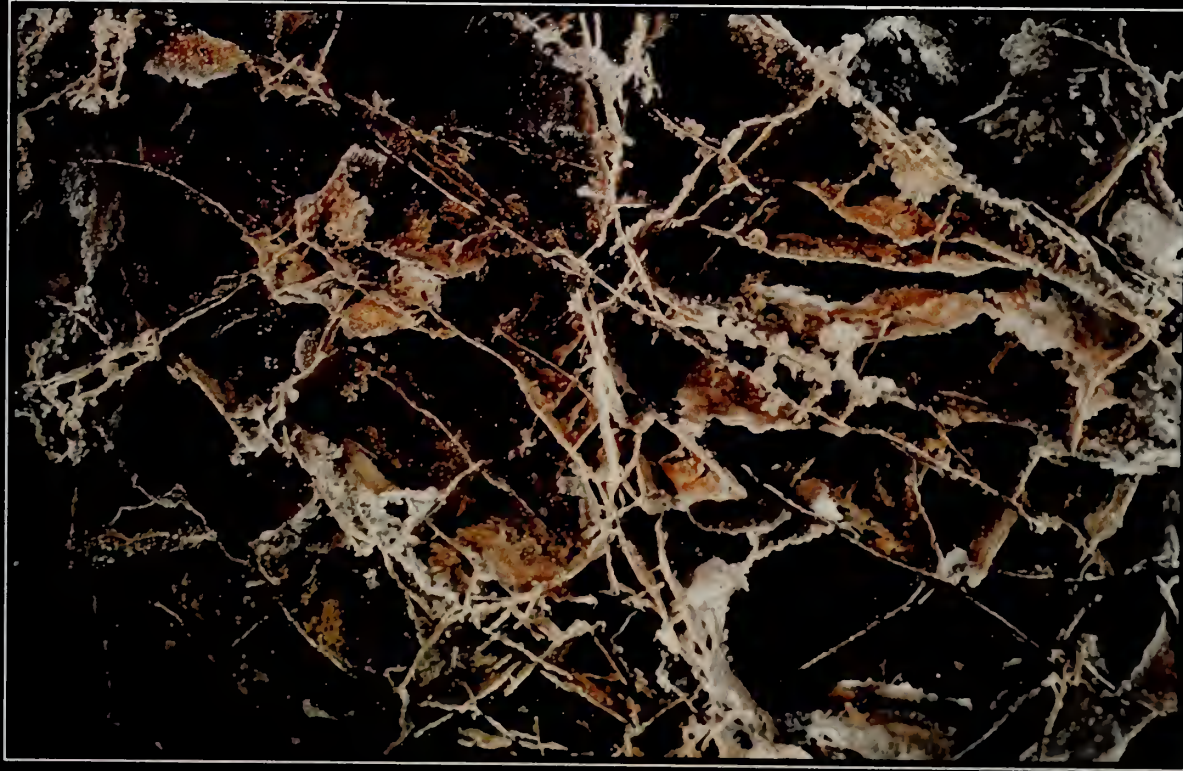

An Ancient World Beneath The Hills

Wind Cave



Wind Cave

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Wind Cave National Park
Hot Springs, South Dakota 57747

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Wind Cave

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Wind Cave

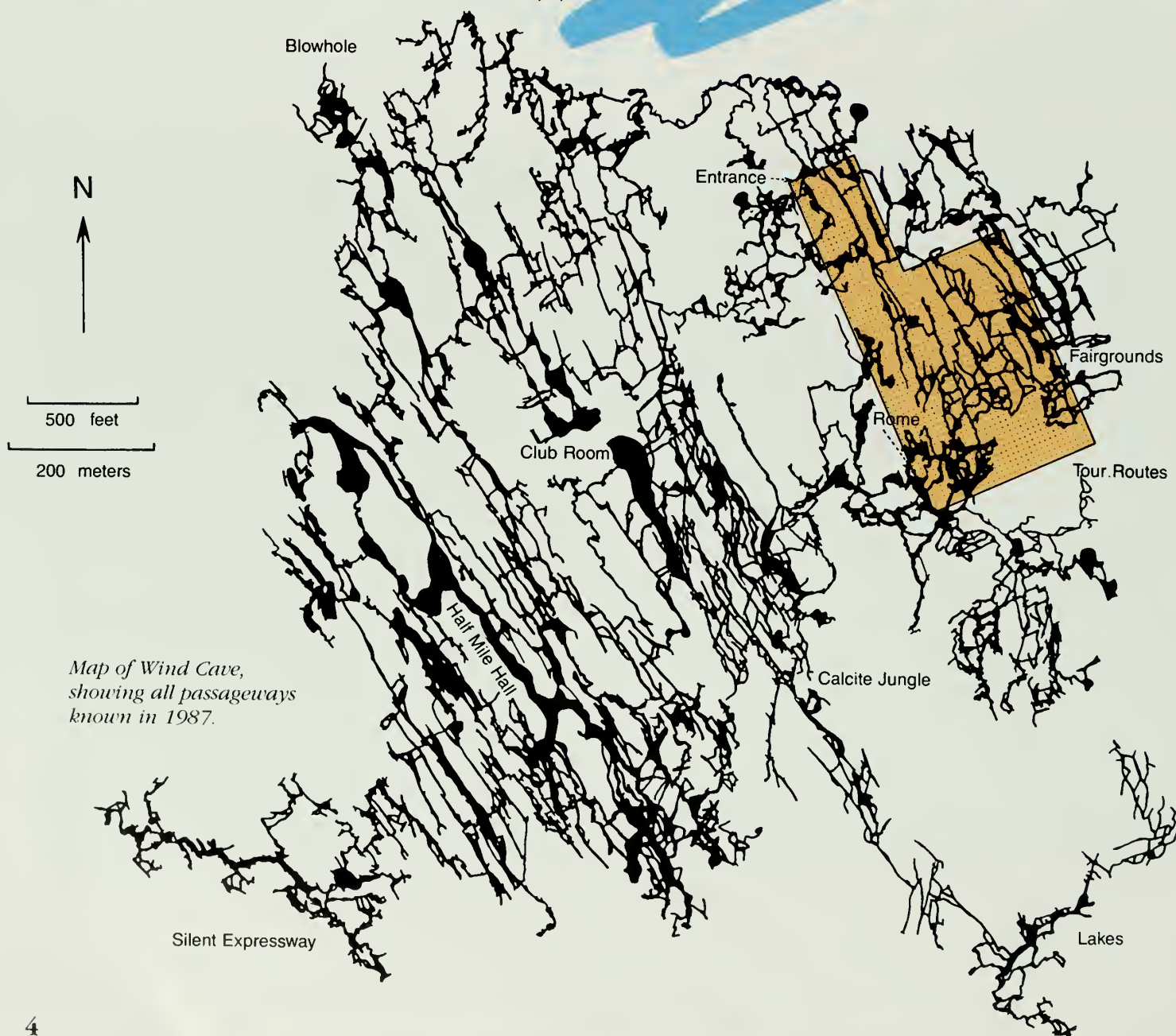


The Pahasapa Limestone forms steep canyon walls on the surface, but underground water dissolves it rapidly enough to form caves.

Wind Cave

The Black Hills rise from the surrounding plains like an island in a calm sea. These eastern-most ramparts of the Rocky Mountains have long been regarded as a mysterious land, a source of spiritual inspiration to the plains Indians, a place of geological wonders. Here the earth has been pushed upward into a dome-shaped mountain range, exposing a rich variety of rock layers, each with its own story to tell. Hidden deep within one of these layers is Wind Cave. Of all the natural curiosities in the Black Hills, this is one of the most fascinating and puzzling.

Wind Cave



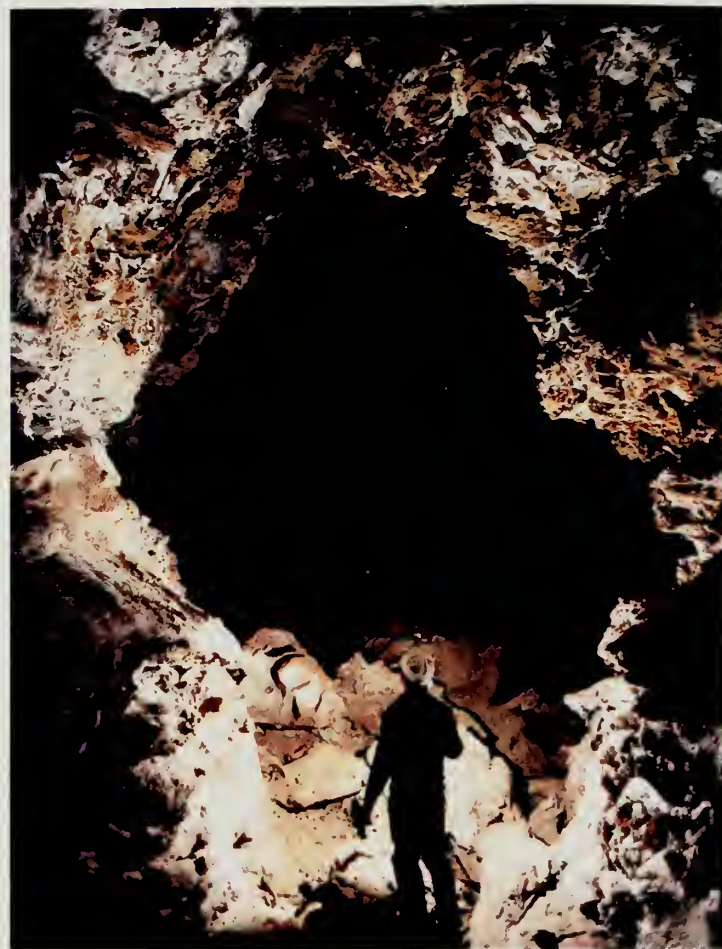
Wind Cave

Like most caves, Wind Cave was formed by the dissolving action of underground water passing through limestone bedrock. A thick band of limestone extends around the entire Black Hills, so it is not surprising that there are many well-known caves in the region. This cavernous rock layer is known as the Pahasapa Limestone, a name fashioned from the Lakota words “paha sapa”, meaning “hills black”.

Wind Cave, is the best known cave in the region. With more than 50 mi (80 km) of mapped passageways, it is third longest in the United States and seventh longest in the world. It is an intricate three-dimensional maze of passageways that branch off in many directions at almost every step. Some are high and narrow fissures that follow the natural cracks in the limestone. Others are wide irregular corridors that follow the rock layers. In places the cave opens into large rooms with high, arched ceilings. Some areas are so confusing that even those who are exploring the cave have difficulty finding their way through. The map of the cave shown here is a simplified two-dimensional view that gives only a hint of how complex the cave really is.

Most caves are still being formed or altered by underground water, but Wind Cave gives us a glimpse of far-away times quite different from today. It is now almost totally dry, except for several deep lakes at the lowest points, and it contains very few of the formations built up by dripping water, such as stalactites and stalagmites. Although it is no longer being enlarged by water, Wind Cave is still very much “alive”. Enough water seeps into it from rain and snowmelt to leave a tracery of fine crystals on the walls. These are wonderfully delicate, as different from the massive formations deposited by dripping water as the fine details of a watercolor miniature are from the broad paintbrush strokes on a barn.

The most remarkable feature in Wind Cave is its



Wind Cave



Water that seeps slowly into the cave leaves delicate deposits such as this "cave popcorn" in the Garden of Eden. Width of photo is 6 inches (15 cm).

