INTRODUCTION TO THREE FIELD TRIP GUIDES: Karst Features in the Black Hills, Wyoming and South Dakota- Prepared for the Karst Interest Group Workshop, September 2005

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This years Karst Interest Group (KIG) field trips will demonstrate the varieties of karst to be seen in the semi-arid Black Hills of South Dakota and Wyoming, and will offer comparisons to karst seen in the two previous KIG trips in Florida (Tihansky and Knochenmus, 2001) and Virginia (Orndorff and Harlow, 2002) in the more humid eastern United States.

The Black Hills comprise an irregularly shaped uplift, elongated in a northwest direction, and about 130 miles long and 60 miles wide (figure 1). Erosion, following tectonic uplift in the late Cretaceous, has exposed a core of Precambrian metamorphic and igneous rocks which are in turn rimmed by a series of sediments of Paleozoic and Mesozoic age which generally dip away from the center of the uplift. The homoclinal dips are locally interrupted by monoclines, structural terraces, low-amplitude folds, faults, and igneous intrusions. These rocks are overlapped by Tertiary and Quaternary sediments and have been intruded by scattered Tertiary igneous rocks. The depositional environments of the Paleozoic and Mesozoic sedimentary rocks ranged from shallow marine to near shore-terrestrial. Study of the various sandstones, shales, siltstones, dolomites and limestones indicate that these rocks were deposited in shallow marine environments, tidal flats, sand dunes, carbonate platforms, and by rivers. More than 300 ft (91 m) of gypsum and anhydrite were deposited at various times in evaporite basins.

Erosion of these uplifted rocks produced the landscape we see today. Rocks of the Pahasapa Limestone (Madison of some reports), Minnelusa Formation and older sediments form a limestone plateau that rims the central Precambrian metamorphic core. Erosion of weak red siltstones and shales of the Spearfish Formation has formed the "Red Valley”, the main area of present and proposed future housing and industrial development. White gypsum caps many of the hills in the Spearfish and is a conspicuous landform in the overlying Gypsum Spring Formation. Resistant sandstones that are interbedded with other rocks lie outboard from the Red Valley and form the hogback that encircles the Black Hills and defines its outer physiographic perimeter.

Relatively soluble rocks, including dolomite, limestone, gypsum and anhydrite, comprise about 35 percent of the total stratigraphic section within the topographic Black Hills, that is, the area including and within the “Dakota sandstone hogback” (fig. 1), comprising rocks of the Inyan Kara Group (fig. 2). Karst is significant in many formations in the limestone plateau and Red Valley (fig. 2). World-class caves, sinking streams, and other features are found in the Pahasapa Limestone. Lesser karst features are found in the other carbonate units. Evaporite karst has developed extensively in the anhydrite and gypsum in the Minnelusa, Spearfish, and Gypsum Spring Formations. Solution of soluble evaporate and carbonate rocks at depth has produced collapse in non-soluble bedrock and surficial deposits at the surface, which in several places extends many hundreds of feet above the soluble rocks.

