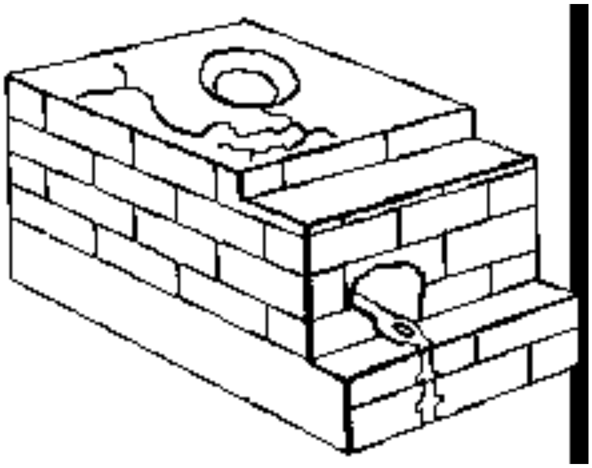
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Karst Topography

Computer animations and paper model

By
Tau Rho Alpha, John P. Galloway, and John C. Tinsley III

Open-file Report 97-536-A



U.S. Geological Survey
Menlo Park, CA 94025

Comments encouraged
tralpha@geodata.wr.usgs.gov
jgallway@mojave.wr.usgs.gov
jtlnsley@sierra.wr.usgs.gov

Description of Report

This report illustrates, through computer animation and a paper model, why caves develop in limestone. By studying the animations and the paper model, students will better understand the evolution of Karst topography.

Included in the paper and diskette versions of this report are templates for making a paper model, instructions for its assembly, and a discussion of development of Karst topography. In addition, the diskette version includes an animation of how Karst topography changes through time.

Many people provided help and encouragement in the development of this HyperCard stack particularly Page Mosier, Maura Hogan and Sue Priest.

Requirements for using the diskette version are: Apple Computer, Inc., HyperCard 2.2™ software and an Apple Macintosh™ computer with an internal disk drive. If you are using System 7, we recommend having at least 8 MB of physical RAM with 4.5MB of memory available for HyperCard.

The animation is accompanied by sound. If no sound is heard, change the memory of HyperCard to 4500K and ensure that the control panel "Sound," which is in the "Control Panels" folder under the "Apple" menu, has the volume set to at least 2. To change the memory available to HyperCard, quit this stack. Highlight the HyperCard program icon and choose "Get Info" from the File Menu. Change the "memory requirements" to 4500K and start this stack again.

To see the entire page (card size: MacPaint), select "Scroll" from the "Go" menu and move the hand pointer in the scroll window. If you are experiencing trouble with user-level buttons, select "message" from the "Go" menu. Type "magic" in the message box and press return. Three more user-level buttons should appear.

The date of this Open File Report is 10/10/1997. OFR 97-536-A, paper copy, 36p.; OFR 97-536-B, 3.5-in. Macintosh 1.4-MB high-density diskette.

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Teachers Guide

KARST - Introduction

Throughout the world **karst** landscapes vary from rolling hills dotted with sinkholes, as found in portions of the central United States, to jagged hills and pinnacle karst found in the tropics. The development of all karst landforms requires the presence of rock which is capable of being dissolved by surface water or **ground water.**

The term karst describes a distinctive topography that indicates **dissolution** (also called chemical solution) of underlying soluble rocks by surface water or ground water. Although commonly associated with **carbonate rocks** (limestone and dolomite) other highly soluble rocks such as evaporates (gypsum and rock salt) can be sculpted into karst terrain.

Understanding caves and karst is important because ten percent of the Earth's surface is occupied by karst landscape and as much as a quarter of the world's population depends upon water supplied from karst areas. Though most abundant in humid regions where carbonate rock is present, karst terrain occurs in temperate, tropical, alpine and polar environments. Karst features range in scale from microscopic (chemical precipitates) to entire drainage systems and ecosystems which cover hundreds of square miles, and broad karst plateaus.

Although karst processes sculpt beautiful landscapes, karst systems are very vulnerable to ground water pollution due to the relatively rapid rate of water flow and the lack of a natural filtration system. This puts local drinking water supplies at risk of being contaminated. In the mid 1980's, flooding of caves in the highly populated area of Bowling Green, Kentucky, caused industrial waste to leak into the vast system of underground fissures polluting the ground water in local wells. Due to urban expansion millions of dollars is spent annually in the United States to repair damage to roads, buildings and other structures which are built on unstable karst surfaces.

Karst Topography

The degree of development of karst landforms varies greatly from region to region. Large drainage systems in karst areas are likely to have both **fluvial** (surface) and karst (underground) drainage components. As stated in the introduction, the term **karst** describes a distinctive topography that indicates **dissolution** of underlying rocks by surface water or ground water.

Water falls as rain or snow and soaks into the soil. The water becomes weakly acidic because it reacts chemically with carbon dioxide that occurs naturally in the atmosphere and the soil. This acid is named carbonic acid and is the same compound that makes carbonated beverages taste tangy. Rainwater seeps downward through the soil and through fractures in the rock responding to the force of gravity. The carbonic acid in the moving ground water dissolves the bedrock along the surfaces of joints, fractures and bedding planes, eventually forming cave passages and caverns.

Limestone is a sedimentary rock consisting primarily of calcium carbonate in the form of the mineral calcite. Rainwater dissolves the limestone by the following reaction: Calcite + Carbonic acid = Calcium ions dissolved in ground water + Bicarbonate ions dissolved in ground water.

Cracks and joints that interconnect in the soil and bedrock allow the water to reach a zone below the surface of the land where all the fractures and void spaces are completely filled (also known as saturated) with water. This water-rich zone is called the saturated zone and its upper surface is called the **water table.** The volume of void space (space filled with air or water) in soil or bedrock is termed **porosity.** The larger the proportion of voids in a given volume of soil or rock the greater the porosity. When these voids are interconnected, water or air (or other fluids) can migrate from void to void. Thus the soil or bedrock is said to be **permeable** because fluids (air and water) can easily move through them. Permeable bedrock makes a good aquifer, a rock layer that holds and conducts water. If the ground water that flows through the underlying permeable bedrock is acidic and the bedrock is soluble, a distinctive type of topography, karst topography, can be created.

