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...If you call out for

Insight...

You will understand the fear of the LORD and find the knowledge of God.

Based on Proverbs 2:3-5

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Origin of Limestone Caves

by Steven A. Austin, Ph.D. *

Introduction

A cave is a natural opening or cavity within the earth, generally extending from the earth's surface to beyond the zone of light. Three generic classes of caves can be recognized according to the major sculpturing process: (1) caves formed by pressure or flow, (2) caves carved by erosion, and (3) caves dissolved by solution. Those structures formed by mechanical pressure or flow include lava tunnels associated with volcanoes (e.g., Catacombs Cave in Lava Beds National Monument, California) and "badland caves" excavated from poorly consolidated rock by hydraulic pressure (e.g., small caves of the arid Badlands of South Dakota). The caves carved by erosion include shoreline grottos created by the mechanical action of waves (e.g., La Jolla sea caves near San Diego, California) and rock shelters cut by river meanders (e.g., the massive sandstone alcoves of the famed cliff-dwelling Pueblo Indians). The caves dissolved by solution include ice caves associated with glaciers and the familiar limestone caverns or caves. Limestone caves are, by far, the most common type of caves.

The great size and beauty of limestone caves have made them features of public amazement and wonder. More than 130 caves in the United States are open commercially, and at least 13 national parks and monuments contain caves. The world's longest cave appears to be Kentucky's Mammoth Cave which has more than 240 kilometers (150 miles) of accessible passages. The largest subterranean chamber yet discovered is the Big Room of New Mexico's Carlsbad Caverns. The Big Room is about 400 meters (1,312 feet) long, 200 meters (656 feet) wide, 90 meters (295 feet) high, and contains the Great Dome, a stalagmite 19 meters (62 feet) tall. Gouffre Berger Cave near Grenoble, France, descends at least 1,100 meters (3,680 feet) below the surface and is the deepest cave yet explored by man. Records of the National Speleological Society of America indicate more than 11,000 caves in the United States, and it appears likely that 100,000 caves exist in the whole earth.

Caves are of interest to the student of the Bible because the Bible lands are rich in limestone caves. In Old Testament times caves often served as refuge or

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emergency shelter (Genesis 19:30; 1 Samuel 22:1, 24:1-8; Hebrews 11:37-40). Caves were also used as places of burial (Genesis 23:17; John 11:38). After the great confrontation between Elijah and the prophets of Baal, Elijah lodged in a cave and received the Word of the Lord there (1 Kings 19:9 - 11). Psalms 57 and 142 were composed in a cave by David after he fled from Saul. The famed "Dead Sea Scrolls" were discovered in caves.

A great deal of scientific interest has been generated by caves. Speleology is a multidisciplinary science which deals with the cave environment: cave discovery, exploration, surveying, archaeology, zoology, botany, paleontology, meteorology, and geology. Mineralogists and gem collectors know that caves contain many large and perfect crystals. Paleontologists have found fossils in caves which shed light on the history of man (e.g., Neanderthal man). Geologists have attempted to answer several theoretical and practical questions posed by caves. One of the most difficult problems has been to interpret the history of limestone caves in relation to the Biblical framework for earth history.

Solution of Limestone

Solution cave chemistry can be simply stated: limestone and dolostone, the host rocks for most caves, are dissolved by natural acids (carbonic, sulfuric, and various organic acids) which occur in groundwater. Calcite ($CaCO_3$), the principal mineral comprising limestone, is dissolved in the presence of acid to produce calcium ion (Ca^{++}) and bicarbonate ion (HCO_3^-). Dolomite [$CaMg(CO_3)_2$], the most important mineral in dolostone, is dissolved by acid to produce calcium ion (Ca^{++}), magnesium ion (Mg^{++}), and bicarbonate ions (HCO_3^-). If the acid is able to flow through the rock, ions will be removed and a cavity or solution conduit will form.

That many limestone caves formed by the solution process is indicated by four types of geologic evidence.

1. *Modern limestone caves often show evidence of ongoing solution* - the groundwater leaving a cave often has a higher concentration of calcium and bicarbonate ions than the water entering the cave.[1] Dripstone deposits on the interior of caves prove that solution occurs above the cave.

