams. Observed deformational features included cymoidal fractures and roof synclines similar to those in coal mines (Osterwald, 1962, p. 66, 68).

Cymoidal fractures (fig. 5A) are curving, flattened S-shaped fractures resulting from commonly vertical compressive stress in the walls. Such fractures nearly parallel bedding planes near the roof of the cave, steepen downward into the walls, and probably flatten again near the floor of the caves. Such fractures are found in many parts of the Flint Ridge and Mammoth cave systems. In Mammoth Cave they are common where crossbeds in the limestones of the Girkin and Ste. Genevieve are parallel to the expectable orientation of cymoidal fractures and where large sections of cave openings cause high stress concentration. Thin curving slabs of unsupported rock that project into the cave openings are produced by slight slipping movements along cymoidal fractures. Further weakening of these slabs by solution or by even slight vibrations will cause them to fall. Such slabs are particularly abundant in the outer end of Pohl Avenue of the Flint Ridge cave system. Pohl Avenue has a low arch-shaped cross section, but many thin curving slabs, some as much as 50 feet long, have fallen from the roof. Infall of these slabs results from a long-continuing natural process; it has proceeded throughout the geologic history of the caves and will continue until the caves no longer exist. It has not resulted from any human works, and cannot be considered damage to the cave.

Roof synclines (fig. 5B) are sags in the roof in which rock layers may actually separate. They are nearly parallel to the trend of the cave openings, and result in tensional failure by bending of the strata in the roof. Roof synclines are most common in those parts of the caves with nearly flat roofs in thin-bedded rocks. They are the result of small amounts of relative horizontal movement along bedding planes, caused by small horizontal stress components (Osterwald, 1962, p. 68). If these stress components are applied long enough, the roofs will fail in tension, causing blocks of rock to fall into the opening. Roof synclines are particularly pronounced in Floyd Collins' Crystal Cave ("Crystal Cave" on fig. 1), and apparently are most prominent in those parts of the cave where floor sediments have been excavated to provide trails for visitors. The excavation probably altered the stable, natural stress distribution around the openings, thereby exerting additional horizontal stress on the flat, thin-bedded roof. Only slight further disturbance of these roofs may be necessary to cause loose blocks of rock to fall into the openings.