The first part of our animation shows evolution of karst landforms created by downward movement of water accompanied by dissolution of rock and mass transport of sediments in stream channels. In tropical areas with thick massive limestones, a remarkable and distinctive landscape of jagged hills and narrow gorges completely dominates the landscape. Movement of solution along fractures and joints etches the bedrock and leaves limestone blocks as isolated spires or pinnacles. Pinnacles range from small features a few inches tall to intermediate forms a few feet tall to large pinnacles hundreds of feet tall. Besides the etching of pinnacles and residual hills, sheets of flowing water move down sloping surfaces creating a variety of etched surface features. Our computer animation shows the dominant landforms, such as pinnacles, cones, and towers, commonly found in the tropical karst environment of northern Puerto Rico.

Our paper model represents another type of karst landscape, that of a rolling limestone plain such as is found in south-central Kentucky, northern Florida, and the Highland Rim of central Tennessee where **doline** karst is the dominate feature. Doline karst is the most widely distributed type of karst landscape. The landscape is dotted with **sinkholes** (dolines) which can vary widely in number and size. For the Sinkhole Plain in central Kentucky, there are approximately 5.4 sinkholes per square kilometer over a 153 square kilometer area. For north Florida there are almost 8 sinkholes per square kilometer over a 427 square kilometer area (White, 1988, table 4.1, page 100).

Karst topography dominated by sinkholes or dolines usually has several distinct surface features. Our paper model shows features normally associated with karst topography. Sinkholes (also known as dolines) are surface depressions formed by either: 1) the dissolution of bedrock forming a bowl-shaped depression, or 2) the collapse of shallow caves that were formed by dissolution of the bedrock. These sinkholes or shallow basins may fill with water forming lakes or ponds. Springs are locations where ground water emerges at the surface of the earth. **Disappearing streams** are streams which terminate abruptly by flowing or seeping into the ground. Disappearing streams are evidence of disrupted surface drainage and thus indicate the presence of an underground drainage system. **Cave entrances** are natural openings in the earth large enough to allow a person to enter. Caves may reflect a complex underground drainage system.

Underground Features in Karst Regions

The second part of our computer animation shows the development of some "typical" underground karst features. Much of the drainage in karst areas occurs underground rather than as surface runoff. As rainwater seeps into the ground along bedding planes or fractures in bedrock, the acidic water dissolves any limestone it touches. If the dissolution of bedrock continues, a large underground cavity can form. By one definition, if the cavity is large enough for a person to enter, and if it extends beyond daylight, it is called a **cave.** Caves may have a complex underground drainage system composed of a continuous sequence of conduits (passages) and smaller openings in the bedrock. A cave can be very small, yet occasionally caves may widen into huge subterranean galleries having many miles of passages. The exploration of caves either for scientific purposes or for fun is known as **speleology.** There are many extensive cave systems in the world, below is a short list of the longest caves found in the United States and a selected list of the numbers of caves described for various States.

Brief list of the longest caves in the United States

Name and Location of Cave	**Kilometers Mapped**[*]
Mammoth Cave-Flint Ridge System - Kentucky	500
Jewel Cave - South Dakota	118
Wind Cave - South Dakota	73
Friars Hole System - West Virginia	68
Fisher Ridge Cave System - Kentucky	64

[*] Numbers are rounded to nearest kilometer
(modified from White, 1988, table 3.1, page 65)

A selected list of the number of caves described for some states

State	**Number of caves described**
Alabama	2020
California	400
Indiana	398
Kentucky	1057*
Missouri	5475**
Oregon	19
Virginia	2319
Washington	155

*Although only 1057 caves have been mapped, there are more than 3770 known caves in Kentucky, Dougherty, 1985 (modified from White, 1988, table 3.2, page 67)
** The MSS Liaison, 1997, Newsletter of the Missouri Speleological Survey, v. 37, nos. 8-9. p. 2.

What do Caves Contain?

Moving water may transport earth materials into and through caves physically or chemically. Caves contain interesting features as a result of the physical and chemical processes that form them.

Among these features are **breakdown** blocks of rock formed by collapse of cave ceilings. Also seen are sediments containing boulders, sand, silt, and clay deposited from water flowing in and through cave passages and conduits. **Speleogens** are irregular or distinctive shapes of carbonate rock etched from bedrock by dripping or running water. Speleogens can form where bedrock is not uniform in chemical composition. Consequently, the less soluble rock dissolves slower than adjacent more soluble rock through time. The less soluble rock tends to stand in relief and projects from walls and ceilings of caves.

Away from their entrances, caves usually provide a relatively constant temperature and humidity over a long period of time. Thus, caves provide an ideal environment for chemical deposition of minerals. As water laden with dissolved carbonate seeps into the air-filled cave passage, it may lose excess carbon dioxide to the cave atmosphere, or the water itself may evaporate, causing the dripwater to precipitate secondary carbonate or other minerals from solution, creating cave formations or **speleothems** including cone-shaped **stalactites**, **stalagmites**, **flowstone** or rimstone, or other interesting shapes. Caves in karst areas often have stalactites (icicle-like masses of chemical limestone) that hang from cave ceilings and stout stalagmites protruding from the cave floor. Stalactites and stalagmites can be a few inches to several feet long. Sometimes the drip water will flow down the walls and over the cave floor creating flowstone or rimstone deposits. Where drip water seeps from a joint and then drips over the edges of ledges, deposits of great complexity known as draperies are formed. The color of dripstones and flowstones comes from organic and/or iron oxide compounds brought in from the surface, giving the speleothems an orange brown color or from the presence of oxides and hydroxides of iron and manganese which give the speleothems a deep brown or black color.

What Lives Underground?