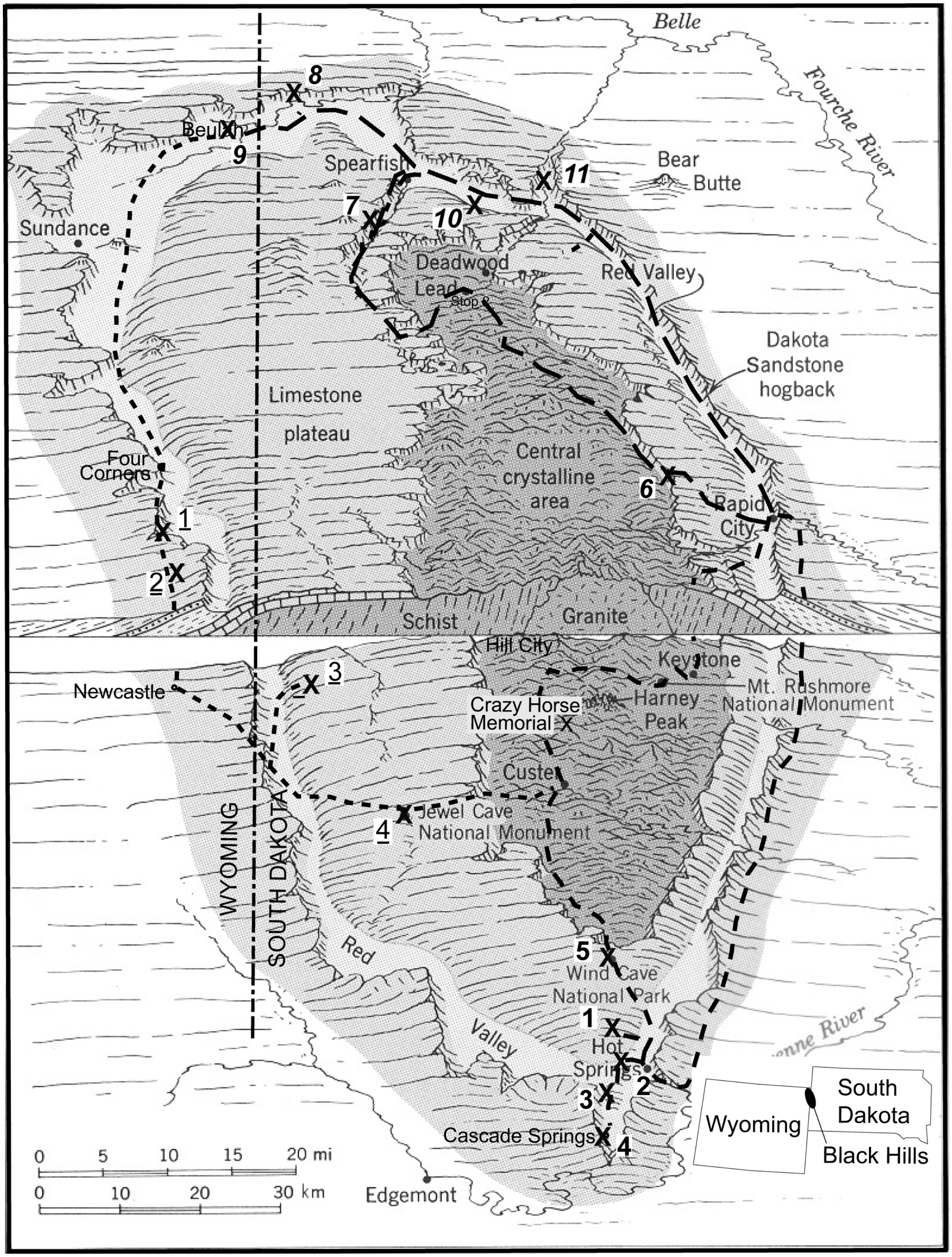

Figure 1. Generalized diagram showing the geology and geomorphology of the Black Hills and route of three 2005 Karst Interest Group field trips (southern trip, regular numbers; Northern trip, italics; western trip, numbers underlined). Most of the urban development and karst features are in the Red Valley, underlain by Triassic red beds and in the limestone plauteau, underlain by a variety of Pennsylvanian and Permian rocks. Modified from Strahler and Strahler (1987) with permission.

AGE			FORMATION	LITHOLOGY (Thickness in feet) (*thicknesses mostly from DeWitt and others, 1989*)	KARST FEATURES	FIELD TRIP STOP
CENOZOIC	QUATERNARY	Holocene/ Pleistocene	Terrace deposits, alluvium, colluvium, landslide deposits, sinkhole fill, spring deposits	Gravel, sand, silt, clay, and calcareous tufa	Collapse sinkholes due to dissolution of evaporites and carbonates in formations below; spring deposits; paleontologic animal traps	2, 8, 9, 11
MESOZOIC	CRETACEOUS	Upper	Hell Creek Formation	Shale and sandstone, lignite (425+)		
			Fox Hills Sandstone	Sandstone (25-200)		
			Pierre Shale	Dark-gray and black shale (1,200-2,700)		
			Niobrara Formation	Calcareous shale and impure chalk (80-300)		
			CarlileShale	Light- to dark-gray shale (325-750)		
			Greenhorn Limestone	Shaly limestone and calcareous shale (225-400)		
			Belle Fourche Shale	Gray shale with limestone concretions and bentonite (150-850)		
			Mowry Shale	Gray siliceous shale (125-250)		
			Newcastle Sandstone	Brown and white sandstone (0-100)		
			Skull Creek Shale	Dark-gray to black shale (150-270)		
		Lower	Fall River Sandstone	Massive to slabby sandstone (10-200)		
			Lakota Formation	Cross-bedded, copnglomeratic sandstone, shale, clay and local impure limestone (35-700)	Breccia pipes extending down to the Minnelusa Formation	
	JURASSIC	Upper	Morrison Formation	Green to maroon shale and thin sandstone (0-220)		
			Unkpapa Sandstone	Fine-grained sandstone (0-275)		
			Sundance Formation	Greenish-gray shale, yellow sandstone, and reddish sandstone and siltstone (250-475)		
		Middle	Gypsum Spring Formation	Gypsum, red siltstone, limestone, dolomite (0-45)	Gypsum karst: sinkholes; contorted gypsum.	11
	TRIASSIC	Lower	Spearfish Formation	Red shale, siltstone, fine-grained sandstone and gypsum (250-900)	Gypsum karst: sinkholes; probable caves at depth in several stratigraphic intervals; contorted gypsum; gypsum stringers; springs.	2, 4, 8, 9
PALEO.	PERMIAN	Upper	Minnekahta Limestone	Laminated, purplish-gray limestone (30-65)	Minor carbonate karst: solution-enlarged fractures; few sinkholes; color leaching in Opeche below.	3, 4, 10

Figure 2. Generalized stratigraphic section showing known karst features in sedimentary rocks in the Black Hills, South Dakota-Wyoming. Numbers indicate formations visited during the formal conference. Underlined numbers indicate stops in the supplementary western field trip.