2. *The shapes of bedrock structures in limestone caves often resemble those produced in solution experiments*. For example, the shapes produced at intersections of joints in cave bedrock can be predicted based on the theory of solution kinetics.[2]

3. *The passages in limestone caves usually follow joints, fractures, and the level of the land surface in such a way as to suggest that the permeability of the bedrock has influenced the position of cave passages*. Maps and cross-sections of caves often show the regular spacing and orientation of passageways caused by joints.[3]

4. *Caves resembling those found in limestone and dolostone do not occur in insoluble, non-carbonate rocks*. The apparent causal relationship implies that some characteristic of the rock (i.e., solubility) has affected the occurrence of the caves.

Solution Theories

That solution is a major factor in the formation of limestone caves appears to be well substantiated. The hydrologic conditions and sequence of events leading to cave formation, however, are poorly understood by geologists. The Encyclopedia Ameri-

near the surface. The tectonic forces would induce movement on joints and build up fluid pressure, and the removal of overburden would make compaction in and flow from partially consolidated sediments proceed at faster rates. The pressure gradient would have been highest near the surface, causing sediment to be removed by piping. As the joints were opened, a conduit system for vertical and horizontal flow would have been established.

Step 3 - Horizontal groundwater drainage and solution of limestone.

After the flood waters had completely receded, the regional groundwater level would be in disequilibrium and horizontal flow would be significant. Acids from organic decomposition at the surface and at depth would tend to move to just below the water table where the highest horizontal velocities of flow would exist. Solution of newly consolidated limestone would occur chiefly in horizontal conduits at a level just below the water table. The mixing of vadose water (CO_2 rich, oxygen rich, organic poor, and low salinity) with phreatic water (CO_2 poor, oxygen poor, organic rich, and high salinity) would also produce conditions ideal for solution of limestone near the water table. As a result, a cave system would be developed at a certain level.

Step 4 - Deposition of speleothems.

After the groundwater drainage had been largely accomplished and the caves dissolved out, the water table would be at a lower level and caves would be filled with air, not water. Thus, the final step would be the rapid deposition of stalactites, stalagmites, and flowstone.

Conclusion

Caves are among the most fascinating structures in the earth's crust. The processes which removed material from caves in principle are rather simple, but they were manifest geologically in response to many environmental factors. Deposition in caves was also complex. Although there is much in caves to challenge further study, it appears that they can be interpreted within the basic framework of earth history presented in Scripture.

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complex environmental factors which affect the rates of solution of calcite (see above discussion). Therefore, some of the great ages for speleothems claimed by cave guides and "spelunkers" may be significantly in error.

A large number of reports concern the rapid growth of stalactites and stalagmites.[17] Most of these observations have been made in tunnels, bridges, dams, mines, or other dated man-made structures which approximate cave conditions. Fisher[18] summarized some of the early literature where stalactite growth averages about 1.25 centimeters (0.5 inch) yearly with some observed to grow over 7.6 centimeters (3 inches) yearly. Stalagmites observed by Fisher grew 0.6 centimeter (0.25 inch) in height and 0.9 centimeter (0.36 inch) in diameter at the base each year. At this rate of height increase the 1,900 centimeter tall stalagmite called "Great Dome" in Carlsbad Caverns might grow in less than 4,000 years.

A large stalagmite like Great Dome may contain 100 million cubic centimeters of calcite, which, if accumulated in 4,000 years, would require a deposition rate of 25,000 cubic centimeters (67,000 grams) of calcite yearly. If the dripping water is assumed to deposit 0.5 gram of calcite per liter, 133,000 liters of water would have to drip over the stalagmite each year. Because about 6,000 drops comprise 1 liter, it would take about 800 million drops of water per year to form the stalagmite. This works out to 25 drops of water per second; which is a considerable flow. Whether a stalagmite would be deposited in the above hypothetical situation is not known. One would want to carefully examine the assumptions and the complex environmental factors which might affect stalagmite growth.

In addition to the observations of speleothem growth in cave or cave-like natural environments, some interesting experiments have been performed to simulate stalactite and stalagmite growth in control led laboratory situations. Williams and Herdklotz[19] are studying the effects of acidity, salinity, temperature, humidity, and other factors on rates of stalactite growth in the laboratory. Their work applies to natural cave environments, and indicates that stalactites can form very rapidly.

A Model for The Origin of Caves

Having examined the processes which can form limestone caves, we are now ready to formulate a model which is consistent with the geologic data and in harmony with a Biblical framework for earth history.[20]

Step 1 - Deposition and burial of limestone.