Some scientists are interested in cave ecology and how cave animals interact with cave **microclimates.** Animals found in caves include everything from surface dwelling animals like raccoons that occasionally use the cave, to animals that have adapted exclusively to life in the cave **(troglobites)**. Troglobites cannot survive outside caves. These may include such diverse animals as eyeless fish and crayfish, cave beetles, flatworms, and other unusual types of insects. Many of these animals have lost body pigmentation and are white or transparent in color. Although the cave environment appears to be stable, change can and does occur. The temperature of the cave varies due to air movement near the entrances and the temperature of water entering the cave. In reality, some caves have their own weather systems which create wind due to temperature and pressure differences between the entrance and interior passageways.

Many animals, such as bats, cave crickets, and pack rats, regularly visit, raise their young, or hibernate in caves. These animals are called **trogloxenes**. Caves may support large numbers of different types of bats. Bats may be among the most beneficial animals to people and the ecosystem as insect-eaters and plant pollinators. The little brown bat can eat 600 mosquitoes in an hour thus performing the work of a "natural insecticide," helping control crop pests and other insects. The Mammoth Cave-Flint Ridge System in Kentucky, which is the most extensive cave system in the world, has a biodiversity of 43 mammals, 15 reptiles, 19 amphibians and 3 fish. In 1981, the United

Nations designated Mammoth Cave National Park as a World Heritage Site. An excellent summary of the Mammoth Cave area and other caves found in the U. S. National Park System can be found on the World Wide Web at: http://www.nps.gov/htdocs2/maca/cavepark.htm.

In 1988 the United States passed the Federal Cave Resource Protection Act which preserves and protects all significant caves found on federal land for future generations of Americans.

What's in it for Me?

Knowing where karst features are located could help city and town planners, as well as individual landowners, to make decisions on where to build houses and other structures. This information could save cities thousand of dollars in repairs to buildings that are built on unstable karst terrain.

Karst springs supply drinking water to millions of people. Knowledge of karst terrain and the movement of water in underground drainage systems is important for maintaining good quality and safe drinking water. Pollution of ground water is a major problem in karst terrain.

Caves provide a venue for recreation. Although most of the caves located in National Parks are protected, there are over 200 commercial show caves nationwide which are open to the public. Recreational caving has become a popular hobby. The National Speleological Society has about 20,000 active affiliates nationwide.

Deposits preserved in caves can tell geologists about past climates. Fossils and artifacts found in caves help geologists and archaeologists unravel the prehistory of an area.

Caves support a unique community of bacteria, fungi and animals not seen on the surface of the Earth.

Questions

Why is there often a wind at the mouth of a cave?

Do large caves form in dry environments above the water table?

Do dripstone features such as stalactites and stalagmites form in caves that are below or above the water table? Why or why not?

Is the water table always level?

Should a person explore a cave alone?

Should a person build a house near a sinkhole?

Should a person collect stalagtites and stalagmites?

Should a person collect cave-dwelling animals?

Glossary

Breakdown - An underground rock fall. Blocks of rock become detached from the roof of the cave. The accumulation produces a series of rough angular rock fragments scattered on the cave floor.

Carbonate rocks - Sedimentary rocks composed mainly of calcium carbonate.

Carbonic acid - A mild acid formed when water and carbon dioxide chemically combine in the atmosphere and soil.

Cave - A natural opening in rock large enough to be entered by man and extending to points where daylight does not penetrate.

Cave system - A cave or caves having a complex network of interconnected chambers and passages that constitute an underground drainage system.

Disappearing streams - In karst areas, streams often disappear into the ground usually at a sinkhole.

Dissolution (also called chemical solution) - The process of chemical weathering of bedrock in which the combination of water and acid slowly removes mineral compounds from solid bedrock and carries them away in liquid solution.

Dolines (also known as sinkholes) - A closed surface depression draining underground in karst landscape. Dolines are usually "bowl-shaped" and can be a few to many hundreds of meters in diameter.

Flowstone - A general term referring to a deposit formed from thin films or trickles of water, the minerals are usually calcium carbonate and encrust floors or walls.

Fluvial - Pertaining to a river or rivers.

Ground water - Water below the level at which all voids in the rock are completely filled with water.

Karst - A distinctive topography that indicates dissolution of underlying soluble rocks by surface water or ground water.

Microclimate - The climate (temperature, humidity, air flow) of a local or confined area such as part of a cave.

Permeability - The property of rock or soil that permits water to pass by flowing through interconnected voids (spaces). Permeable bedrock makes a good aquifer, a rock layer that yields water to wells.

Porosity - The volume of void space (space filled with air or water) in soil or bedrock. When these voids are interconnected, water or air (or other fluids) can migrate from void to void. Thus interconnected pores make the soil or bedrock permeable.

Sinkholes (also known as dolines) - A closed surface depression draining underground in karst landscape. Sinkholes are often "bowl-shaped" and can be a few to many hundreds of meters in diameter.

Speleology - The exploration and study of caves.

Speleothems – A deposit, usually calcium carbonate, formed in caves by chemical precipitation from drips or thin films of water. Common speleothem forms are: Stalactite: which hangs downwards from a roof or wall of a cave and Stalagmite: which projects vertically upwards from a cave floor.

Stalactite - See speleothems (above).

Stalagmite - See speleothems (above).

Spring - A spring or resurgence is the point where ground water reappears at the earth's surface and begins flowing downhill as a surface stream. The opposite of a sinking stream.

Troglobites ("cave dwellers") - These animals can only complete their life cycle in caves and typically exhibit adaptations to the totally dark cave environment, including low metabolism, unpigmented skin, long feelers or pedipalps, and loss of eyes in adult forms.

Trogloxene - An animal which spends only part of its life cycle in caves, such as a bat.

Water table - The surface between the zone of pure saturation and zone of pure aeration underground.

An excellent description of cave and karst terminology was prepared by J. N. Jennings and can be found on the World Wide Web at: http://techpkwa.curtin.edu.au/interests/Speleology/termcp.html

References

Dougherty, Percy H., editor, 1985, Caves and Karst of Kentucky, Kentucky Geological Survey Special Publications 12 Series XI, 196 pages.