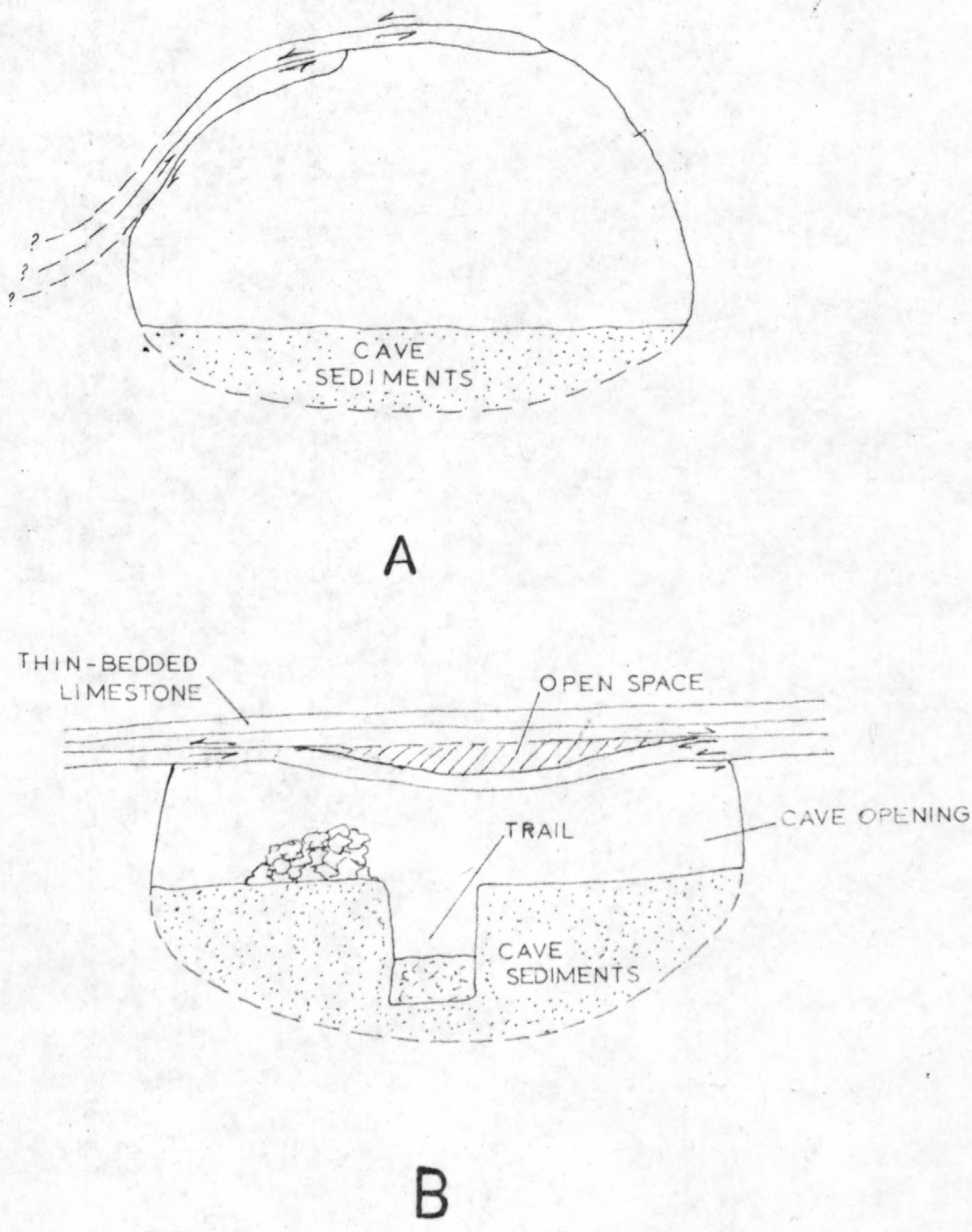


Figure 5.--Diagrammatic sketches of deformational features in caves of Mammoth Cave National Park, A. Cymoidal fractures, B. Roof synclines and tensional failure. Arrows indicate direction of relative movement.

Masses of rock loosened by deformational features, weakened by solution along bedding and joint planes, and disturbed by stress-readjustment from natural near-surface activity such as hillside creep, are major contributors to the so-called "terminal breakdowns" of Brucker (1966). Together with joint blocks loosened by solution in dome-pits and canyons, they constitute one of the major factors in active underground erosion of the vadose parts of the cave systems. These processes have operated for long periods of time--many fallen blocks of rock are embedded in cave floor sediments, above the flood-levels of present-day streams. The block-falls are at least as old as Pleistocene, and are clearly not the result of any human activities. Many fallen blocks in Salts Cave were evidently down before the cave was visited by prehistoric people as much as 3,000 years ago (Watson, 1966; Benington and others, 1962), but some small blocks have fallen more recently, as evidenced by the fact that the scars on roof and walls from which they fell are not blackened by smoke from the primitive torches. Dislodging of blocks is a continuing, natural process that cannot be prevented--blocks will continue to fall. It does constitute a potential hazard to visitors to the various caves which can, however, be partly minimized by carefully observing and avoiding particularly loose slabs. The process is probably most active during and slightly after periods of heavy rainfall--when solution is most active in the caves. That dislodging of loose blocks is a hazard to cave visitors is demonstrated by the mummy of a prehistoric gypsum miner who was killed by a 5-ton block (Livesay, 1962, p. 32).

## Mineral zoning and growth

A form of mineral zoning is common in many parts of the cave systems but is particularly pronounced in Great Onyx Cave. Calcium carbonate minerals in flowstone, dripstone, and rimstone forms are actively forming in wet parts below the present valley slopes. Towards the ridges from these wet parts and beneath the edges of the present ridges, these forms become smaller, less active, and in some places are replaced by carbonate helictites. Farther inward beneath the ridges the caves become still drier, and calcium sulfate minerals, particularly gypsum, become abundant. In the very dry parts, other sulfate minerals such as mirabilite (Glauber's salt) are found. No evidence was seen indicating that the zoning has been altered by or is the result of any surface works of man. On the contrary, the close correspondence between mineral forms which grow very slowly--1 cubic inch per 100 years on a given speleothem is the rate estimated for carbonate dripstone and flowstone (Livesay, 1962, p. 20)--and the present hydrologic conditions in the caves suggests that surface activities have not significantly altered the physico-chemical conditions in the cave.