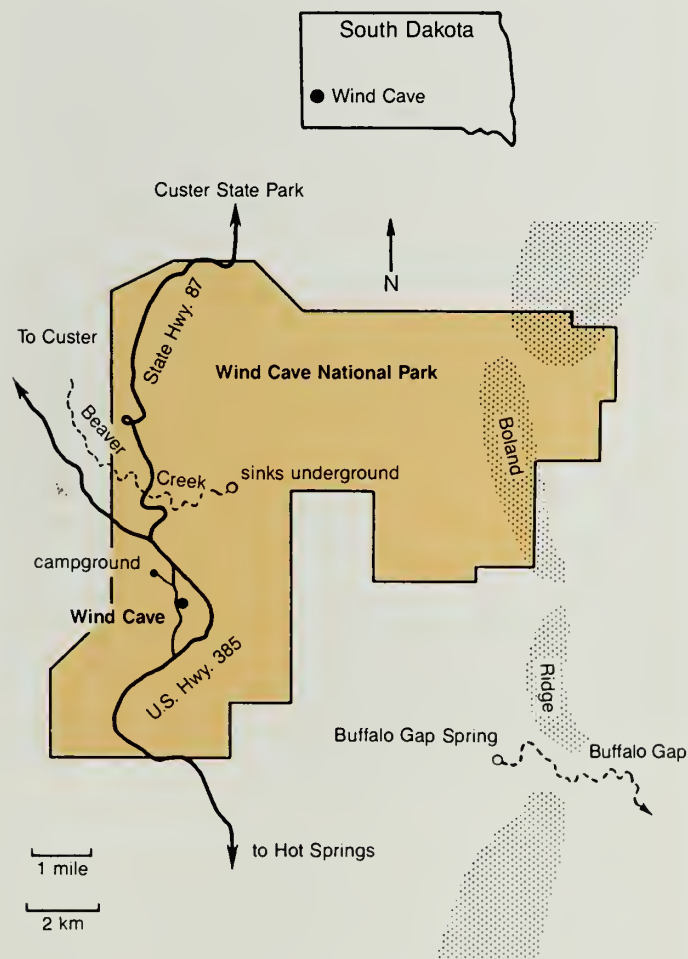
boxwork. This is a criss-cross pattern of thin crystalline fins that project from the walls and ceilings, giving the appearance of honeycombs or post-office boxes. Very few caves contain boxwork at all, and no other cave in the world displays the same abundance and variety that Wind Cave does. Its many bizarre shapes, with colors ranging from transparent orange-yellow to dusky brown or black, give the impression of an extra-terrestrial landscape.

Wind Cave is a place of mysteries. How old is it? Where did the water come from that formed it? Where do all those passages lead? What is the cause of the wind that blows out of the cave on some days and inward at other times? Even the people who have spent years studying its geology or exploring its most remote passages find that each answer only leads to more questions. Today we have a basic understanding of the cave, enough to tell a long and fascinating tale, but explorers and scientists will always be drawn to it by the questions that remain.



Boxwork is one of the main attractions of Wind Cave. Intersecting reins of the mineral calcite project from the cave walls and ceiling where the intervening bedrock has been dissolved or weathered away. Width of photo is one foot (30 cm).

Wind Cave



Wind Cave National Park.

Wind Cave National Park is located 10 mi (16 km) north of Hot Springs, South Dakota, at the south-eastern edge of the Black Hills. It is most easily reached from the south or northwest by U.S. Route 385, and from the north by State Route 87. The park and cave are open year round.

The park covers 44 square mile (113 square kilometers) of grassy uplands intersected by steep-walled canyons. The wooded peaks of the Black Hills look down from the north and west, and beyond a prominent ridge the Great Plains stretch to the east and south. Prairie grassland, cactus, and sparse pine forests are typical of this semi-arid region, which averages only 16 inches (40 cm) of rainfall per year. Although the original purpose of the park was to make Wind Cave accessible to the public and to protect its delicate cave features, that purpose has been broadened to include the protection and preservation of wildlife such as bison, elk, pronghorn, deer, and prairie dogs and their associated ecosystems. In contrast to the surface, life is very sparse in the cave. A few bats sleep inside, flying out at night to feed on insects, and small rodents and invertebrates may live permanently near entrances. Far from the entrances some invertebrates live close to the surface where organic matter is available. No large animals make the cave their home.

Visitors to Wind Cave have the choice of four guided tours, each emphasizing different aspects of the cave. The year-round temperature is 53°F, (11°C), regardless of the outside temperature, so a light

Wind Cave



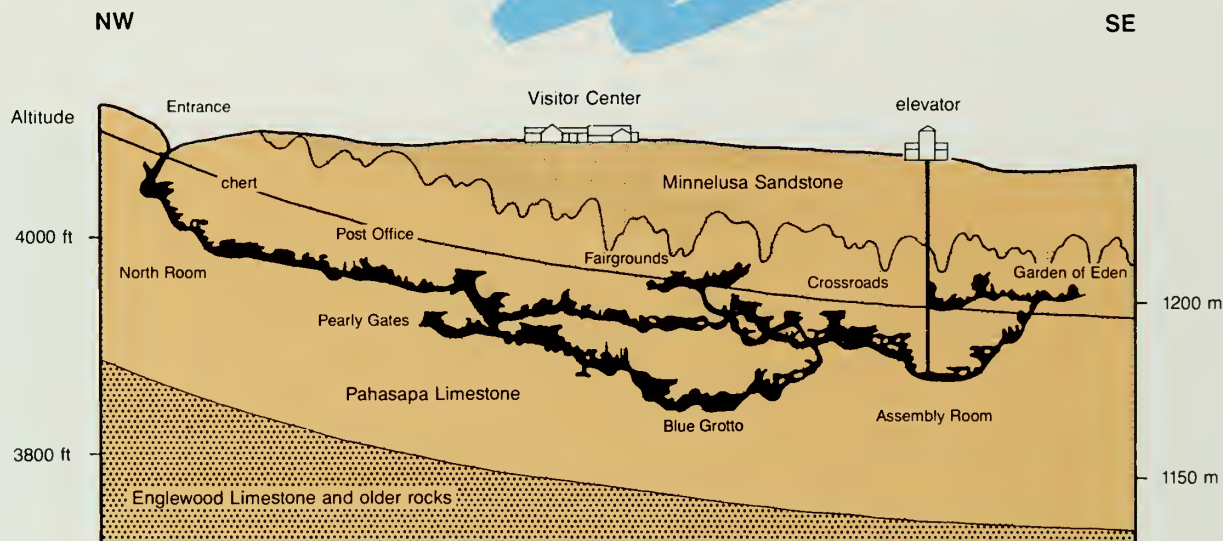
Land surface over Wind Cave. The main peaks of the Black Hills rise in the background.

Wind Cave



Map of tour routes.

Wind Cave



Profile of tour routes. The width of the section shown is about 2000 feet (600 m).

jacket or sweater is recommended for warmth. The Half-Mile Tour and One-Mile Tour are the most popular ways to see the cave. Both enter the cave at the walk-in entrance and leave from the elevator (see map). The longer tour includes a loop through the Fairgrounds, the largest room open to the public. All trails are surfaced, and stairs provide access from one level to another. Each tour is moderately strenuous, equivalent in effort to a surface hike of twice its length. Low- heeled, non-slip shoes are recommended. The Candlelight Tour gives an opportunity to see how the cave was explored during the late 19th century. Candle lanterns are used for illumination off the paved trails. Historic aspects of the cave are emphasized on this tour. Sturdy walking shoes are re-

quired, since much of the trail remains unpaved, as it was during the first tours almost 100 years ago. The Spelunking Tour gives a view of the cave as a present-day explorer would see it. It is rather strenuous, as it involves scrambling and crawling through passages that have no trails or lighting. Rugged clothes and sturdy boots are essential. Helmets, lamps, flashlights, and knee pads are provided. This tour is available only during the summer season. Groups are limited in size, so it is best to make reservations at least a day in advance: call (605) 745-4600. For more information about Wind Cave National Park, write: Superintendent, Wind Cave National Park, Hot Springs, South Dakota 57747.

Wind Cave



A tour group in the Fairgrounds, one of the largest rooms open to the public.



The Candlelight Tour.

DISCOVERY AND EXPLORATION

The original entrance to Wind Cave is a small, inconspicuous hole in the floor of a dry canyon. Its reputed discovery was in 1881, when a Black Hills pioneer, Tom Bingham, was amazed to find a blast of air strong enough to blow off his hat coming out of the earth. At first the hole and the apparently small cave beyond were considered a mere curiosity. In 1890, the South Dakota Mining Company filed claim to the land that included the cave. The manager of the claim, Jesse McDonald, and his two sons, Elmer and Alvin, ventured far beyond the entrance into a labyrinth of passageways that seemed to stretch endlessly into the heart of the plateau. The keenest explorer was Alvin, who was only in his teens. Regrettably, when only 20 years old, he died of typhoid fever contracted during a visit to the Columbian Exposition in Chicago.

In 1892, after building trails and opening a new walk-in entrance, Jesse McDonald and several partners opened the cave to guided tours. This venture lasted until 1903, when President Theodore Roosevelt signed the bill creating Wind Cave National Park. This became the seventh of our national parks, and the first devoted to a cave.

Exploration of Wind Cave progressed in several stages. The McDonalds and their companions discovered all the sections now open to the public, as well as many miles of interconnecting passages. Their explorations ended at a confusing junction they named Rome. Beyond this point the cave seemed to pinch down into unpromising crawl spaces.

Little further exploration took place until 1959, when a week-long expedition was held at Wind Cave by the National Speleological Society, a group devoted to the exploration, study, and protection of caves. They discovered and mapped some new passages in the vicinity of the tour routes, however their main contribution was to call widespread attention to the unusual pattern and mineral deposits of the cave.

By the middle 1960's, Herb and Jan Conn, from the nearby town of Custer, had gained reputations as the chief explorers and mappers of even larger Jewel Cave, located in Jewel Cave National Monument west of Custer. At the invitation of the National Park Service, and in company with Dave Schnute, a Park employee from Hot Springs, they mapped the known sections of Wind Cave and pushed far beyond the previous limits of exploration. On one trip beyond Rome they crawled through a low slot in the side of a remote room and discovered an extensive new section that doubled the known size of the cave. This section included huge chambers such as the Club Room, crystal-lined passages below any previously known, and a deep lake (Calcite Lake) at the cave's lowest point.

In the 1970's, the Windy City (Chicago) Chapter of the National Speleological Society was given a permit to continue the exploration and mapping. They extended the cave westward through a series of devious routes off the Club Room that culminated in Half Mile Hall, the largest known passage in Wind Cave. Several new lakes were also discovered at the lower end of the cave. The cave is still being explored today by local teams and by Park Service staff. Discoveries in the past few years include a new entrance, the Blowhole, at the northwestern end of the cave, many large passages beyond Half Mile Hall, and several new lakes at the southern end of the cave.

It is a rare thrill to discover a new cave, but explorers find that their efforts are not complete unless they map their findings. Cave mapping is just as exciting as the original discovery, for that is the only way to know how large the cave is and where it leads. Using a tape to measure distance, a compass for direction, and a device for measuring vertical angles, it is possible to survey an entire cave bit by bit. A sketch is made along with the measurements, so a faithful

Wind Cave



map can be drawn from the survey notes. The maps of Wind Cave shown in this book were made in this way, although they have been simplified for clarity. A larger, more detailed map is sold in the Visitor Center.

The original entrance to Wind Cave is a tiny hole with wind blowing either in or out, depending on changes in atmospheric pressure. An artificial walk-in entrance is located nearby.

CAVE CONSERVATION

Most natural processes operate very slowly in caves. Their features, once destroyed, may never be replaced, and scars and litter left by careless visitors will remain indefinitely. Many features in Wind Cave are so fragile that the slightest touch would damage them. Broken cave formations look pathetically out of place when taken outside. Even the bare bedrock walls can be soiled when touched. Federal agencies and many states have laws that prohibit removal of items from caves, even those on private property, and a national cave protection bill is now in Congress. When you visit a cave or any other undisturbed work of nature, please try to leave no trace of your having passed through. Bring a camera and flash attachment to help you remember your visit. For further information about caves, write the National Speleological Society, Cave Avenue, Huntsville, Alabama 35810.