PALEOZOIC	PERMIAN	Up.	Opeche Shale	Red shale, siltstone, and fine-grianed sandstone and scattered gypsum (25-150)	Possible minor dissolution of gypsum	10
	PERMIAN PENNSYLVANIAN	Lower Upper	Minnelusa Formation	Yellow, red, cross-bedded sandstone, gray cherty limestone, dolomite, red shale and siltstone, and anhydrite in subsurface that is mostly absent at the surfrface due to dissolution. (350-1,500)	Intrastratal anhydrite karst in upper half: advancing dissolution front at depth; disrupted bedding, caves, collapse breccia; breccia pipes, some extending upwards as much as 1,000 feet into the Lakota Formation; paleokarst sinkhole fill at base.	1
	MISSISSIPPIAN	Lower	Pahasapa Limestone (Madison Limestone)	Massive, gray limestone that is locally dolomitic, with an irregular upper contact due to pre-Pennsylvanian karst weathering. (300-630)	Carbonate karst: world-class caves in upper part; swallow holes; resurgent springs; sinking streams; paleokarst; few surface sinkholes, if any.	5, 6, 7 Evening Cave Trips to Wind and Jewel Caves
	DEVONIAN	Upper	Englewood Formation	Gray to lavender limestone with shale at base (30-60)		
	ORDOVICIAN	Upper	Whitewood Formation	Gray dolomite and limestone (0-150)		
			Winnipeg Formation	Green shale and siltstone (0-110)		
	ORDOVICIAN CAMBRIAN	Lower Upper Middle	Deadwood Formation	Brown sandstone, green glauconitic shale, basal conglomerate and limestone-pebble conglomerate (4-700)		
PRECAMBRIAN			Precambrian rocks	Schist, slate, quartzite, sandstone, intruded by amphibolite, granite, and pegmatite.		

Figure 2. Generalized stratigraphic section showing known karst features in sedimentary rocks in the Black Hills, South Dakota-Wyoming. Numbers indicate formations visited during the formal conference. Underlined numbers indicate stops in the supplementary western field trip -continued.

Two major aquifers are located in formations that include karstic rocks water in the Black Hills--c-rbonate karst in the Pahasapa Limestone, and evaporite karst in the Minnelusa formation. The Madison and Minnelusa aquifers are two of the most important aquifers in the Black Hills area and are used extensively for water supplies. Headwater springs originating in the limestone plateau, streamflow losses to the Madison and Minnelusa outcrops, and large artesian springs in the Red Valley are important hydrologic features that are associated with karst processes in these aquifers. Locally, secondary porosity has developed in the lower Spearfish formation due to gypsum dissolution. Sinkhole collapse in gypsum-bearing rocks is common. Sinkholes, of the type's common in the eastern United States are rare. Solution in carbonate rocks has produced the third and sixth largest known recreation caves in the world, Jewel Cave and Wind Cave. A sinkhole in Hot Springs is one of the world's greatest vertebrate paleontologic occurrences. Finally, carbonate rocks are the major aggregate resource in the Black Hills.

Three field trips are offered this year. They are not duplicative; each stop has something different to offer, demonstrating the wide variety of evaporite and carbonate karst in the Black Hills. The trip in the Southern Black Hills will examine evaporite karst in the Minnelusa Formation, artesian springs due to both carbonate and evaporite dissolution at depth, sinkholes and fracturing in the Minnekahta raising the question of the definition of karst, a large sinkhole that trapped Pleistocene animals, and a visit to Wind Cave. The northern trip will discuss dye tracing in carbonate rocks, hydrology in Spearfish Canyon that made the famous Black Hills gold mining possible, a variety of collapse features and gypsum intrusion in the lower Spearfish Formation creating a strong secondary porosity, effects of leaching in the Minnekahta, and a proposed sewage lagoon in a precarious area of evaporite karst. A third trip to the western Black Hills is offered for those wishing to do it on their own. Highlights are an overlook of the steeply dipping rocks in flatirons in a major monocline, a sinkhole in non-soluble rocks extending more than 800 feet down to the source of collapse, the most spectacular cliff exposure of caves, sinkholes, brecciation, and disrupted bedding in the Minnelusa formation, and a trip to Jewel Cave. Two guided evening trips are also planned to Jewel and Wind Caves.

Each field trip guide not only has detailed information for driving instructions and text for each stop, but also, provides comments about sites to see from the vehicle window and the text of historic markers and plaques along the way. The total miles and miles between driving directions, comments, markers, and stops have been noted on each field trip guide.

Parts of the field guide itineraries were borrowed freely from many excellent published guides to the Black Hills (Fahrenbach and Fox, 1996; Gries, 1996; Lisenbee and others, 1996; Martin and others, 1996; Rahn and others, 1977; Rahn and Davis, 1996; Redden and Fahrenbach, 1996). Additional sources of information about the Black Hills or engineering geology are found in Darton (1909) and Rahn (1986).