Gurnee, Russell and Gurnee, Jeane, 1980, Gurnee Guide to American Caves, Zephyrus Press, Teaneck, New Jersey. (A comprehensive guide to caves in the U.S. which are open to the public)

Jennings, Joseph N., 1971, Karst, An Introduction to Systematic Geomorphology, Vol. 7, The M.I.T. Press, Cambridge, Mass. and London, England, 252 pages.

Moore, George W., and Sullivan, Nicholas, 1997, Speleology, Caves and the Cave Environment, 3rd edition, Cave Books, St. Louis, MO, 176 pages.

U.S. Department of the Interior, U.S. Geological Survey - Geology of Caves, U.S. Geological Survey General Interest Publication, 19 pages.

White, William B., 1988, Geomorphology and Hydrology of Karst Terrains, Oxford University Press, New York, 464 pages.

Zumwalt, Gary, ed., 1997, The MSS Liaison (Newsletter of the Missouri Speleological Survey), vol. 37, nos. 8-9, p. 2.

Additional Resources

Guide to Florida Environmental Issues and Information, Chapter 10, Florida's Groundwater.
http://www.arch.usf.edu/fcfguide/chap10/chap10.htm

National Speleological Society, Inc.
2813 Cave Avenue
Huntsville, Al 35810-4431

Philadelphia Grotto - The Geology of Caves
http://www.voicenet.com/~sumped/geology.html (from here you can take a virtual cave tour)

Fundamental Concepts

"SCIENTIFIC LITERACY FOR ALL STUDENTS is a National goal. The National Science Education Standards are a contribution toward achieving that goal." (Draft, November 1994, National

Science Education Standards, prepared by the National Research Council, National Academy of Science)

After building this model and reading the text all students should have developed a basic understanding of the following fundamental concepts of Earth and Space Science as recommended in the National Science Education Standards. Some of these concepts for grades 5-8 and 9-12 are:

Grades 5 - 8
+ The Earth processes we see at work today are similar to those that operated in the past.
+ Animals have adapted to unique environments.

Grades 9 - 12
+ Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.
+ Human activities can enhance the potential for hazards. Students should understand the risks associated with natural and man-made hazards.
+ Humans use many natural systems as resources. Changing the natural system can affect the quality of resources humans use, i.e. drinking water pollution.
+ Each element moves among reservoirs in the solid Earth. Understanding chemical reactions and geochemical cycles is important for maintaining the health of natural environments.

Additional Models and Animations

Alpha, Tau Rho, 1989, How to construct two paper models showing the effects of glacial ice on a mountain valley: U. S. Geological Survey Open-File Report 89-190 A&B (Available as a 3.5-in. MACINTOSH disk or a 30-p. report)

Alpha, Tau Rho, Lahr, John C., and Wagner, Linda F., 1989, How to construct a paper model showing the motion that occurred on the San Andreas fault during the Loma Prieta, California, earthquake of October 17, 1989: U. S. Geological Survey Open-File Report 89-640 A&B (Available as a 3.5-in. MACINTOSH disk or a 10-p. report)

Alpha, Tau Rho, and Lahr, John C., 1990, How to construct seven paper models that describe faulting of the Earth: U. S. Geological Survey Open-File Report 90-257 A&B (Available as a 3.5-in. MACINTOSH disk or a 40-p. report)

Alpha, Tau Rho, 1991, How to construct four paper models that describe island coral reefs: U. S. Geological Survey Open-File Report 91-131 A&B (Available as a 3.5-in. MACINTOSH disk or a 19-p. report)

Alpha, Tau Rho , and Gordon, Leslie C., 1991, Make your own paper model of a volcano: U.S. Geological Survey Open-File Report 91-115 A&B (Available as a 3.5. MACINTOSH disk or a 4-p. report)

Alpha, Tau Rho, Page, Robert A., and Gordon, Leslie C., 1992, Earthquake effects, a computer animation and paper model: U. S. Geological Survey Open-File Report 92-200 A&B (Available as a 3.5-in. MACINTOSH disk or a 22-p. report)

Alpha, Tau Rho 1993, Landslide Effects, A computer animation and paper model: U. S. Geological Survey Open-File Report 93-278 A&B (Available as a 3.5- in. MACINTOSH disk or a 20-p. report)

Alpha, Tau Rho, Starratt, Scott W. and Chang, Cecily C., 1993, Make your own Earth and tectonic globes: U. S. Geological Survey Open-File Report 93-380 A&B (Available as a 3.5in. MACINTOSH disk or a 14-p. report)

Alpha, Tau Rho, and Stein, Ross S., 1994, Make your own paper model of the Northridge, California, earthquake, January 17, 1994: U. S. Geological Survey Open-File Report 94-143 4-p.

Alpha, Tau Rho, and Stein, Ross S., 1994, The Northridge, California, Earthquake of January 17, 1994: A computer animation and paper model: U. S. Geological Survey Open-File Report 94-214 A&B. (Available as a 3.5-in. MACINTOSH disk or a 30-p. report).

Alpha, Tau Rho, Starratt, Scott W., Hendley, James W., III, 1994, Make your own paper fossils, a computer animation and paper models: U.S. Geological Survey Open-File Report 94-667 A&B. (Available on 3.5 MACINTOSH disk or a 42 p. report)

Alpha, Tau Rho, Galloway, John P., Bonito, Mark V., 1995, Sea-Floor Spreading, a computer animation and paper model: U.S. Geological Survey Open-File Report 95-573 A&B. (Available on 3.5 MACINTOSH disk or a 35 p. report)

Alpha, Tau Rho, and Reimnitz, Erk, 1995, Arctic Delta Processes, a computer animation and paper models: U.S. Geological Survey Open-File Report 95-843 A&B. (Available on 3.5 MACINTOSH disk or a 27 p. report)

Alpha, Tau Rho, and Galloway, John P., 1996, Ocean Trenches, a computer animation and paper model: U.S. Geological Survey Open-File Report 96-76 A&B. (Available on 3.5 MACINTOSH disk or a 41 p. report)

Alpha, Tau Rho, Stout, Dorothy L.and Starratt, Scott W., 1997, Crinoids, a computer animation and paper model: U.S. Geological Survey Open-File Report 97-91 A&B. (Available on 3.5 MACINTOSH disk or a 57 p. report)