Mineral zoning and growth does have a small bearing on the relative safety of visitors. Blocks of rocks loosened by the various processes described are recemented in areas of active carbonate deposition. Sulfate minerals, however, tend to grow in the rocks along bedding planes, joints, cymoidal fractures, and other features. Because of the force of crystallization of the sulfate minerals, the stress around the minerals is increased, eventually causing the limestone to break, and loose blocks eventually to fall into the openings. This also is a natural process that cannot be prevented. The hazard is probably small, and can also be minimized by carefully observing and avoiding locations under dangerous blocks.

Potential hazard of the Austin entrance

The so-called Austin entrance to the Flint Ridge cave system (fig. 1), which was artifically excavated in the early 1950's, contains several large loose blocks of rock. The entrance consists of an opencut trending southeast into the side of a ridge, and is nearly parallel to one set of regional joints; the opencut leads into a mined opening in the Girkin limestone. Several small dynamite charges were used in the excavation of this opening (W. T. Austin, 1967, oral communication). At the time of the examination on which this report is based, three large limestone blocks up to 4.5 feet in diameter had rolled into the opencut, nearly blocking the portal. The portal was partly supported by a few old, partially rotten timbers on each side. Above the portal, other large blocks of Girkin limestone, separated by open, steeply dipping joint planes, are supported only by a partial keystone effect and by the old timbers. This portal is extremely unsafe.

## CONCLUSIONS

No evidence was seen by the writer to indicate that human surface activity has caused any physical damage to the Flint Ridge caves. Nearby highway construction projects, as presently planned, are not likely to have any effect on the caves, even from heavy blasting, because the alignments are 3 to 6 miles from the cave systems. Elastic waves generated from such blasts will be greatly attenuated at these distances. The use of heavy construction equipment at the Great Onyx Job Corps Center is not likely to cause physical damage to any cave features because the Center is not directly over any known cave openings, and because the relatively high-frequency vibrations from the equipment will be attenuated within a few hundred feet. Acceleration resulting from such vibration probably will be less in the openings than the effects resulting from nearby activities of cave explorers.

The conclusions that blasting and machine vibrations will not harm the caves are based on limited theoretical considerations, on data taken from the literature, and on a limited amount of laboratory work. The conclusions are thought to be based on conservative estimates of the probable elastic response of various geologic units. If, however, it is desired to further check these conclusions, the following work is recommended:

1. Field seismic measurements by competent specialists to determine wave velocities and attenuations and also response of cave features in place, and in various directions.

2. Field measurements of the frequencies and amplitudes of waves generated by various vehicles and machines at the Great Onyx Job Corps Center.

3. Accurate resurveys of the Job Corps Center equipment yard and shop area, tied carefully to subjacent cave openings, using permanent bench marks and a mine transit or theodolite. This work should be done by a mining engineer who is experienced in underground surveying.

4. Resistivity surveys of the area around the Job Corps Center to delineate any possible unknown cave openings, as was done in England (Oldham, 1965).

5. Soil sampling and laboratory testing in the Job Corps Center, to determine the physical properties, porosity, and permeability of compacted native soils.

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1. Some engineering geology problems at Mammoth Cave National Park, Kentucky, by Frank W. Osterwald. 35 p., 5 figs. 710 West High St., Lexington, Ky. 40508.

2. Comparison of a UV scanner/photomultiplier with an image orthicon, by Howard Goldman and Robert Marshall. 14 p., 1 fig., 1 table.



Corrected list of depositories for the following report, open-filed on July 24, 1967:

Mineral investigations in northeastern Thailand, by Herbert S. Jacobson, Charles T. Pierson, Thawisak Danusawad, Thawat Japakasetr, Boonmai Inthuputi, Charlie Siriratanamongkol, Saner Prapassornkul, and Narin Pholphan. 276 p., 11 pl., 23 figs., 12 tables. Office of the Director General, Royal Dept. of Mineral Resources, Roma VI Road, Phyathai, Bangkok, Thailand; Office of the Executive Agent, Committee for Coordination of Investigations of the Lower Mekong Basin, ECAFE, United Nations, Sala Santitham, Bangkok, Thailand; United Nations, Geneva, Switzerland; United Nations Information Center, London, England; and UNESCO Headquarters Library, Paris, France.