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Field Trip Guide 1 Karst Features of the Southern Black Hills, South Dakota, Karst Interest Group Workshop, September 12, 2005

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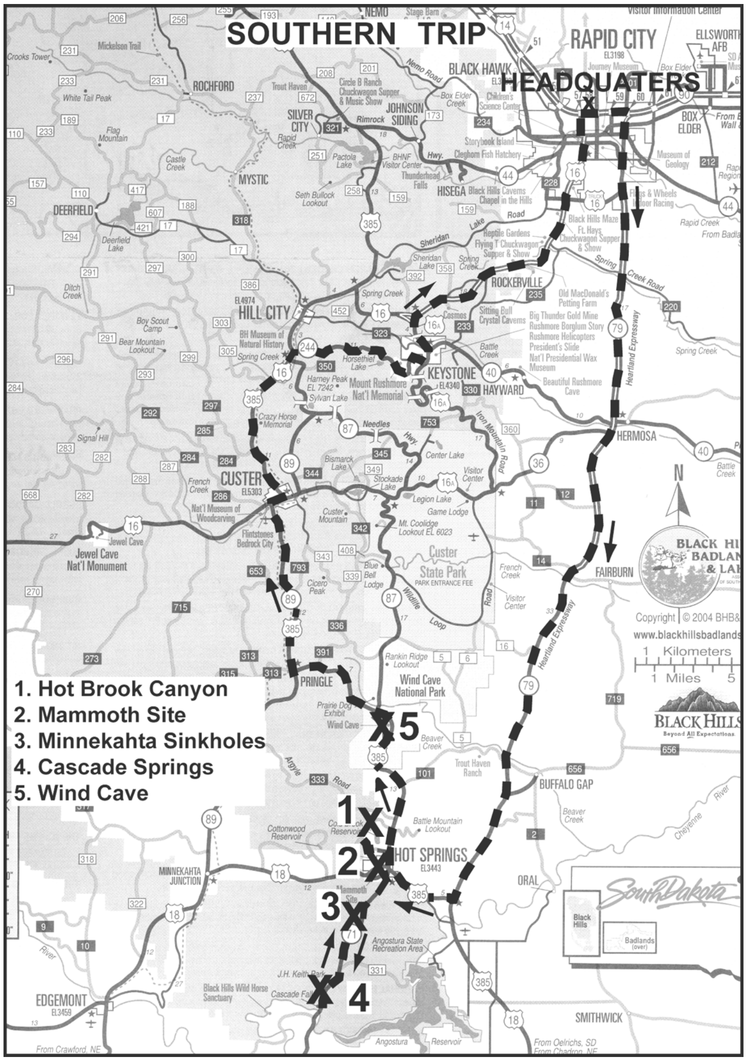


Figure 1. Route map to karst stops in the southern Black Hills.

The field trip originates from the headquarters at the Holiday Inn-Rushmore Plaza, 505 North Fifth Street, Rapid City, South Dakota. The first number is total miles from start and the second number is the miles from the last stop.

0.0 **0.0** Leave Holiday Inn parking lot. Turn right on 6th Street.

0.2 **0.2** Cross Omaha Street.

0.4 **0.2** Cross Main Street.

0.5 **0.1** Turn left on St. Joseph Street.

1.3 **0.8** South Dakota School of Mines and Technology on right. Museum of Geology contains excellent mineral and paleontologic exhibits (free admission).

1.5 **0.2** Geology building to right.

1.7 **0.2** O'Harra stadium on right. Hills underlain by black shales of the Belle Fourche Shale of Late Cretaceous age.

2.6 **0.9** Bear right and merge onto Route 79 South.

3.7 **1.1** East Minnesota Street. Hills in distance to right underlain by rocks in the "Dakota hogback", defining the physiographic boundary of the Black Hills. The Dakota Sandstone was a earlier name for rocks now termed the Inyan Kara Group. The structural boundary of the Black Hills, however, extends farther out into the surrounding Upper Cretaceous sediments in the Great Plains.

5.8 **2.1** Climbing to top of terrace, underlain by Quaternary gravels disconformably overlying the Belle Fourche Shale.

10.3 **4.5** Cross Spring Creek. Streamflow in Spring Creek near Highway 79 at USGS gaging station 06408500 for 56 years of record (US. Geological Survey, 1949-75; U.S. Geological Survey, 1976-2004) was less than 1 cubic feet per second about 54 percent of the time. Most of the base flow in Spring Creek, which originates in the higher elevations of the Black Hills, is lost to swallow holes as the stream crosses outcrops of the Pahasapa Limestone and Minnelusa Formation that are located about 6 miles upstream.

11.3 **1.0** Road ascends Belle Fourche Shale unconformably overlain by tuffaceous deposits of the White River Group of Oligocene-Miocene age. Martin and others (1996) describe these rocks along this route.

13.2 **1.9** Harney Peak comprising Precambrian granite in distance to right, highest point in the Black Hills (7,242 feet).

14.5 **1.3** Pine-covered hills to right held up by sandstones of the Inyan Kara Group (Early Cretaceous) dipping moderately to the east on the east limb of the Black Hills uplift.

16.8 **2.3** Custer County.

18.2 **1.4** US 40 to Keystone on right, continue on 79 south.

18.9 **0.7** US 36 towards Custer State Park on right, continue straight on 79.

26.9 **8.0** Road to Fairburn on left.

29.7 **2.8** Road to Fairburn on left.

30.2 **0.5** Cross French Creek. Gold was first discovered along this creek near Custer, SD, which heralded the gold rush to the Black Hills.