Alpha, Tau Rho, Galloway, John P., and Starratt, Scott W., 1997, Chicxulub impact event, computer animations and paper models: U.S. Geological Survey Open-File Report 97-442 A&B. (Available on 3.5 MACINTOSH disk or a 35 p. report)

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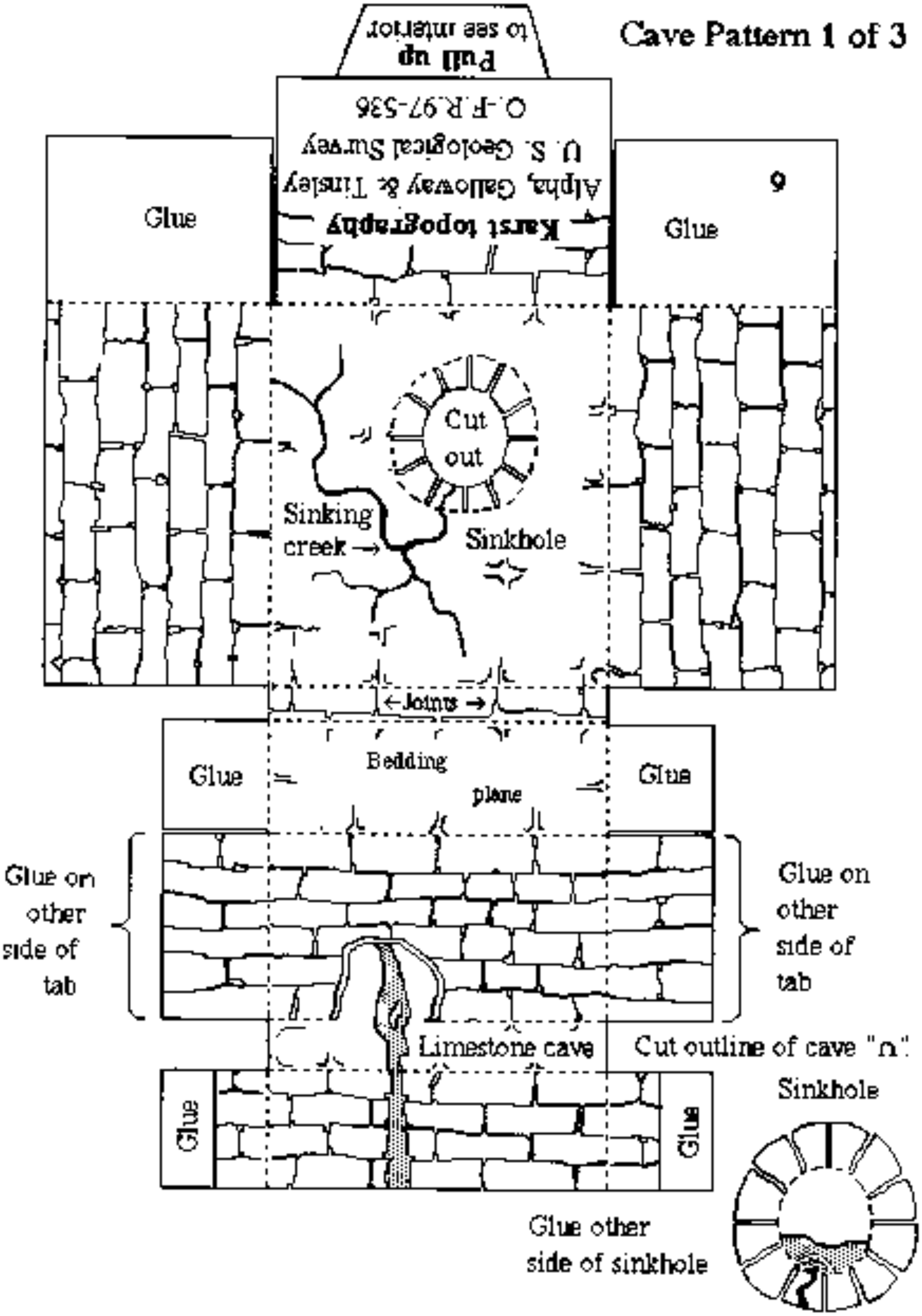
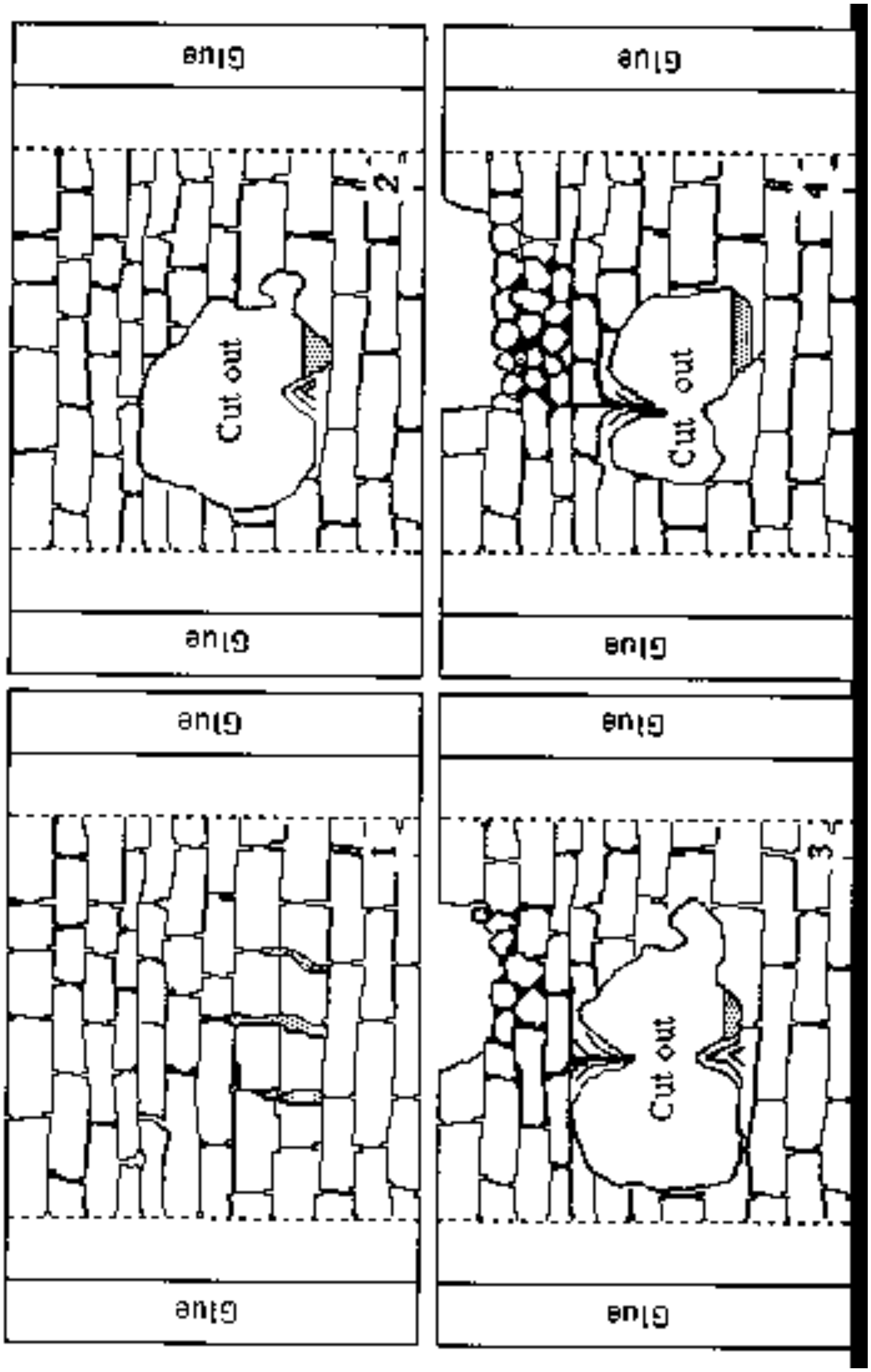
FAX. (303)-202-4695