Wind Cave contains many features that could not survive in the harsh surface environment. This tiny crystalline "tree" is so fragile that a single touch would damage it. Height of photo is 3 inches (7.5 cm).

SUBTERRANEAN WINDS

Wind Cave was named for the natural breezes that blow in and out of the entrance. In most other caves, air simply moves between entrances that lie at different elevations. In summer, when the outside air is warmer, the cool cave air moves downward, drawing air into the upper entrances and forcing it out through the lower ones. The opposite happens in winter. But Wind Cave is different. Its known entrances all lie at the high end of the cave, and they all inhale and exhale together. This breathing is caused by changes in the outside air pressure. When a storm is approaching and the outside pressure drops suddenly, air rushes out of the entrances. When the pressure is rising, as when a cold front is moving through, the cave inhales. By observing this air movement we can use the cave as a giant barometer.

The cave behaves like a bottle with a narrow neck. Air moves fastest in the narrow entrance passages. Winds of more than 70 mph (110 km/hr) have been clocked in the walk-in entrance! The winds are usually rather faint farther in because they are dispersed among many interconnected passages.

Such a large amount of air indicates huge volumes of open space beneath the surface. Intrigued by the wind, Herb and Jan Conn set up a home-made apparatus in the entrance to measure changes in air speed with time. Their measurements agreed with changes in the outside atmospheric pressure. By calculating the volume of air entering and leaving through the entrance, they estimated that the cave has a volume of more than 2 billion cubic feet (57 million cubic meters). Comparing this figure to the known extent suggests that less than 5% of Wind Cave has been discovered! Of course this figure includes many holes too small to explore, but it does show that much more cave lies beyond the presently known limits.

ROCKS AND THEIR HISTORY

A cave is more than just an underground void. It has a distinct character determined mainly by the rocks that make up the walls, ceiling, and floor - the bedrock from which the cave has been dissolved. Depending on the rock type, some passages are broad and arched, others are high, narrow, and straight. Some are smooth-walled, light, and cheery, whereas others are dark and mysterious, with irregular holes leading off in many directions. The rocks also have a tale of their own to tell, covering millions of years of the earth's history.

The rocks in Wind Cave are composed of distinct layers, each representing an individual bed of sediment laid down on the floor of an ancient ocean. Sedimentary rock layers are deposited one on top of the other, with the oldest on the bottom. By examining them it is possible to piece together the many changes that have taken place in the area, just like reading the pages of a history book. Their origin is shown by fossils in the rock, the preserved shells of marine animals. The fossils in the limestone at Wind Cave are from an age known as the Mississippian Period, which occurred 320-360 million years ago. Some are the remains of clam-like animals called brachiopods, whose fan-shaped shells can be seen in the flat ceilings near the Fairgrounds. Some represent relatives of snails, and others are corals that look like bundles of Chinese noodles.

Wind Cave extends through many individual layers of limestone grouped together under the name Pahasapa Limestone. These limestones extend throughout much of the West and are known elsewhere as the Madison Group. From their distribution and character, we know that the sea in which they were deposited once extended over much of the continent but averaged only a few tens of feet deep.

Limestone consists of deposits of calcium

Wind Cave

AGE	ERA	PERIOD	MAJOR EVENTS
(millions of years ago)	CENOZOIC	QUATERNARY	glaciers, age of humans
		TERTIARY	draining of cave
			Wind Cave formed
	MESOZOIC	CRETACEOUS	origin of Black Hills
			other sedimentary rocks deposited
		JURASSIC	dinosaurs
		TRIASSIC	
		PERMIAN	
	PALEOZOIC	PENNSYLVANIAN	Minnelusa Sandstone
		MISSISSIPPIAN	Pahasapa Limestone
		DEVONIAN	Englewood Limestone
		SILURIAN	first vertebrate animals
		ORDOVICIAN	
		CAMBRIAN	Deadwood Sandstone
			first shelled animals
	PRECAMBRIAN		
	0.6-4.5 billion years ago		early mountains of igneous and metamorphic rock
			first primitive plants and animals

Geologic time scale.

Wind Cave

carbonate from water for their shells, and when they die these hard parts collect on the sea floor and are usually broken up by waves. Limestone is formed when the shells and fragments are cemented together by additional calcium carbonate that crystallizes directly from the water.

The lower layers of the Pahasapa "Limestone" actually consist of a similar rock called dolomite, which forms when water rich in dissolved magnesium passes through limestone. About half of the calcium is replaced by magnesium, so the chemical formula becomes $\text{CaMg}(\text{CO}_3)_2$. Dolomite looks almost identical to limestone, and although it dissolves more slowly it is also a good cave-former. At the surface, the Pahasapa Limestone (both the limestone and dolomite) forms steep canyon walls because it is massive and resistant to erosion.

Several other kinds of sedimentary rock are common in the Black Hills. Sandstone is a gray or red, gritty rock composed of sand grains cemented together and has the texture of coarse sandpaper. It is resistant to erosion and forms high cliffs and ridges. Shale is a gray, red, or greenish rock made of compacted mud. It is soft and flaky and erodes easily, forming broad lowlands. The sand and mud that formed these rocks were washed into the sea by streams draining nearby land areas. Gypsum (calcium sulfate containing some attached water) is a soft white deposit formed when sea water evaporates. It dissolves very easily in water and can form caves where it is thick enough. In the Black Hills it is found mainly as thin beds within other types of sedimentary rock. Chert, sometimes known as flint, is a hard rock made of silicon dioxide that forms either directly in sea water or by the replacement of other rocks. It breaks into sharp-edged fragments with smooth, glassy-looking surfaces. The early Indians used chert to make arrowheads and other implements. It occurs mainly in limestone as thin beds and round nodules. Chert hardly dissolves at all in water, so it

forms resistant ledges and knobs that project from the surrounding rock. Several prominent beds of chert are located about one-third of the way down from the top of the Pahasapa Limestone.

The position of sea level helps to determine the character and distribution of sediments deposited in the ocean. Sea level is never static, but is continually rising or falling as polar glaciers advance and retreat or the continents and ocean basins change shape. Today, for example, melting of glacial ice is causing a slow rise in sea level. Immediately after the Pahasapa Limestone was deposited, the sea dropped several hundred feet, causing the limestone to be eroded into a rugged landscape of sinkholes and deep fissures, with underlying caves. At the beginning of the Pennsylvanian Period, about 320 million years ago, sea level gradually rose again to nearly its original elevation. Sand and mud accumulated on the sea floor, forming the Minnelusa Sandstone, a crumbly gray-brown layer up to 650 feet (200 m) thick. It buried the irregular top of the Pahasapa Limestone and filled nearly all the caves that had formed when sea level was lower.

Mountains began to rise in the western part of the continent, and as streams eroded material from their flanks, large amounts of sediment were carried into what is now South Dakota and surrounding states. For this reason the sedimentary rocks above the Minnelusa are nearly all sandstone and shale, with only a few thin limestone layers. They continued to accumulate for 250 million years, building up a total thickness of nearly a mile. These rocks contain some of the finest specimens of fossil bones in the world. During this time, most of the major forms of vertebrate animals appeared, including amphibians, reptiles, mammals, and birds. The evolution and disappearance of the dinosaurs occurred during this time.

Beneath the Pahasapa Limestone are two older

Wind Cave



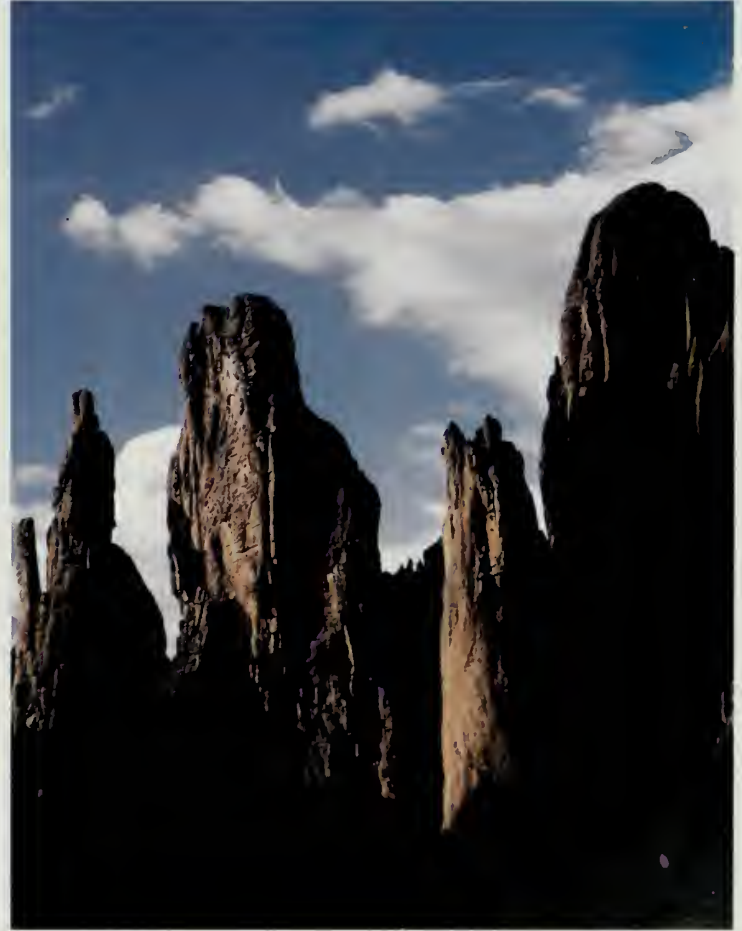
A fossil coral intersected by boxwork veins stands free of the cave walls. Width of the coral is 8 inches (20 cm).



Cliffs of Pahasapa Limestone contain many ancient caves formed during the Mississippian Period and recently intersected by surface erosion. The sand and clay that once filled them have spilled out, leaving open holes.

Wind Cave

sedimentary layers, each only 30 feet (9 m) thick. These are the sandy Englewood Limestone and, below it, the Deadwood Sandstone. These rocks were deposited about 360-600 million years ago. Much older igneous and metamorphic rocks underlie the Deadwood Sandstone. Igneous rocks are formed by the crystallizing of molten material, as when a volcano erupts and the lava solidifies into rock. Most igneous rocks in the Black Hills formed deep beneath the surface, but they can be seen today where the overlying rocks have been stripped away by erosion. They are massive and hard enough to stand as high ridges and mountains. The igneous rock granite forms prominent peaks such as Mt. Rushmore, Harney Peak, and the Needles. It can be recognized from its speckled appearance, in which visible crystals of many different minerals, both light and dark, are mixed together like the pieces of a jigsaw puzzle. Metamorphic rocks are formed when pre-existing sedimentary or igneous rocks are subjected to great heat and pressure deep beneath the earth's surface. They include schist, which is a shiny rock that splits easily into slabs, quartzite, a hard, resistant, gray rock, and gneiss, which contains alternate bands of light and dark minerals. Nearly all the igneous and metamorphic rocks in the Black Hills formed 1.2 to 2.5 billion years ago during the earth's earliest period of geologic time, the Precambrian Era. They give evidence for a complex history of mountain uplift and erosion long before the Black Hills began to form. A few igneous rocks in the northern Black Hills formed much later, during the early Tertiary Period, about 40-60 million years ago, and these same rock-forming processes created the deposits of gold and other important metals now mined there.



The igneous rock called granite forms the highest peaks of the Black Hills. These spires are located along the Needles Highway north of Wind Cave.