34.9 **4.7** Greenhorn Limestone (Late Cretaceous) holds up hill on left. It is an argillaceous limestone with no known karstic features. Moderately dipping beds of the Fall River Formation of the Inyan Kara Group at 1 o’clock.

39.0 **4.1** Inyan Kara hogback to right dipping eastward towards us; smaller hill of Greenhorn Limestone on left dipping less steeply in the Greenhorn "piggyback".

40.0 **1.0** The valley narrows here between the Inyan Kara and Greenhorn because the dips of the beds have steepened. See Martin and others (1996) for a description of the Greenhorn here. Abundant oysters are found in the limestone, possibly edible with the proper cocktail sauce.

42.4 **2.4** Beaver Creek.

42.9 **0.5** Road to Buffalo Gap on left. The small canyon to the left is Calico Canyon in which decorative variegated sandstone has been quarried from the Unkpapa Sandstone of Jurassic age.

44.2 **1.3** Road to Buffalo Gap on left.

45.0 **0.8** Fall River County line.

46.2 **1.2** Elm Creek.

47.4 **1.2** Pine trees favor the siliceous Mowry Shale of Late Cretaceous age in this area.

48.8 **1.4** Greenhorn piggyback on left.

51.0 **2.2** Junction with US 18/US 385; turn right towards Hot Springs.

51.6 **0.6** Fall River Falls historic marker on left. Springflow accounted for about 97 percent of the streamflow in Fall River during 1987 to 1996 (Carter and others, 2001).

FALL RIVER FALLS HISTORIC MARKER

> “The eight mile long Fall River, winding through Fall River Canyon after the joining of Cold and Hot Brook streams above the city of Hot Springs, tumbles below over an outcropping of sandstone falling about 50 feet to form Fall River Falls, as viewed from the gazebo.
>
> In 1907 the city of Hot Springs built a low dam above the falls directing the 89°F water through a flume of native wood staves banded with iron rods and wire wrapped. Older residents remember as children walking the 4,700 foot flume to a point below the falls. Upon leaving the flume the water dropped 115 feet to a small hydroelectric plant which supplied part of Hot Springs' electric power until the late 1960's. The white power house and part of the staircase are still visible in the canyon.

> There exists, however, a dark undercurrent to the picturesque scene lying below. Multiple drownings have occured in the waters beneath the falls, and in August of 1995 a tragic triple drowning took place over a two day period. Later, a temporary diversion of the falls revealed a small cave beneath which creates a whirlpool effect in the water that can trap even strong swimmers."

51.7 **0.1** Passing through the Dakota hogback. Contact between the Fall River Sandstone and Skull Creek Shale on right, dipping 8° to east.

51.8 **0.1** Cross Fall River, type locality of Fall River Sandstone seen on right.

52.6 **0.8** Fall River sandstones to right.

53.9 **1.3** Lakota Formation

54.7 **0.8** Entering Hot Spring. Historic marker on right.

HOT SPRINGS, SOUTH DAKOTA HISTORIC MARKER

> "Tribal tradition states that as long ago as the 16th century the Fall River Valley and canyon area were seldom without groups of tipis belonging to the North American Plains Tribes. They knew the curative value of the warm springs located there and used them for bathing their sick and lame.
>
> Exploration of the area by white men in 1874-75 led to settlement and discovery of 75 geothermal springs. The crystal clear water issues from clefts in rocks or bubbles out of the ground. Bathhouses, swimming plunges, hotels, hospitals and sanitariums were built turning the City of Hot Springs into an early national health resort. Some of these structures still exist, including a sanitarium now used as the VA Center, and the South Dakota Soldiers Home.
>
> Cowboys and others crippled by rheumatism and other afflictions would arrive in wagons or trains and leave on horseback after three weeks in the springs.
>
> From this point the rushing Fall River can be seen and heard."

55.1 **0.4** Truck Route US 18 to left, continue straight.

55.8 **0.7** Traffic light, continue straight.

56.0 **0.2** Bear left on US 385.

56.1 **0.1** Bear right on US 385.

56.3 **0.2** Coarse terrace gravels to left are about 50 feet thick,consisting of massive and crossbedded gravels with angular to well rounded clasts of limestone, sandstone and some chert as much as one foot long from the Minnekahta Limestone and Minnelusa Formation in a tan to reddish calcareous sand matrix. The gravels dip 13° to the south. So far, no one has given an explanation for the dip. The brownstone buildings in this area date back to the late 19th century when that area developed into a major health spa because of the many hot springs. The sandstones were derived from the surrounding Fall River Sandstone.

The gazebo across the creek to left was built in 1920, protecting Kidney Springs, one of 179 springs within the Hot Springs Valley. A metal plaque proclaims "Useful in the treatment of chronic diseases of the gastro-intestinal tract, diseases of the liver and biliary passages disorders of the genito-urinary tract and sluggish conditions of the alimentry tract." The following chemical analysis (in part per million) is also given: Sodium Chloride, 242.60; Potassium Chloride, 68.44; Magnesium Chloride, 118.00; Lithium Sulphate, 15.21; Calcium Sulphate, 703.99; Calcium Phosphate, 2.76; Silica, 23.64;Total solids, 1174.64.