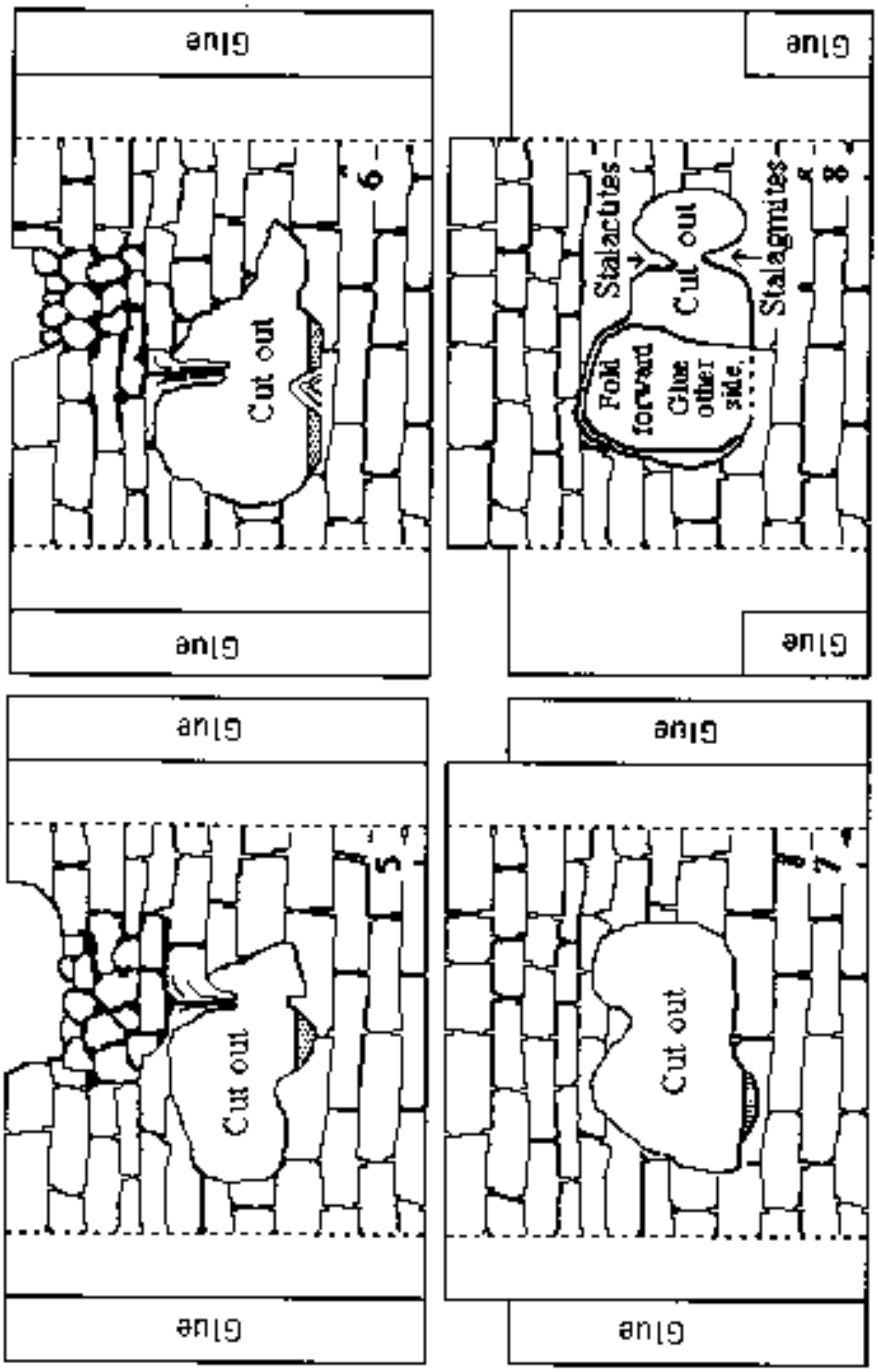
Cave Pattern 1 of 3



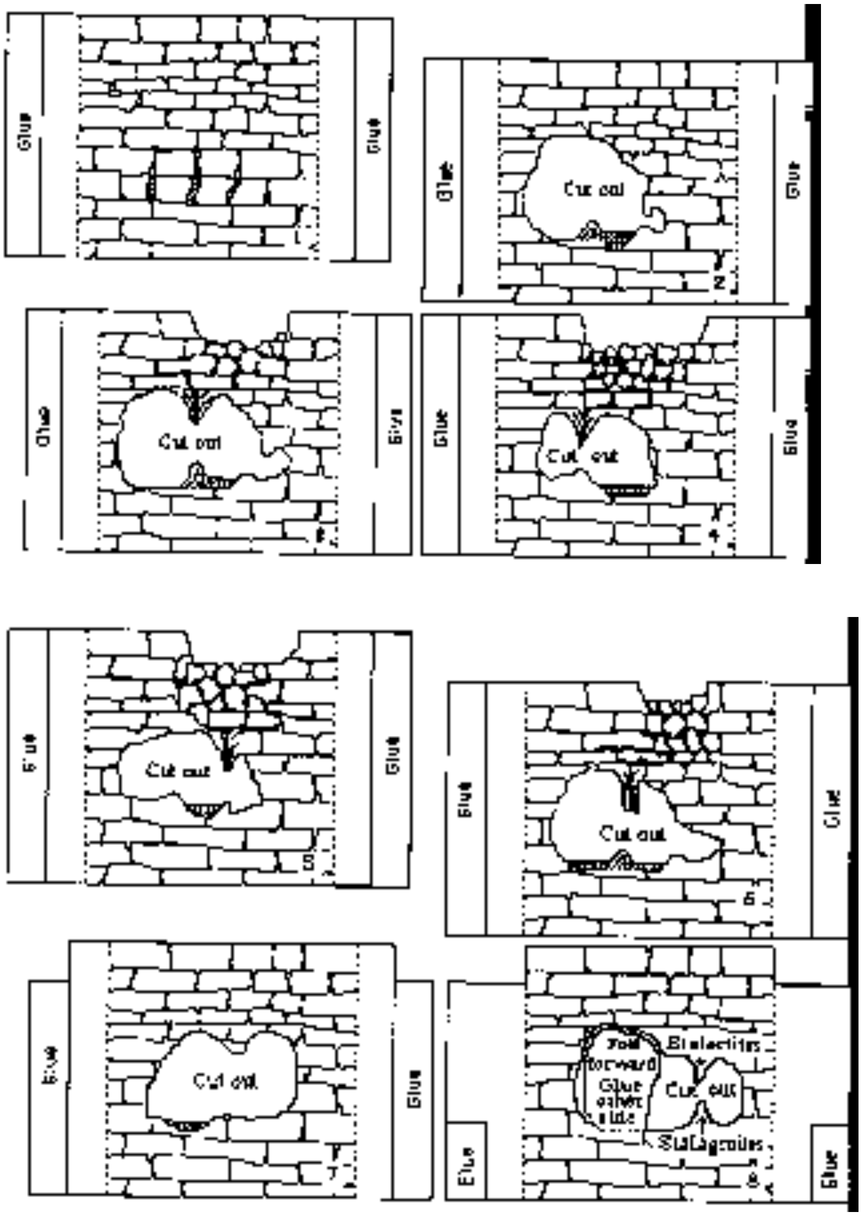
Cave Pattern 2 of 3



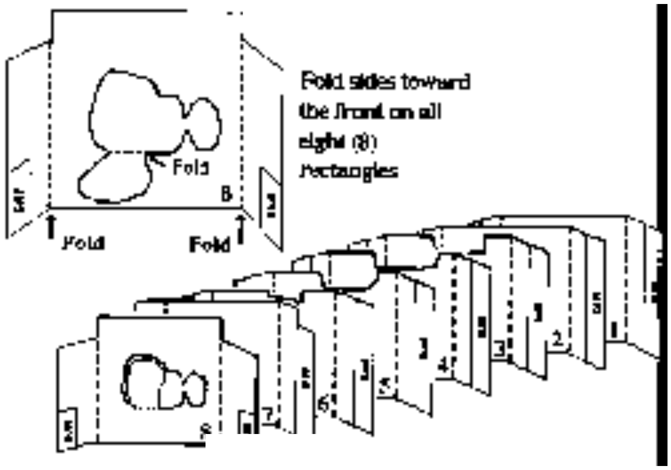
Cave Pattern 3 of 3