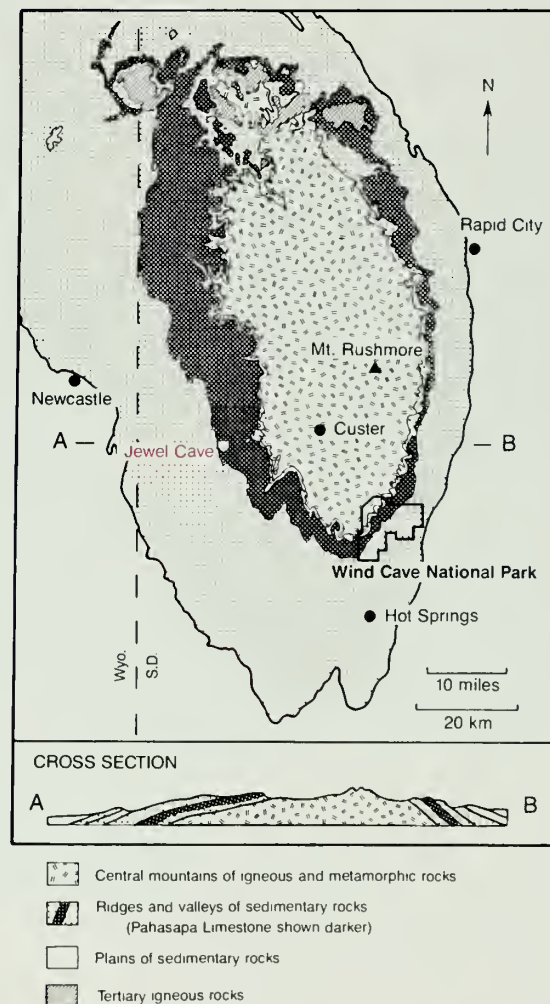
ORIGIN OF THE BLACK HILLS

The Black Hills seem such a permanent part of the landscape that it is difficult to imagine them as newcomers to the geologic scene, far less ancient than the rocks that comprise them. About 60-70 million years ago, near the end of the age of dinosaurs, westward drifting of the North American continent against other parts of the earth's hard outer crust caused widespread buckling of the forward edge of the continent. Where the crust was weak or was already bowed upward slightly from previous phases of mountain formation, the land surface wrinkled into broad domes and folds. Such motions in the earth, rarely more than a few inches each year, are caused by the escape of heat from deep beneath the surface.

As the Black Hills rose, streams carved deep canyons through the sedimentary rocks, eroding them away completely in the highest areas and exposing the much older igneous and metamorphic rocks. These older rocks form the high rugged peaks in the central hills, and the remnants of the sedimentary rock layers slope off to all sides around the edges of the hills. The eroded edges of these layers form concentric ridges and valleys around the high peaks, like the crests and troughs of waves around the point where a pebble has been dropped into water. Hard rock layers project as ridges or plateaus, and the weak, easily eroded ones form lowlands. At Wind Cave all rocks younger than the Minne-lusa Sandstone have been eroded away.

As erosion exposed the Pahasapa Limestone during the uplift of the Black Hills, there was a great increase in the circulation of underground water through the limestone. Wind Cave underwent most of its growth at that time.

Most of the material eroded from the Black Hills was carried by rivers to the Gulf of Mexico as mud, sand, and gravel. During dry periods, or when sea level was slightly higher, much of this sediment accumulated instead around



Geologic map of the Black Hills.

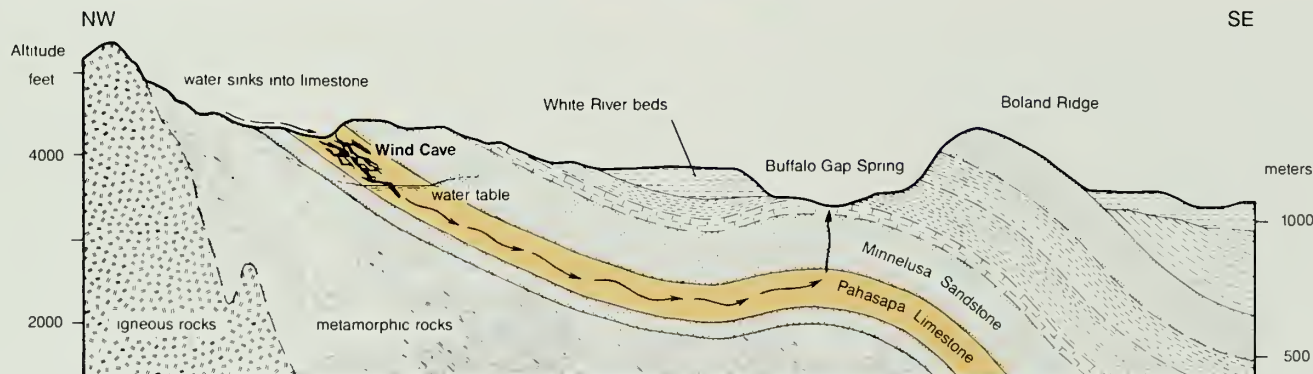
Wind Cave

the edges of the Black Hills. The greatest of these deposits still form a broad sheet extending eastward. They consist mainly of the White River Group, a series of sand and clay beds deposited about 30-40 million years ago, and are so soft that they are barely rock at all. Later erosion by streams and rain has carved them into the strange otherworldly landscape that we see today in Badlands National Park.

The upward arching that formed the Black Hills caused the sedimentary rock layers around the flanks to slope away from the center of the mountains. The amount of tilt decreases outward from the Black Hills, and in the surrounding plains the layers are almost horizontal. At Wind Cave the rocks slope an average of 5 degrees toward the southeast. Although confined to a limestone layer only 300 feet (90 m) thick, the cave spans a vertical range more than twice as great 640 feet (195 m) because it follows the layer for nearly a mile in the direction of tilt.

Uplift of the Black Hills also caused the rocks to crack. Many cracks were older ones that enlarged at this time, but some new ones also formed. A simple fracture involving no visible movement is called a joint. A crack along which there has been movement, where one rock mass has slipped past another, is called a fault. Most joints and faults in the sedimentary rocks are nearly vertical, cutting across the rock layers at essentially right angles. The largest faults are inclined at various angles. Most of the passages in Wind Cave are solutionally enlarged joints and small faults, and that accounts for their high, narrow, straight patterns. They are oriented mainly northwest-southeast with minor ones oriented northeast-southwest, reflecting the pattern of stress in the limestone when the mountains formed.

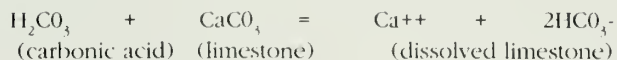
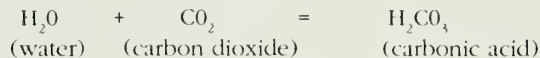
WATER AND ITS WORK



Flow of underground water through the Pahasapa Limestone. The width of the section shown is about 12 miles (19 km).

The original tiny holes and cracks in the Pahasapa Limestone were enlarged by the dissolving action of underground water to form the many interconnected passages and rooms of Wind Cave. All rocks are soluble in water to some extent, but most dissolve so slowly that the land surface is eroded down faster than caves can form. Limestone is the most common exception.

Limestone hardly dissolves at all in pure water, but if the water contains some acid, as it almost always does, it dissolves much more readily. The most common natural acid is carbonic acid, formed when water absorbs carbon dioxide from the atmosphere and soil. Carbon dioxide is a gas produced mainly by biological processes such as respiration and the decay of organic material. The solution of limestone involves these reactions:



Dolomite dissolves in a similar way.

Carbon dioxide is abundant in the soil, and a large amount of this gas is absorbed by water as it seeps into the ground. As soon as the water reaches limestone or dolomite it begins to dissolve the walls of the cracks and other openings through which it flows. If there is enough water flow for a long enough time, a cave will form. It takes hundreds of thousands of years of slow water seepage for the original cracks to grow into caves. Enlargement is much faster where water flows freely through caves that have already formed. But the water that formed Wind Cave moved very slowly, and it probably took millions of years of gradual dissolving to form it.

Another source of cave-forming acid is hydrogen sulfide, a gas easily recognized by its rotten egg smell. This is a gas produced by the bacterial breakdown of organic material and gypsum beneath the surface where there is no oxygen. If the hydrogen sulfide moves toward the surface and reacts with oxygen it can form sulfuric acid, which is even more effective in dissolving limestone.

Wind Cave



Windy City Lake, at the southern end of Wind Cave, is the largest known water body in any cave in the Black Hills. Its depth is 28 feet (8.5 meters).

Wind Cave

Caves tend to form where the flow of water is greatest. Most flow is along the large cracks, rather than through tiny pores, and that is why so many of the passages in Wind Cave follow joints and faults. Underground water starts its journey by seeping through the soil or flowing into openings in the limestone. At first it is pulled downward by gravity along the steepest available cracks, but eventually it reaches a zone where all the openings in the bedrock are filled with water. The top of this zone is called the water table. In general, this is the level at which water stands in a well. Below the water table, water flows along the most efficient routes to emerge as springs at lower elevations, usually in stream valleys.

Wind Cave originated almost entirely below the water table, as shown by its rambling maze pattern and the lack of any indication of rapid water flow. As surface streams eroded the land downward, new springs became available at lower elevations and the water table dropped, emptying the cave of water. For that reason, most of the cave is air-filled today.

The streams that drain from the Black Hills today sink underground where they flow across the Pahasapa Limestone. Also, rain and snowmelt seep into the limestone either directly or through the overlying Minnelusa Sandstone. Most of this underground water follows the limestone to great depths beneath the surface by following the tilt of the layers. Underground water in the Wind Cave area exits at Buffalo Gap Spring, located 4.5 miles (7 km) to the east where an upward arch in the rocks brings the limestone close to the surface. Even so, the water has to rise through the overlying Minnelusa Sandstone to reach the spring. Water easily passes through the cavernous limestone, but it requires a great deal of pressure to move upward through the narrow cracks in the sandstone. The lakes in Wind Cave, which represent the local water table, stand 200 feet (60 m) higher than the

spring. This elevation difference provides the necessary pressure.

Changes in the amount of water sinking into the limestone cause the water table in the limestone to fluctuate. The water level is therefore very sensitive to changes in climate. Periodic advance and retreat of glaciers during the last two million years caused great variations in the amount of rainfall in the Black Hills and in the level of water in Wind Cave.

Springs draining the limestone in the southern Black Hills have shifted their positions over the years as stream erosion changed the configuration of valley bottoms. Past spring locations can sometimes be recognized by the presence of sand carried up from below and by the fossil bones of animals that used the springs as watering holes. Workers at the Mammoth Site, located in the city of Hot Springs, believe that the site was once a spring outlet, an oasis containing thick mud and quicksand that trapped the mammoths and other animals who came to drink.

It might seem logical that Wind Cave was formed by the water that flows directly into the limestone from the surface, because that is what we see today. However, its origin is much more complex, with water flow patterns that were quite different. It is useful to take a closer look at the various cave features before deciding how the cave formed.

PASSAGE TYPES

Most large caves contain different passage levels, like the stories in a building. They are usually formed one after the other as the water table drops, with the recent ones at the lowest levels. In Wind Cave, however, the passage types are controlled by the different layers within the Pahasapa Limestone. There are no true levels, because the passages are not horizontal but are tilted at roughly the same angle as the limestone. Some passages are confined to a single rock layer; others shift from one layer to another, and as they do so their character changes according to the local rock type.