56.5 **0.2** Nice exposure of coarse terrace gravels along sidewalk to right.

56.7 **0.2** Stop sign. Continue straight across US 385. White gypsum in Spearfish redbeds to right.

56.8 **0.1** Evans Plunge on right built in 1890. The building houses a recreation pool deriving water from several springs in the creek bed with a total flow of 5,000 gallons per minute. The history of Evans Plunge and an analysis of the water is shown on the sign to left:

> "Long before the white man discovered the valley of healing waters, the Sioux and Cheyenne Indian tribes fought for possession of the natural warm water springs. Legend tells us that the battle raged on the high peak above the springs and the Sioux emerged victorious.
>
> The Mammoth spring at the north end in the interior of the plunge is known as the "Original Indian Spring". Here the Indians drank and bathed in its warm healing water.
>
> The Evans Plunge was built in 1890 over numerous small sparkling springs and one mammoth spring of mineral water with a temperature of 87 degrees and of medicinal qualities proclaimed, on good authority, to be superior to that of the famous Warm Springs, Georgia.
>
> From the inflow of 5,000 gallons of water per minute from the springs arising out of the pebble bottom, there is a complete change of water 16 times daily, thus insuring clean, fresh, living water at all times.
>
> The pool, 50 x 200 feet, ranges in depth from 4 feet to 6 feet with two shallow enclosures for children."

CHEMICAL ANALYSIS

Water temperature....	87 degrees
Total residue	87.9995
Inorganic & non-volatile	4.9160
Organic & volatile......	8.050
Sulphate of sodium ...	8.824
Sulphate of potassium	3.331
Sulphate of calcium...	16.290
Nitrate of magnesium	0.150
Iron susqui-oxide.......	0.260
Alumia	0.021
Silica	1.830

56.9 **0.1** "Y" in road. Continue straight on Fall River Co 18B. Terrace gravels cap Spearfish Formation to left.

57.0 **0.1** Minnekahta Limestone on left.

57.1 **0.1** Small cave high up in Minnekahta on left. The Minnekahta here is about 50 feet thick.

57.3 **0.2** Minnekahta Limestone rises above purplish shales at the top of the underlying Opeche Shale. One belief is that the purple shales were produced during weathering and is an ancient soil, but another explanation is that it is due to bleaching from water percolating downward from the overlying Minnekahta (see Stop 10 of Northern Trip).

57.5 **0.2** Note undulations in the Minnekahta on left, due to differential collapse in the underlying Minnelusa.

57.7 **0.2** Brecciated uppermost Minnelusa (see figure 2A).

58.0 **0.3** Brecciated Minnelusa with distorted bedding overlain by Opeche Shale and Minnekahta Limestone straight ahead (see figure 2B).

58.9 **0.9** **Buses pull off to the side of the road at curve.**

STOP 1: HOT BROOK CANYON: MINNELUSA EVAPORITE KARST

Leaders: Mark Fahrenbach and Jack Epstein

The Minnelusa Formation comprises interbedded sandstone, limestone, dolomite, shale, and anhydrite, and ranges from more than 1,000 feet thick in the southern Black Hills to about 400 feet thick in the northern Hills (Jarrell, 2000). As much as 235 feet of anhydrite has been observed from well logs describing the subsurface near Jewel Cave, occurring mainly in the middle of the formation (Braddock, 1963; Brobst and Epstein, 1963). In Hot Brook Canyon about 300 feet of the Minnelusa is exposed, the lower part of the formation and the contact with the Pahasapa Limestone are covered. The red shale, siltstone, and sandstone of the overlying Opeche Formation, and the succeeding Minnekahta Limestone, are visible at the very top of the cliff. Minnelusa and Opeche are the Lakota names for Rapid Creek and Battle Creek respectively, and Minnekahta is the Lakota word for hot springs.

The Minnelusa Formation is an important stratigraphic unit in a geologic mapping project of five quadrangles located between Jewel and Wind Caves in the southern Black Hills (Wind Cave, Pringle, Argyle, Fourmile, and Jewel Cave quadrangles). The Minnelusa can be subdivided into six stratigraphic units. The initial mapping, which began as a cooperative venture between the National Park Service, the U.S Geological Survey and the South Dakota Geological Survey, covered units 1-4 of the Minnelusa Formation to see if there was any correlation with the Minnelusa units and cave development in the underlying Pahasapa Limestone. This is one of several methods to determine the location of undiscovered cave passages in the Jewel Cave-Wind Cave area that will be discussed at this KIG Conference. Fracture orientations were also measured to see if these trends were visible or controlled passage orientation in Jewel Cave. Subsequently, it was decided to map units 5 and 6 of the Minnelusa Formation, with the long term goal of mapping the entire quadrangles.

No evaporites are present at the outcrop of Stop 1. They have been removed by solution at depth, resulting in foundering of the overlying beds. Characteristic evaporate dissolution features that are produced are collapse breccias, breccia pipes, distorted bedding, and cavities (fig. 2C). Elsewhere, such as in Redbird Canyon, 12 miles southeast of Newcastle, WY, collapse sinkholes are present in the cliff faces (Epstein, Field Trip Guide 3, Western Black Hills, this volume, fig. 8).