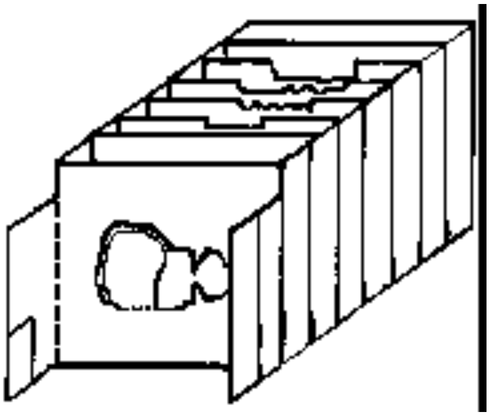
Cave Assembly



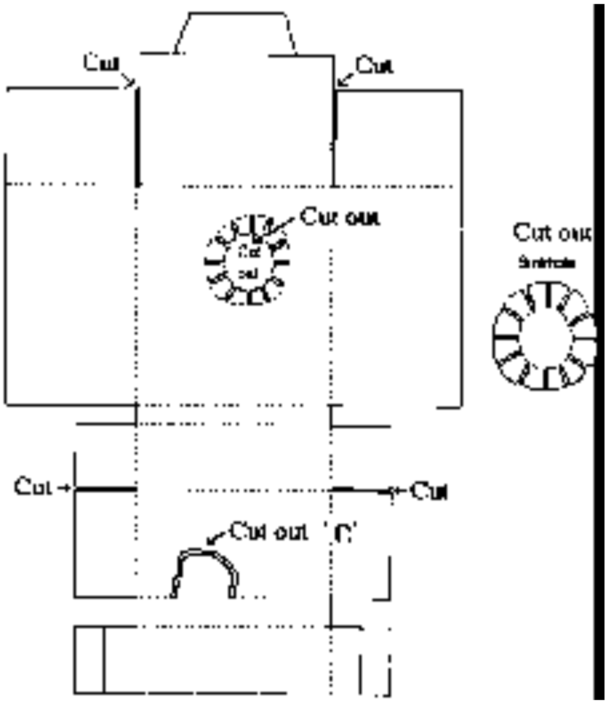
Step 1. Cut out eight rectangles from pattern pieces 2 and 3.
Cut out “cave” hole on rectangles 2 through 8.