The first step for the formation of a cave is obviously to deposit the limestone. Most major limestone strata appear to have accumulated during the Flood. After a lime sediment layer (which later contained a cave) was deposited, it would have been buried rapidly under perhaps several thousand feet of sediments. The weight of overburden would compact the lime sediment and tend to expel interstitial water. Although the fluid pressure would have been great within the sediment, the lack of a direct escape route for the pore water would impede water loss and prevent complete lithification. The major means of water loss was probably through joints which formed during the early stage of compaction while the sediment was only partially consolidated.

Step 2 - Deformation and erosion of limestone and overburden.

As the Flood waters receded, tectonic activity would deform the sediments and bevel the upper layers down to a new level. The lime sediment layer would again be

cana begins its discussion of the origin of solution caves with the following admission:

> The origin of solution caves in limestone and related rocks is complex, and scientists are not in full accord as to the exact sequence of events that lead to the formation of such caves.[4]

The problem is that we are attempting to understand the origin of a cavity for which the evidence of the events forming it has been largely dissolved.

Two basic types of theories concern the water conditions when the cave formed. These are the vadose and phreatic theories.[5] The vadose theory suggests that solution of the cavity occurred while the limestone was above the level of groundwater (water table) and that the cavity was largely filled with air. The phreatic theory claims that the cavity formed when it was below the level of groundwater when it was completely filled with water.

Non - Solution Processes

Although solution was a major process in the formation of limestone caves, some major problems are encountered if these caves are considered to have formed only by solution. The first problem is the origin of the original fracture porosity along which circulation of acidic groundwater could be initiated. The original hairline fractures in the limestone would not transmit water, and, therefore, solution conduits would not be expected to form. Davis[6] suggested that groundwater flow could be initiated by tectonic stresses on the rock which opened fractures and created the driving force for fluid flow. The process of "piping" (the production of underground conduits by removal of fine particles by water driven by pressure through poorly consolidated material) may also be important in producing fracture porosity. "Badlands caves" in shaly rocks form by this process.

A second problem for solution theory is the evidence of erosion and abrasion in limestone caves. Many caves contain large amounts of clay, gravel, cobbles, and boulders which could not have been dissolved from the limestone. Instead, the cave-filling material appears to have been transported by moving water from a sediment source outside the cave. These cave deposits show that some caves at one time were essentially "underground rivers," and, as such, could have experienced abrasion and erosion such as occurs in modern channels. The amount of material removed from caves by this process, however, appears to be small compared to that removed by solution.

Factors Affecting Solution

The solubility of calcite and dolomite, and the rate at which solution occurs, are dependent on at least eight factors: amount of carbon dioxide in solution, pH, oxidation of organic matter, temperature, pressure, concentration of added salts, rate of solution flow, and degree of solution mixing. Calcite is more soluble if carbon dioxide is increased, acidity is increased, oxygen and organic matter are increased, temperature is decreased, pressure is increased, concentration of salts is increased, rate of flow is increased, and degree of mixing is increased.[7]

The amount of carbon dioxide (CO_2) in solution is probably the single most important factor affecting solution because carbon dioxide combines with water to produce carbonic acid (H_2CO_3). The air, which normally has a pressure of 1 atmosphere, has a partial pressure of only 0.0003 atmosphere of CO_2. Rain water in equilibrium with air can dissolve very little calcite. Water containing oxygen and decaying organic material, however, can possess 0.1 atmosphere of CO2 (over 300 times more CO2 than normal rain water) and is able to dissolve a lot of calcite.[8] It is possible to make undersaturated solutions simply by mixing two types of water having different pressures of CO2, different salinities, or different temperatures. Undersaturation occurs in the case of CO2 because a non-linear relationship exists between the partial pressure of CO2 and the solubility of calcite. A swiftly moving, turbulent flow promotes washing of the limestone walls of its conduit, and is, also, more effective at dissolving calcite.[9]

Rates Of Limestone Solution

Because at least eight complex variables determine the rate of solution of limestone, an estimate of solution rates based on the theory of chemical thermodynamics and kinetics would be a monumental task! A better way to estimate solution rates would be to go to the cave environment, measure the various physical and chemical parameters, and relate them to observed solution rates. Unfortunately, the cave environment where solution may be occurring exists deep in the earth, in total darkness, in passages which are completely flooded with water. This environment is very inhospitable to man, and no data are available.

Another way of attacking the problem is to study a large cave-containing area where water chemistry and flow rates are known in order to estimate overall rates. An excellent area for this type of study is the large limestone and dolostone Sinkhole Plain-Mammoth Cave Upland region of central Kentucky. The area is between Green River, Barren River, and Beaver Creek, and comprises several hundred square kilometers. Although it receives 122 centimeters (48 inches) mean annual rainfall[10] and would naturally have about 51 centimeters (20 inches) of average annual runoff,[11] the area has virtually no surface streams! The runoff is channeled into sinkholes which distribute the water into a widespread limestone and dolostone formation which is about 100 meters (330 feet) thick. Caves and solution conduits in the aquifer transport most of the water northward where it discharges at springs into the Green River.