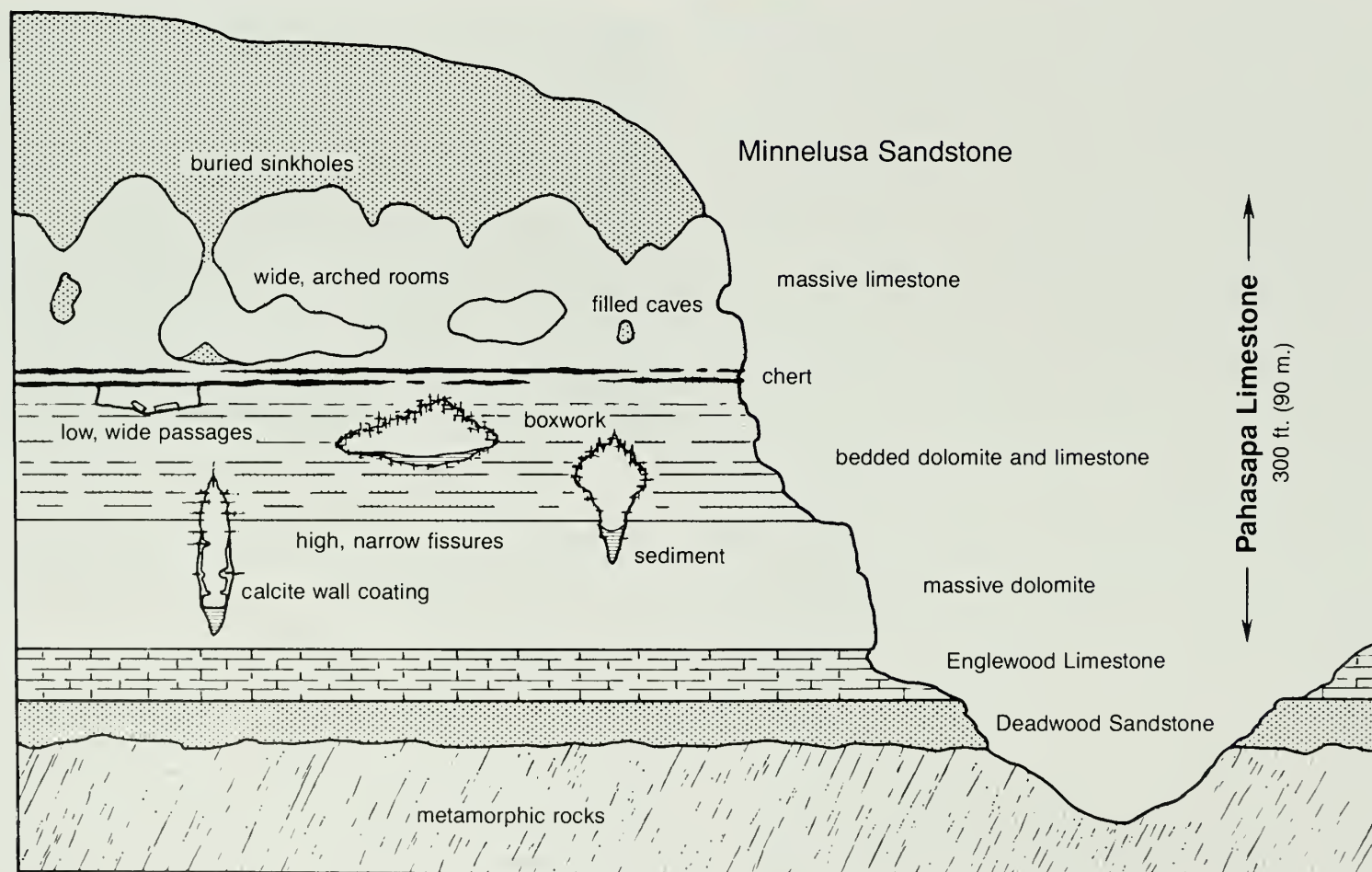
There are three major layers in the Pahasapa Limestone, each about 100 feet (30 m) thick. The upper one is massive light-gray limestone with many fossil shells near the base. Its upper surface is very irregular because of the erosion that took place at the end of the Mississippian Period, before the overlying sandstone was deposited. It contains many solution pockets, remnants of caves that formed during that same erosional period. In surface canyons the layer forms high cliffs weathered to dark gray. In the cave it forms wide vaulted rooms with light gray or sandy colored surfaces indented with rounded hollows. The Fairgrounds and the Garden of Eden are good examples. The boxwork so common elsewhere in the cave is almost entirely absent in this layer, except in a few isolated pockets just above the base (as in the Garden of Eden). Where the present cave intersects ancient filled caves of Mississippian age, they can be recognized by the bright red or yellow sediment they contain. This material, which filled the openings early in the Pennsylvanian Period, is mainly sand and clay with interspersed fragments of limestone and chert. In places the sediment has subsided out of the ancient caves into more recent passages, forming conical piles or thin layers covering the floor and ledges.



The upper levels in Wind Cave have smooth, rounded limestone walls and ceilings. A miner's carbide lamp 5 inches (13 cm) high is shown for scale.

The middle layer of the Pahasapa Limestone consists of bedded limestone and dolomite. Most of the trails open to visitors are in this layer. Its contact with the overlying layer is located in the entrance passage part way down the first staircase. On the surface it usually forms irregular slopes rather than steep cliffs. Most of the boxwork occurs in this layer. Fossils, particularly shells, are common near the top. Several chert beds occur at the top, spaced a few feet apart. Chert beds and fossils are clearly visible in the passages

Wind Cave



Rock layers in the Pahasapa Limestone and the types of cave passages and canyon walls that occur within them.

Wind Cave

between the Elk's Room and the Fairgrounds. Remnants of Mississippian caves occur near the top of the middle layer but are smaller and less abundant than those in the upper layer. Cave passages in the middle layer are quite varied. Near the top they may be low and wide, particularly where the ceiling coincides with one of the insoluble chert beds. Complex, irregular passages or interconnected rooms are typical in the middle parts of the layer. Resistant beds project slightly from the cave walls as ledges, and weaker ones form recessed niches. Near the bottom of this layer, high, narrow fissures along joints and faults are common. In many places the cave walls have weathered to a powdery coating of different colors such as red, black, orange, yellow, brown, and gray. For example, the golden yellow ceiling just beyond the Beauty Parlor on the main tour route is due to weathering of iron-rich dolomite beds.

The lower third of the Pahasapa Limestone is thick-bedded dolomite fractured by prominent joints and faults. Like the top layer, it forms massive cliffs. Because of its large fractures, most of the cave passages in this layer are high, narrow fissures that extend for long distances in straight lines. On the tour routes this layer is visible in only a few places—such as the Blue Grotto. The layer includes a large part of the cave not open to the public, such as the passages between the Club Room and the lakes. In this section of the cave the walls are covered with a thick layer of calcite crystals. Boxwork occurs in many places in the upper parts of this layer but is not so common as in the layer above.



Passages in the middle layer of the Pahasapa Limestone typically have boxwork, projecting ledges, and tricky footing (except on the tour routes).

Wind Cave



Chert forms the remarkably flat ceilings near the Fairgrounds.

Passages in the lowest layer of the Pahasapa Limestone are high, narrow fissures that follow joints and faults. This is the main route to the lakes.

CAVE DECORATIONS



Flowstone draperies are formed by water seeping into the cave and depositing calcium carbonate as it flows down the wall. Water dripping from the edge of one drapery has formed stalactites. Width of photo is one foot (30 cm).

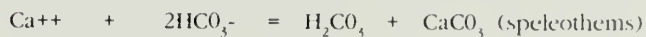
After a cave forms, it becomes the host for a variety of mineral deposits. These are the speleothems (popularly known as “cave formations”) that give a cave much of its beauty. Water that seeps slowly into the cave, or which remains standing in pools, does not have the dissolving power to create new passageways. Instead it deposits some of its dissolved minerals as crystals that take on many strange and intriguing shapes.

Most of these deposits are made of calcium carbonate (CaCO_3) that precipitates from water. This is the same material that makes up the limestone bedrock in which the cave is



Dogtooth spar lines a solutional pocket like the teeth of a shark. Height of photo is four inches (10 cm).

located. Water passing downward through the soil absorbs a large amount of carbon dioxide produced by plants and animals, and becomes slightly acidic. This weak acid is able to dissolve limestone. However, if this water drains into a cave that is air filled, the water loses much of its carbon dioxide to the cave air, and some of the dissolved calcium carbonate may precipitate as crystals:



This process is exactly the opposite of the solution of limestone.

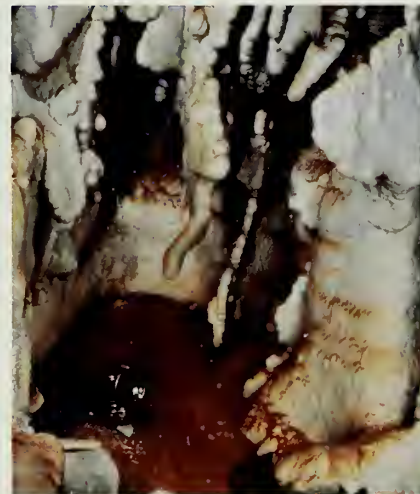
Calcium carbonate takes on two different crystal types in the cave: calcite and aragonite. Calcite forms lozenge-shaped crystals (with parallelogram-shaped sides) or complex many-sided prisms. Aragonite forms thin needle-like crystals and is usually deposited instead of calcite where there is intense evaporation. Speleothems composed of pure calcite or aragonite are white or transparent, but a surprisingly small amount of foreign elements in the calcium carbonate can produce brilliant colors such as red, yellow, and orange.

If an ultraviolet light ("black light") is shined on cave minerals, some of them produce an eerie greenish glow called fluorescence. The invisible ultraviolet light is absorbed by certain types of crystals and released as visible light. When the light is turned off, the minerals may continue to glow briefly (phosphoresce). Calcite is the most common mineral of this type, but it behaves this way only if it contains impurities such as manganese and organic compounds. Aragonite does not ordinarily show either fluorescence or phosphorescence.

The shape and mineral content of speleothems depend on the amount and chemical composition of water available. The most common kinds of speleothems in Wind Cave are described below, roughly in order from the wettest to the driest cave environments:

CRYSTAL LINING ON WALLS

In the lowest levels of the cave a thick coating of white, yellow, or brown calcite crystals has grown on the cave walls, completely hiding the bedrock. These crystals were deposited when the lower parts of the cave were filled with standing water, and they are still forming in some of the lakes



Walls of the lowest cave passages are coated with a thick layer of calcite crystals. The coating is usually less than half an inch thick but reaches several inches in places. A miner's headlamp 5 inches (13 cm) high is included for scale.

today. This water is different from that which formed the cave, as it is saturated with dissolved limestone and is unable to dissolve more. The ends of the crystals form a continuous surface of tightly clustered knobs or points that project from the walls like the tips of pineapple segments. Wall coatings of this type are most common in the area south of the Club Room known as the Calcite Jungle, where the coating reaches a thickness up to 2 inches (5 cm). In most areas it is only a fraction of an inch thick. Nearby Jewel Cave is noted for its crystal wall coating, which is up to half a foot (15 cm) thick. Crystal linings are fairly thin along the public trails in Wind

Wind Cave

Cave and look like a sparkling glaze over the bedrock.

GEODES

Some of the crystals in Wind Cave are not related to the cave at all, but form the linings of small pockets that have merely been intersected by it. These crystal-lined pockets are called geodes. Most were originally small blobs of gypsum deposited along with the limestone and later dissolved away by underground water. Many geodes have a hard outer shell of mineral deposits that allow them to weather out of the bedrock as nearly round balls with hollow centers. Those in Wind Cave are generally too delicate to do so. They range from a few inches to a few feet in diameter. Two kinds of crystals are common: quartz, and a variety of calcite called dogtooth spar. Both probably formed deep beneath the surface long before the origin of the cave.

Quartz crystals are usually clear as ice and reflect light brilliantly. They form most easily in hot water. Many of them in Wind Cave have grown around particles of iron oxide, which can be seen as dark brown or black cores. The largest are finger-like and hang downward in thin strands, like sugar crystals on strings, up to about half an inch (one centimeter) in diameter. Small quartz crystals line many small fractures throughout the cave, but no quartz geodes are visible along the tour routes.