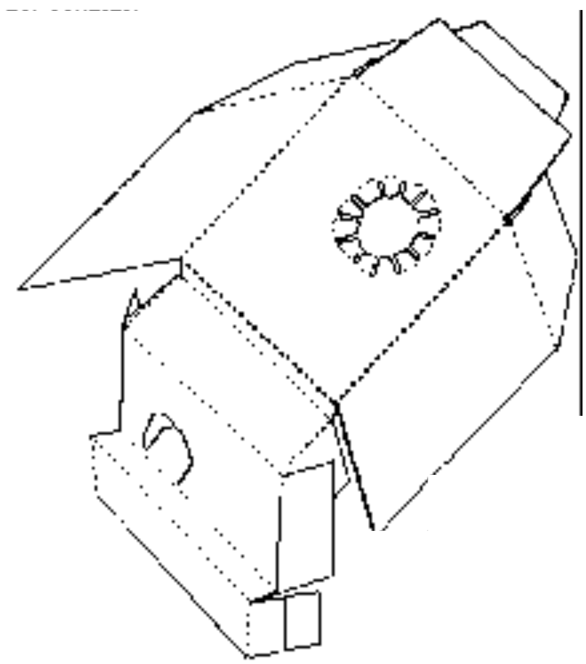
Step 2. Fold sides toward the front on all 8 rectangles. Glue tabs.



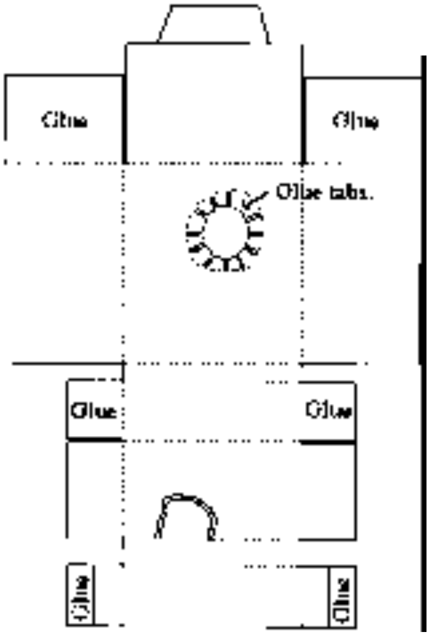
Step 3. Assemble the 8 rectangles in numerical order.



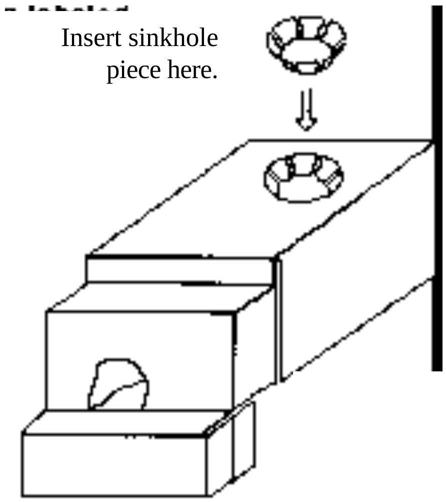
Step 4. Cut out karst topography box and sinkhole.



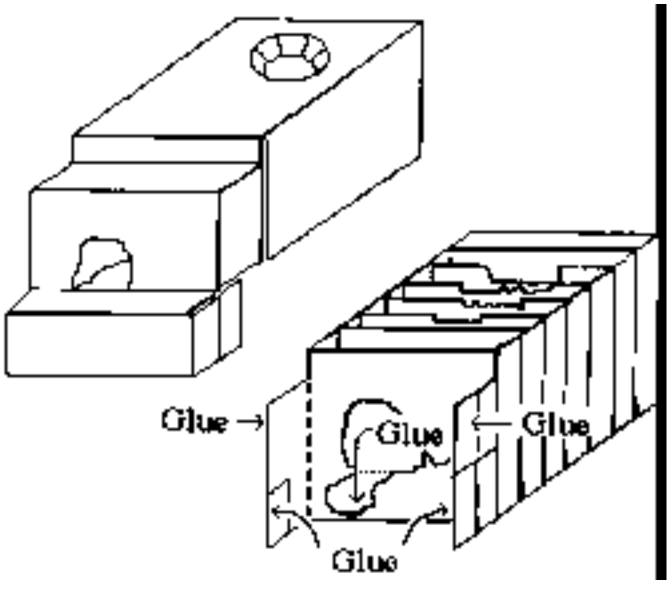
Step 5. Fold karst topography box.



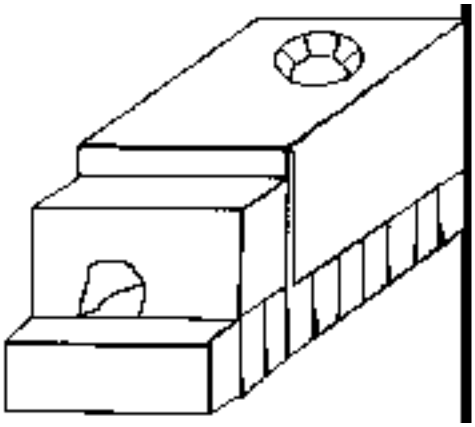
Step 6. Glue karst topography box and sinkhole tabs.



Step 7. Assemble karst box as shown.



Step 8. Glue karst box over the 8 rectangles.



Step 9. Finished cave model should look like this.