Chemical analyses of the area's groundwater by Thrailkill[12] indicate that mean calcium ion concentration is 49.0 milligram per liter and the mean magnesium ion is 9.7 milligram per liter. Because rain water has only trace amounts of calcium and magnesium, essentially all of the dissolved calcium and magnesium in the groundwater must come from solution of calcite and dolomite. By simple chemical calculation it can be shown that these concentrations represent 0.16 gram of dissolved calcite and dolomite per liter of groundwater.

It is reasonable to assume that about 1.0 meter of the 1.22 meters of mean annual rainfall go into the aquifer. Therefore, each square kilometer (1 million square meters) of central Kentucky receives about 1 million cubic meters of infiltration each year (1,000,000 m2 x l m = 1,000,000 m3). Because a cubic meter of water contains 1 thousand liters, 1 billion liters of water enter the ground through each square kilometer of land surface each year.

The above data can be used to calculate the amount of calcite and dolomite dissolved each year. This is done by multiplying the mass of minerals per liter times the water infiltration rate (0.16 g/l x 1,000,000,000 l/yr = 160,000,000 g/yr). The answer is 160 million grams (176 tons) of dissolved calcite and dolomite per year over each square kilometer of land surface. If the mass of calcite and dolomite dissolved is divided by the density of the minerals, the volume is obtained (160,000,000 g/yr ÷ 2,700,000g/m3 = 59 m3/yr). Thus, if the dissolving power of the acid in one square kilometer of central Kentucky is carried in one conduit, a cave 1 meter square and 59 meters long could form in a year![13]

The high rate of solution of limestone and dolostone should be a matter of alarm to uniformitarian geologists. In 2 million years (the assumed duration of the Pleistocene Epoch and the inferred age of many caves), a layer of limestone well over 100 meters thick could be completely dissolved off of Kentucky (assuming present rates and conditions). Any reasonable estimate of the volume of limestone actually removed by solution of Kentucky caves and karst would be insignificant compared to that predicted by an evolutionary model.

The solution data are not at odds with a catastrophist interpretation of earth history. The data of Thrailkill[14] show that the groundwater in central Kentucky is actually undersaturated with respect to calcite and dolomite, and that the full dissolving power of the acidic water is not being utilized in attacking the limestone. Calcite is dissolved only to about 55% of saturation and dolomite only to about 14% of saturation.[15] Furthermore, climatic and geomorphic evidence in Kentucky suggests that rates of groundwater flow and rates of solution have not remained unchanged. The more humid, cooler climate of the Pleistocene would have increased groundwater flow and increased rates of solution. It is also probable that the atmosphere had more CO2. In the final analysis there appears to be no major obstacle to a short time period for the solution of limestone caves.

Stalactites, Stalagmites, And Flowstone

The formations which hang from the ceiling of a cave are stalactites; those built up above the floor of a cave are stalagmites; whereas those sheet-like, layered deposits on the walls or floors are flowstone. A column forms by the joining of a stalactite and a stalagmite. Together these cave formations are known as speleothems.

The origin and age of speleothems is a controversial subject. A popular theory for the origin of caves involves two stages. The first stage was when the cavity was filled with water, and solution of limestone occurred. The second stage was when the cavity or cavern was filled with air, and deposition of speleothems began from solutions depositing calcium carbonate. A less popular theory is that there was only one stage in cave formation with solution occurring in the water-filled part of the chamber concurrently with speleothem deposition in the air-filled spaces. Radiocarbon (C-14) dating of speleothems has been used by some scientists to support the great age of cave formations. However, attempts to date the carbonate minerals directly give deceptively old ages because carbon from limestone with infinite radiocarbon age (carbon out of equilibrium with atmospheric carbon) has been incorporated in minerals with atmospheric carbon.

Most of the stalactites and stalagmites in modem caves are not growing, and it appears impossible to estimate their former rate of growth. The ones that are growing may be subject to extreme variation in growth rate.[16] Because the Pleistocene Epoch was a time of higher humidity and rainfall than today, it is probable that more speleothems were growing and that they were growing at faster rates than today. It must be remembered that the rates of deposition of calcite are subject to the same