Dogtooth spar is a variety of calcite with sharp tooth-like crystals. It may have formed when the gypsum was being dissolved from pockets in the limestone, because adding gypsum to calcite-saturated water will force calcite to deposit. Some are clear or white, and others are a delicate honey color. The largest crystals are about two inches (5 cm) long. There are many small pockets lined with dogtooth



Quartz crystals surrounding a core of iron oxide. Height of photo is 3 inches (7.5 cm).



Calcite rafts litter the shores of Calcite Lake and almost cover its surface. Width of photo is about two feet (60 cm).

spar along the main trail between the walk-in entrance and elevator.

CALCITE RAFTS

Calcite may crystallize from the water as thin floating rafts, especially if a faint dust of weathered limestone settles

onto the surface of a standing body of water. The dust provides attachment points for the calcite crystals. The resulting rafts look like lily pads, except that they are usually pure white or yellow. They may coalesce into a continuous sheet that looks like ice. Calcite Lake is almost completely covered by a layer of calcite. Rafts are only paper thin, and they are able to float because of the surface tension of the water. If they are disturbed or grow too heavy they sink to the bottom. When the lake surface drops, a litter of calcite rafts is left behind, stacked chaotically like autumn leaves.

FLOWSTONE AND DRIPSTONE

Where enough water seeps into the cave to form distinct drips or trickles, it deposits calcium carbonate as flowstone or dripstone. Flowstone forms smooth, rippled sheets or draperies where water runs over the cave walls. Drops falling from the ceiling deposit dripstone. This includes stalactites, which hang from the ceiling like icicles, and stalagmites, which grow upward as mounds on the floor where the drops fall. If a stalactite and stalagmite grow long enough to join, a column is formed between the ceiling and floor. These features are most common where the cave underlies surface valleys. Small cascades of yellow flowstone occur in the main passages near the Devil's Lookout and beside the staircase leading to the Garden of Eden, but there is almost no dripstone visible from the tour routes.

HELICTITES

Helictites are bushy growths of calcium carbonate that twist and branch like gnarled twigs. The largest helictite bushes in Wind Cave are about 3 feet (one meter) tall, with individual branches that range in thickness up to finger size.

Wind Cave



Helictites near the lakes twist upward from the floor like the performers in a snake dance. The tallest is about 1.5 feet (45 cm).

Some are grotesque, like rocky tentacles, and others are delicate and graceful. They form where water seeps from the limestone in amounts so small that it moves by capillary forces, rather than by gravity. Water is drawn through tiny central tubes to the growing tips.

Most helictites in Wind Cave are located in the southern part of the cave, near the lakes. They grow mainly from the floor and are coated with a calcite crust like that on adjacent cave walls, showing that they have spent a great deal of time below water. It is possible for helictites to grow under water, but only in unusual chemical conditions. These most likely formed in air, growing upward from deposits of weathered limestone powder that accumulated from upper levels, apparently when the powder was moistened by pools of water immediately below. Later rises in water level coated them with layers of calcite, making them thicker and sturdier.

CAVE POPCORN

Where tiny amounts of water seep into the cave, knobby growths of calcium carbonate may eventually form that look like grapes or popcorn. They form the same way that helictites do, except that the water seeps out of the limestone more uniformly, depositing many small knobs instead of a few large branches. Popcorn can also form where there is a thin film of water on the cave wall from the splashing of nearby drips. In many places it grows along the edges of boxwork like the teeth of a dull saw. Popcorn occurs in many places throughout the cave. Along the public trails it is most easily seen in the Fairgrounds, the Pearly Gates, and the Garden of Eden.

Wind Cave



Cave popcorn grows where water seeps slowly into the cave or forms a thin film on the surface from nearby drips. Width of photo is about 5 inches (13 cm).

Wind Cave



Frostwork consists of aragonite needles that crystallize in areas of high evaporation. Width of photo is 6 inches (15 cm).

FROSTWORK

Water that seeps into the cave and evaporates forms delicate needle-shaped crystals of aragonite, which project from the walls as needles or flower-like clusters called frostwork. Most frostwork crystals are about the diameter of a pin and less than an inch long, but some are as long as several inches. They grow from nearly every kind of rock or mineral surface in the cave, including limestone bedrock, boxwork, and popcorn. In places the crystals form intricate growths up to a foot (30 cm) in height that look like evergreen trees. Frostwork is most abundant where the cave walls are porous dolomite, especially in places where there is air movement, such as narrow spots in a passage. Some of the moisture that formed the frostwork may have seeped upward through pores in the bedrock from the water table when it was higher. The Fairgrounds and Garden of Eden contain good displays of frostwork.

MOONMILK

Moonmilk is a white deposit of microscopic crystals, usually consisting of the mineral hydromagnesite, $\text{Mg}_5(\text{OH})_2(\text{CO}_3)_4 \cdot 4\text{H}_2\text{O}$. It is pasty when wet and powdery when dry and forms coatings or small blobs on the cave walls. It is thought to be formed where magnesium-rich water seeps into particularly dry parts of the cave. Bacteria or other micro-organisms may contribute to its precipitation.

GYPSUM

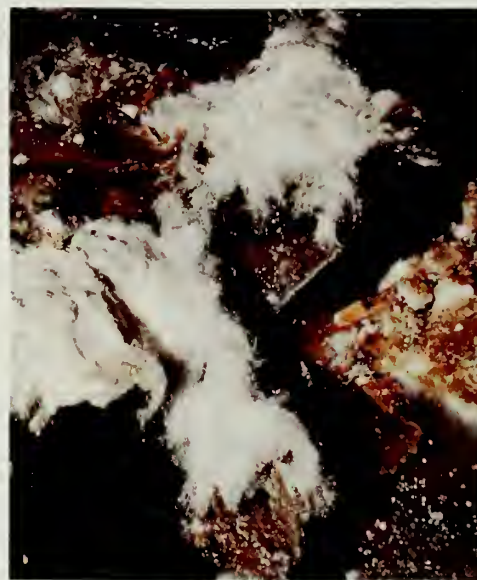
Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is a soft white mineral that forms in very dry parts of the cave. Dissolved gypsum is carried into the cave by water that seeps in small quantities through

Wind Cave



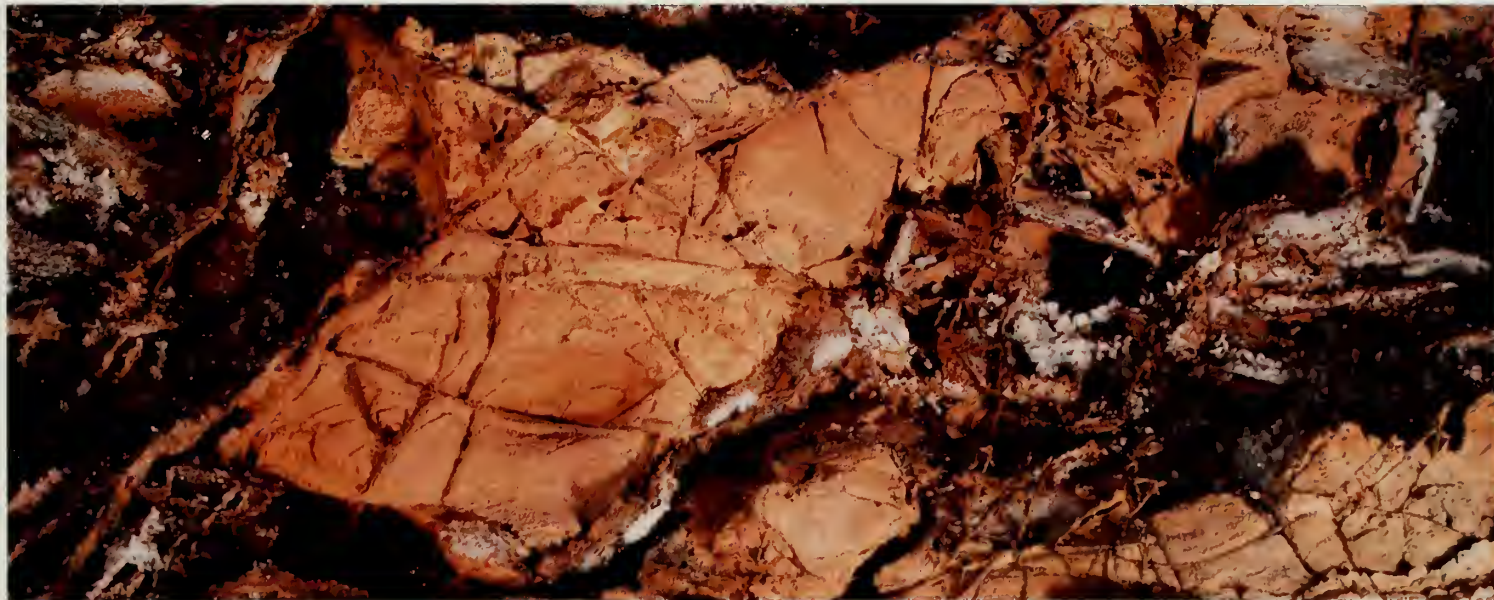
An aragonite "Christmas tree" 8 inches (20 cm) high near the Club Room.

the limestone by capillary forces. Most of it is probably picked up from gypsum beds within the overlying sandstone. Some is formed by the weathering of iron pyrite (fool's gold) within the bedrock. Wind Cave contains several different forms of gypsum. Most common are "star-bursts" of brown radiating crystals a few inches long hugging the bedrock surface. In a few places the gypsum forms long thin needles clustered together in white, life-sized "beards."



A gypsum "beard" near the Pearly Gates. Height of photo is one foot (30 cm).

THE CAVE SHOWS ITS AGE



Deep weathering of dolomite has produced a thick powdery rind brightly colored by iron oxides. As the powder falls away, calcite veins protrude as boxwork. Width of photo is one foot (30 cm).

The craggy mountains and canyons of the West may seem enormously old, but, geologically speaking, they are really quite recent. Their bedrock walls are under frequent attack by running water and the prying action of freeze-thaw cycles. However, a dry cave, abandoned by the water that formed it, is protected from these agents of destruction. Meanwhile, chemical changes can produce an exotic display of extremely fragile minerals that would never survive the rigors of the outside world. Wind Cave gives a glimpse of a truly ancient "landscape" far older than any surface feature and nearly any other cave.

Where there is no lining of calcite crystals, weathering of the cave walls has produced soft powdery coatings. These are simply disintegrated bedrock, with impurities brightly colored by lengthy exposure to the moist cave air. Iron oxide (red, yellow, orange, black or brown) and manganese dioxide (blue-gray or black) are the most common. In places the weathered coating on the walls is several inches thick.

This much weathering requires more than just time. A cave atmosphere rich in carbon dioxide or hydrogen sulfide is also important. Water seeping into the cave through pores in the bedrock will absorb these gases and become very

Wind Cave

corrosive. The same is true for water that condenses on the cool cave walls from moist warm air rising from pools. The walls are especially corroded where oxygen combines with pyrite in the bedrock of the old gypsum zones to produce sulfuric acid. Today, with the great amount of air circulation from the surface, the cave atmosphere is very much like that of the outside air, and weathering of the cave walls is not as vigorous as in the past.

When weathering attacks the cave walls, much of the resulting powder falls to the floor and accumulates in piles. Huge amounts of this material have collected in the lower levels, blocking many passages. During the latest stages of cave development the water level fluctuated up and down many times, carrying most of these deposits downward into even lower levels, sometimes dissolving them or cementing them into hard rock-like material, depending on the water chemistry. The remaining weathered deposits are draped over ledges or form gray or red-brown mounds on the floor. In the lower levels the surfaces are cemented into a hard crust that is usually underlain by loose powder. Where this underlying material has settled downward the hard crust is left as a hollow floor.