In Hot Brook Canyon, the position of the anhydrite that has been removed and is clearly deciphered on the canyon wall by the disrupted bedding, with approximately 200 feet of the upper Minnelusa being brecciated. Below the steep covered slope in the middle of the exposure at this locality, the beds are undisturbed (fig. 2B). The anhydrite, therefore, was positioned at the level of the covered slope above the undisturbed beds.

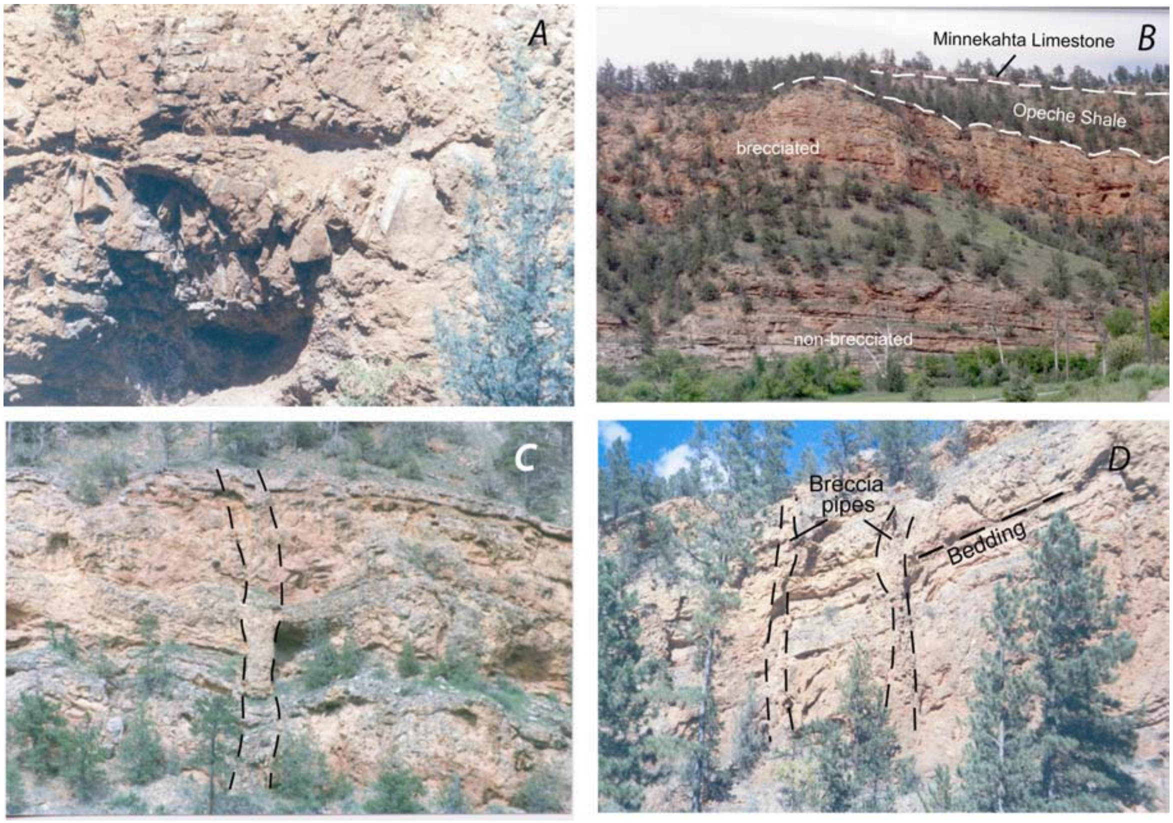


Figure 2. Evaporite karst features in the Minnelusa Formation, Hot Brook Canyon, Hot Springs, Fall River Co., SD.

A, Angular clasts of all sizes form a characteristic breccia in the upper part of the formation.

B, The position of many tens of feet of anhydrite that were removed from the Minnelusa is indicated by brecciated rocks above and non-brecciated rocks below the covered slope. The uppermost Minnelusa beds are wavy due to subsidence, as are the beds in the Minnekahta Limestone above.

C, Breccia pipe extending to the top of the Minnelusa.

D, Near-vertical breccia pipes (short dash) in moderately dipping (15^{o}) beds (long dash) of the Minnelusa Fomation, at mileage 59.3, suggesting that the beds were tilted prior to pipe formation.

Brecciation, caused by removal of anhydrite at depth, was undoubtedly initiated after the Black Hills were uplifted and the Minnelusa breached after the Late Cretaceous. Dissolution probably occurred within a zone about 1,000 feet below the ground surface based on breccia pipes extending as high as the Lakota Formation and the total thickness of these overlying formations.

A short distance west of Stop 1, to be seen as the buses continue up the canyon to turn around, there are near-vertical breccia pipes cutting beds that dip 15^{o} westward (fig. 2D). If the brecciation occurred prior to tilting, the pipes, which would have formed vertically, would have been rotated by the tilting. Clearly, because the pipes are vertical, they formed after the beds were tilted. Similar relationships can be seen elsewhere in the Black Hills (Epstein, 2005b, figure 8).