Where ancient Mississippian caves have been intersected by the present cave, part of their sand and clay filling spills into the newer cave passages, revealing parts of the older caves as they originally looked before being filled with sediment. This material is easily recognized by its deep red or yellow color. A fine example is seen in the Beauty Parlor, where the passage has intersected a narrow pocket containing red clay so bright that it looks like lipstick.

Blocks and slabs of rock have occasionally fallen from the roof and walls of the cave. Most are small, but in wide chambers such as the Club Room and Half Mile Hall some are the size of railroad cars. Visitors may eye them suspi-

ciously and wonder when the next one is coming down. But there is almost no chance of fresh pieces breaking off today, especially in the areas open to the public. These blocks fell long ago while the cave was forming, as shown by deep weathering and sediment on their surfaces. Many of them came down when the water table dropped and the buoyant effect of the water was lost.



Where the most recent cave passages intersected ancient caves or sinkholes filled with sand and clay, this loose material spills into the younger cave, revealing the older openings as they were when they formed 320 million years ago.

BOXWORK

Boxwork is the most unusual result of weathering. Few caves contain boxwork at all, and no other in the world contains the quantity and variety that Wind Cave does. It is made of thin blades or fins of calcite that project into the cave from the walls and ceiling. Boxwork in the cave floor is mostly obscured by weathered deposits. Boxwork fins tend to intersect one another at various angles, usually nearly at right angles, forming open chambers. In many places the gaps between the boxwork fins are still occupied by crumbly, weathered bedrock that would fall out at the slightest touch. Whenever the water level rose in the past and covered these areas, this weathered material became mushy and dropped out of the holes between the boxwork fins. Boxwork is most common in the dolomite beds in the middle of the Pahasapa Limestone but is almost entirely absent from the limestone above. In the passages open to the public, some of the best displays are in the Post Office (named for the shape of its boxwork) and the Elk's Room.

Some boxwork is paper thin and very delicate, but in the lower levels it is coated with a lining of calcite crystals or weathered wall powder. Water seeping out of the walls also deposits frostwork and popcorn on the edges of the boxwork. In this way, most of the original boxwork veins have been strengthened and decorated.

The origin of boxwork can be traced all the way back to when the bedrock was deposited. As limestone accumulated in the shallow sea during the Mississippian Period, layers and lenses of gypsum occasionally crystallized from the sea water, especially during dry periods or when the sea was shallow. Gypsum is very soft and flows like putty when pressure is applied. As more rocks were deposited on top, the gypsum was squeezed from high-pressure zones into areas of lower pressure. As the gypsum compacted and flowed, the surrounding brittle limestone became cracked. Occasionally the

shallow inland sea retreated from the area, allowing fresh rainwater to circulate underground, readily dissolving the gypsum and causing the limestone to collapse and fracture still more. The cracks in the limestone were then refilled with gypsum squeezed into them by pressure or crystallized from the underground water.

Gypsum and limestone are similar, as they are both salts of calcium, and either one is able to replace the other, depending on the chemical nature of the underground water. As fresh water continued to flow through the bedrock, the gypsum veins remaining in the cracks were converted to calcite. The projecting fins of boxwork that we see in the cave today are formed by these resistant calcite veins projecting outward from the walls as the surrounding bedrock weathers away.

Determining the origin of boxwork is like a detective story, where many scattered clues point in the same direction. A microscopic view of the boxwork shows mineral textures that were inherited from the original gypsum, even though the gypsum is no longer there. The color of the veins offers another clue. They are yellow with iron oxide, which is often derived from gypsum deposits. The gypsum was broken down into hydrogen sulfide by bacterial action, and the hydrogen sulfide reacted with dissolved iron to produce iron sulfide. This in turn weathered to iron oxide when it was exposed to oxygen near the surface, and this accounts for the yellow-orange color of the walls in the middle levels of the cave. As a final clue, boxwork that is still gypsum occurs in a few caves in other parts of the world, and the rock relationships and textures are identical to those described here.

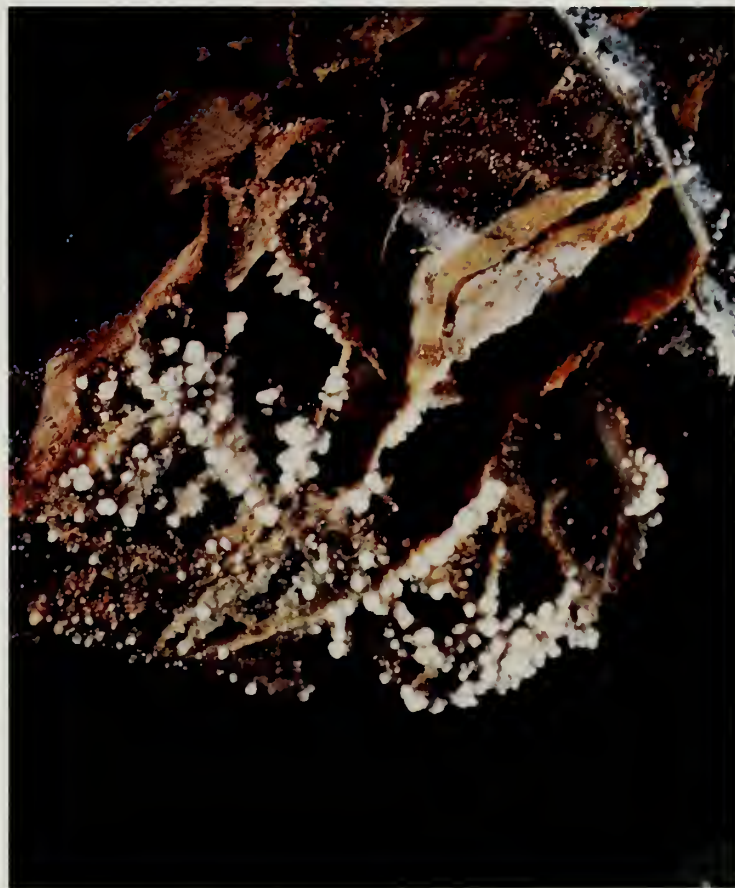
Calcite veins alone are not sufficient to form boxwork. In the moist cave environment, lengthy chemical weathering of the bedrock between the veins has caused it to crumble to



Wind Cave

powder, allowing the calcite fins to stand in relief. Limestone ordinarily resists this kind of disintegration, but the complex fluctuations between sea water and fresh water during the Mississippian Period caused many chemical changes that left the bedrock in the boxwork zones weak and crumbly. Through the microscope it is possible to see places where the original limestone was partly replaced by gypsum and then later converted to dolomite. Where the more soluble minerals were removed by underground water and not completely replaced by other minerals, the resulting gaps make the rock porous and easily weathered.

Why is boxwork so rare in other caves? After all, gypsum is common in many limestone deposits throughout the world. But usually the gypsum is completely dissolved away by circulating underground water before it can be converted to calcite boxwork veins. In the southern Black Hills the gypsum-filled cracks were covered by younger rocks before the gypsum could be dissolved away completely. The boxwork that we see so clearly in the walls of Wind Cave is the record of a rare and short-lived event preserved for millions of years under the protection of the overlying rocks.



Many boxwork fins acquire a fringe of popcorn and frostwork. Width of photo is two feet (60 cm).

Boxwork in the ceiling of the Elk's Room. Width of photo is three feet (one meter).

GEOLOGIC HISTORY OF WIND CAVE

Many caves contain underground streams that are still enlarging the passages they originally formed. Wind Cave is not one of them. The water that formed it drained away long ago. Like many other features of Wind Cave, even its origin must be puzzled over by weighing many conflicting geological clues.

A cave is created only if there is sufficient flow of acid-rich underground water. Therefore, Wind Cave could only have formed after the Pahasapa Limestone was exposed to erosion by uplift of the Black Hills 60-70 million years ago. The Black Hills provided a local window where the Pahasapa Limestone was brought to the surface, allowing large amounts of water to pass through the limestone for the first time since it was buried beneath the younger sedimentary rocks. The new cave passages intersected many of the older filled caves and solution pockets, combining two entirely different sets of openings into a single cave.

This new phase of cave origin most likely took place early in the Tertiary Period, about 40-60 million years ago, because that is when the limestone was first being uncovered by erosion. Surprisingly, the landscape we see today at Wind Cave was formed more than 40 million years ago and has hardly changed since. We know this because the eroded surface was covered by the White River beds, 30-40 million years old, remnants of which are still found in the valleys around the present springs.

Where did the cave-forming water come from? Today most of the streams that drain off the central hills of igneous and metamorphic rocks sink underground where they encounter the soluble Pahasapa Limestone. For example, Beaver Creek, just north of Wind Cave, is swallowed completely by a hole at the base of a limestone cliff and reappears at Buffalo Gap Spring. It might seem that Wind Cave was formed by this same kind of water. However, a close

look at the cave shows features quite different from those formed by underground streams. The passages loop up and down and interconnect in a three-dimensional maze. Sand and gravel deposits, which would indicate water flowing in from the surface, are almost totally absent. It seems that the water from sinking streams is merely following and enlarging caves that were already there.

Instead, the peculiar weathering and boxwork suggest unusual chemical conditions. Irregular rooms with high ceiling pockets indicate slow water movement that filled the cave entirely. It seems that the water that formed the cave must have come from deep beneath the surface. Only recently has this kind of cave origin been demonstrated to be possible for many of the large and unusual caves of the West. Deep beneath the surface the sedimentary rocks of the surrounding region contained water charged with dissolved gases such as hydrogen sulfide and carbon dioxide produced by the breakdown of gypsum and organic materials trapped within the original sediments. As the rise of the Black Hills brought the limestone to the surface, an outlet was provided for these gas-rich waters. Water was driven upward along the limestone beds either by the pressure of the overlying rock layers in the surrounding plains, or by heat from deep igneous rocks. The dissolving action of the gases was most potent near surface outlets because limestone is more soluble in cold water, and because hydrogen sulfide increases its solution vigor by combining with oxygen near the surface to form sulfuric acid.

An origin of this kind is supported by the fact that the walls of the cave were once coated with gypsum. This is a typical by-product of the sulfuric acid reaction with limestone. The gypsum was dissolved just before the wall coatings of calcite were deposited, and its former existence is known only from minerals that have inherited the shape of

Wind Cave

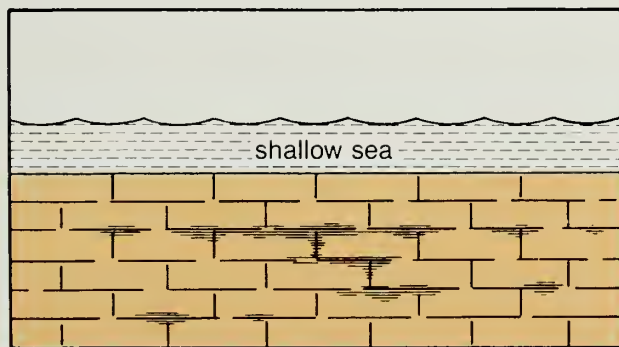
the earlier gypsum crystals. Chemical analysis of the calcite wall coating in the lower levels also lends strength to this view. They show that the calcite was deposited in water that came from deep within the limestone, rather than directly from the surface. Of course the cave could not have been formed by this water because it was saturated with dissolved limestone and could not dissolve more. Still, this information shows that the latest water to fill the cave did not come from surface streams. The lakes are the last remnants of this water.

The underground water flow that formed the cave was rather temporary, and it was not long before it ceased altogether. As the Black Hills continued to rise, surface

streams began to sink into the limestone, reversing the direction of flow. This change in flow marked the end of Wind Cave's main period of growth. The cave then began to drain. It is not certain when the cave ceased forming, but the age of the calcite wall coating, determined from analysis of radioactive minerals, shows that water last filled the lower half of the cave no more than a few million years ago.

The Wind Cave that we see today is a showcase for more than 300 million years of the earth's history. Events of long ago whose traces have disappeared almost entirely from the surface are recorded underground in vivid detail. The major phases of this long and complex history are reviewed here:

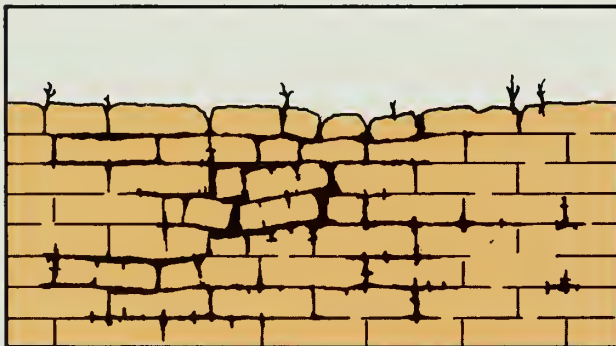
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1. The Pahasapa Limestone was deposited in a shallow sea during the Mississippian Period, 330-360 million years ago. The layers included more gypsum and dolomite as the water became shallower and evaporation increased.

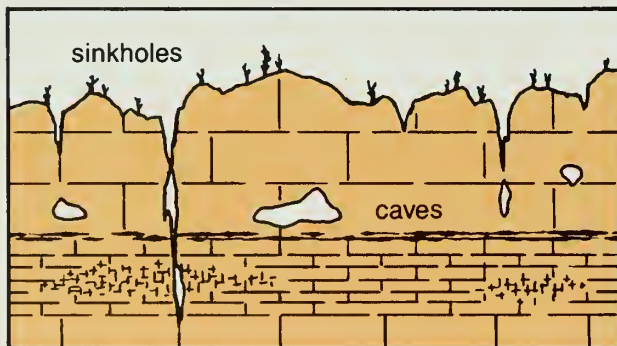
Wind Cave

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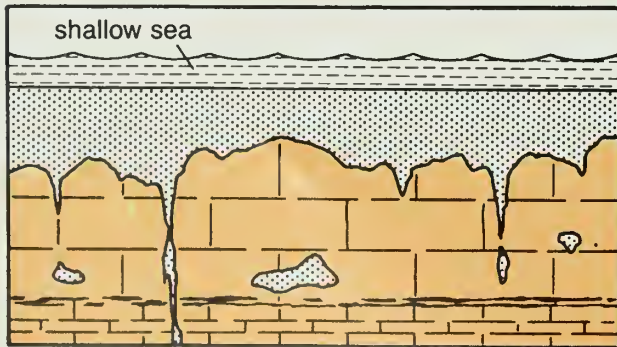
2. Before the upper third of the limestone was deposited, the rock surface was exposed briefly above sea level, allowing fresh water to penetrate underground from the surface. This water brought about several chemical changes. It dissolved most of the gypsum, cracking the surrounding limestone. Gypsum remaining in cracks was converted to calcite. The same water also altered much of the limestone to dolomite.

3



3. A lengthy drop in sea level at the end of the Mississippian Period, 320-330 million years ago, exposed the limestone to surface erosion. Fresh water began to circulate through it. Limestone dissolved along the paths of most active water flow, forming sinkholes at the surface and caves below. The caves were mainly irregular rooms and fissures formed at the zone of mixing between fresh water and sea water, as is happening today in the seacoast limestones of Bermuda and the Bahamas. Because there was no period of weathering in the caves, they contained no boxwork.

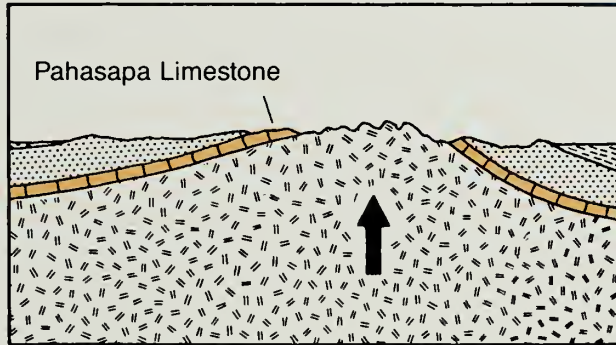
4



4. Sea level rose again at the beginning of the Pennsylvanian Period, 320 million years ago. All the sinkholes and nearly all the caves were filled with sand and mud washed into the sea from remaining land areas. These sediments were the earliest layers of the Minnelusa Sandstone. Over the next 200 million years more than a mile of sedimentary rocks were laid down over the region, concealing the early caves deep beneath the surface. Except for the slow growth of dogtooth spar and quartz crystals in isolated pockets, this was a period of stagnation for Wind Cave.

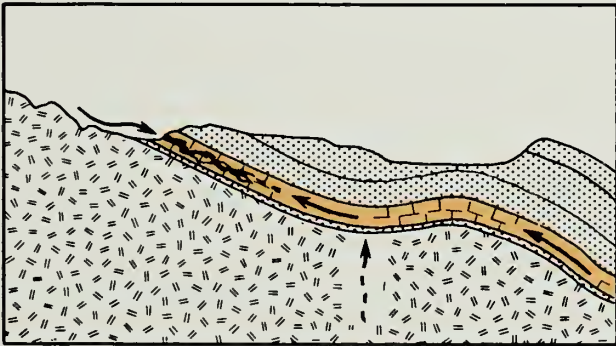
Wind Cave

5



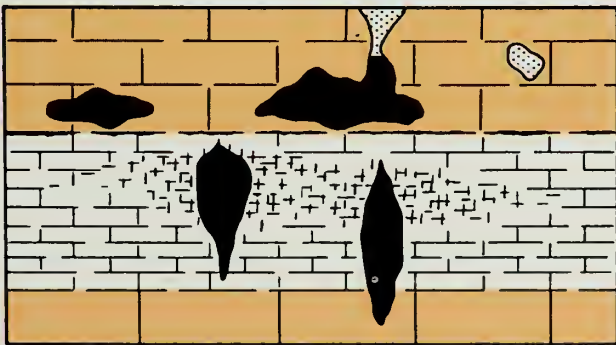
5. The Black Hills rose as the result of compression of the continent during the late Cretaceous and early Tertiary Periods, 60-70 million years ago. Where uplift was greatest, stream erosion removed the sedimentary cover from the ancient igneous and metamorphic rocks.

6



6. Intersection of the Pahasapa Limestone by erosion allowed caves to develop during the early Tertiary Period, probably 40-60 million years ago. Most of Wind Cave dates from that time. The original cave-forming water appears to have come from below, either by compaction of sedimentary rocks around the Black Hills or by convection where temperatures were great enough at depth to cause water to rise. Streams draining from the Black Hills and sinking into the limestone caused further cave enlargement. The relative importance of these three water sources in forming the cave is uncertain.

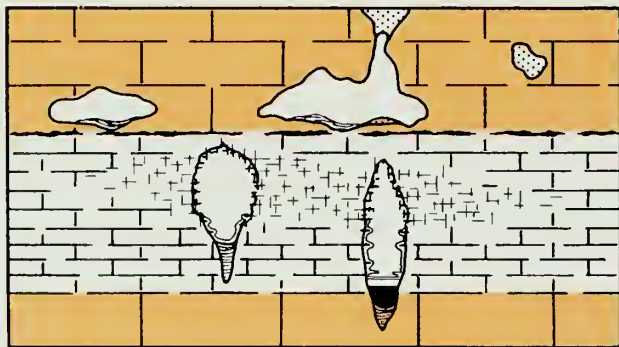
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7. Wind Cave acquired the passage pattern that it has today. The new passages intersected the ancient Mississippian caves, partly excavating and enlarging them.

Wind Cave

8



8. Partial draining of the cave allowed the bedrock walls to weather deeply. Calcite veins from stage 2 projected as boxwork. Powdered bedrock formed a sediment partly choking the lowest cave passages. Frostwork, popcorn, helictites, and other speleothems began to form. Intermittent rises of static limestone-saturated water coated the lower walls of the cave with calcite. Surfaces of the powdered bedrock sediment were cemented into a hard crust, while the underlying loose powder subsided into lower levels. The natural entrances to Wind Cave are fairly recent. Passages were intersected at random by stream erosion in canyons, probably no more than a few thousand years ago.

Each event in this long history left its mark on Wind Cave. Surprisingly, everything is so well preserved in the sheltered environment of the cave that even the most ancient features look no older than recent ones. Perhaps this is the most unusual aspect of Wind Cave: we lose our sense of time.

WHERE DOES THE CAVE END?

Until it is fully explored, the exact size of any cave is unknown. Even with delicate instruments to measure the earth's gravity it is not possible to detect a deep cave such as this from the surface. Its size beyond the explored limits can only be guessed from the local geology. The cave cannot extend any farther than the layer of Pahasapa Limestone in which it is located. This is not a serious limitation, because the limestone extends continuously around the entire outer edge of the Black Hills. All 50 miles (80 km) of Wind Cave lie beneath a land area of only 480 acres (1.9 square kilometer), which is insignificant compared to the total limestone area. However, to the northwest of Wind Cave the limestone has been eroded away, so it is impossible for the cave to continue very far in that direction. To the southeast the limestone extends below the water table, and without diving it is not possible to follow the cave beyond the lakes.

Large faults in the limestone can also limit exploration. Small ones occur in many places, ordinarily with little effect. In fact, many of the largest cave passages, such as the Club Room, are located at least partly along faults. But where the cave intersects a large fault there is usually a great deal of breakdown due to the intense fracturing of the rock around it. Many passages end in breakdown at these points. This is probably the most serious hindrance to exploration. Another curious limit to exploration is that there seem to be no passages at all in some places. Where the cave ends in the lakes and seems to continue only under water, more than half the Pahasapa Limestone lies above, but there are no known passages in those higher layers.

Is it possible that Wind and Jewel Caves are merely insignificant parts of an enormous cave system extending all around the Black Hills? Jewel Cave is even larger than Wind Cave, with 76 miles (122 km) of mapped passages, and is

currently fourth longest in the world, second longest in the country. Nearly every visitor who sees both caves wonders if they will ever be connected into a single huge one. The limestone is continuous between them, and both surely extend far beyond their presently known limits. Yet there are also reasons why an explorable connection between the caves is unlikely to be found. The water table below Jewel Cave is 1280 feet (390 m) higher than the water table in Wind Cave, represented by the lakes. There can be no large water-filled openings between the two caves, because it would be impossible for there to be such a large difference in the height of the water table. Even if there is an air-filled connection large enough for humans to pass through, it may be impossible to explore. The straight-line distance between the two caves is more than 20 miles (32 km). The most remote passage in Wind Cave is only 4 per cent of that distance from the nearest entrance, yet to reach it requires a strenuous 8-hour round trip for even the most experienced explorers.

Discovery of a cave takes place in spurts, because large sections are separated by tiny, obscure connections. Explorers cannot find new passages wherever they choose. They must poke into many openings to find the few that lead onward into the unknown. Many new passages are explored each year in Wind Cave, but most are dead ends or simply loop back again to known parts of the cave. Sometimes it is possible to follow air currents through the most promising passages, but the wind is divided among so many passages that it is imperceptible in most places.

It is impossible to say whether most of the accessible parts of Wind Cave have already been explored, or whether explorers are only on the threshold of even larger passages. But it is encouraging to know that as the cave is explored farther toward the west, the average passage size is

increasing. At this time one of the farthest explored points is a narrow slot with wind whistling through it even on calm days.

Despite their efforts to discover new passageways, explorers do not want to find the end of Wind Cave. Today when daily life is so predictable and even the most remote land areas have been mapped by satellite, it is exciting to realize that there is an unknown world right beneath our feet.



Until each hole is explored, no one knows which ones pinch down to dead ends and which ones open into spacious rooms beyond.

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