Close-up examination of the Minnelusa shows extensive fracturing and brecciation producing angular blocks of many sizes (fig. 2A). Effects of brecciation appear to decrease upwards in the formation, and the effects of collapse in the overlying formations are not dramatically apparent. The resistant, thin, Minnekahta Limestone, overlying the red beds of the Opeche Shale above the Minnelusa, contains only scattered collapse features such as sinkholes (Stop 3) and breccia pipes that may be ascribed to foundering in the underlying Minnelusa (Stop 4). The most significant effect on the Minnekahta is the undulation of beds visible in outcrop throughout the Black Hills. The limestone may have a local relief of several tens of feet, and basins and saddles are common. The soft sediments of the Opeche may have acted as a buffer between the Minnekahta and Minnelusa, absorbing some of the differential settlement. Bedding in the Opeche is not generally visible because of poor exposure.

Resume driving west on Hot Brook Canyon Road.

59.3 0.4 Vertical breccia pipe in brecciated Minnelusa beds that dip 15° to the west indicate that brecciation occurred after the deformation that formed the Black Hills uplift (fig. 2D; Epstein, *this volume*, figure 8).

Turn around and retrace route back to Hot Springs.

60.7 1.4 Closer view of Minnelusa breccia to left.

62.1 1.4 Stop sign. Continue straight along US 385 South into Hot Springs.

62.7 0.6 Bear left on US 385 South towards Mammoth Site.

62.8 0.1 Bear right on US 385 South.

62.9 0.1 Stop light, continue straight.

63.7 0.8 Turn right (west) on Truck US 16 towards route 71.

64.5 0.8 Intersection with Route 71 on left, continue straight ahead. Mammoth Site, historic sign:

MAMMOTH SITE OF HOT SPRINGS, SOUTH DAKOTA HISTORIC MARKER

> “Gigantic Mammoths, ancestors of the elephants of today once roamed freely across the High Plains of North America. A repository of their remains, along with other prehistoric animals, lay undisturbed until their discovery over 26,000 years later, in June of 1974.
>
> Limestone deposits beneath the Earth's surface dissolved in water from underground springs. The land then collapsed and the resulting sinkhole filled with 95 degree water that lured mammoths to drink or feed on vegetation. Once in the water they could not go up the slippery, steep incline. Death by starvation or drowning was the fate of most animals that came to the sinkhole. Along with the mammoth, remains of the giant short faced bear, white-tailed prairie dog, fish and other associated fauna have also been found at this site.
>
> As centuries passed the sinkhole gradually filled. Rain, snow and wind deposited soil leaving a hil1 of buried skeletons. This hill remained undisturbed until1974 when excavation for a housing project by Phil and Elenora Anderson revealed bones and tusks of these huge animals.
>
> In 1975, Mammoth Site of Hot Springs, South Dakota, Inc. was formed as a non-profit corporation dedicated to the preservation of the fossils, protecting and developing the site as an insitu (bones left as found) exhibit.
>
> The Mammoth site is quite different from most museums. It is not merely a display of collected items; most of the excavated bones remain exactly were they were found. Visitors also witness the complete process of paleontology from start to finish. Along with the scientists, they will see for the first time bones of animals that lived before any person walked the land.
>
> In 1980 the Mammoth Site was designated as a Registered National Landmark by the Department of the Interior. The Mammoth Site of Hot Springs is truly a gift from Nature—our inheritance held in trust for over 26000 years. We would diminish ourselves if we failed to perceive the historical and scientific value of this discovery.”

Turn right into parking area and park.

STOP 2: THE MAMMOTH SITE: A PLEISTOCENE FAUNA SINKHOLE TRAP

Leaders: Kris Thompson and Larry Agenbroad

The Mammoth Site is located within the southern city limits of Hot Springs, South Dakota. The site represents a hydrologic-geologic natural trap of late Pleistocene fauna. Located within the Spearfish Formation, which is exposed at the margins of the interior Black Hills, the surface expression is that of a low hill. This topographic feature is the result of inverse topography, in that the former topographic sink became a topographic high due to differential erosion. The sedimentary fill of the sinkhole containing Pleistocene fossils was more resistant than the surrounding Spearfish Formation.

The sinkhole formation is interpreted as a consequence of extensive dissolution and removal of up to 76 m of anhydrite in the Minnelusa Formation by ground water. The Minnelusa Formation is stratigraphically located approximately 60 m below the Spearfish Formation. Post-solution collapse within the Minnelusa initiated subsidence and the upward development of vertical breccia pipes, as much as 76 meters in diameter. Down hole collapse within these breccia pipes has produced numerous steep-walled sinkholes in the Black Hills since early Tertiary. The Mammoth Site at Hot Springs resides in one of these sinks.

In addition to the physical formation of the breccia pipe and resulting sinkhole, a critical factor in producing an animal trap in what would otherwise be just another sinkhole was the presence of an artesian spring. Groundwater in the Minnelusa flowed up the conduit formed by the breccia pipe, producing the spring and contributed to the standing body of water. The water was warm, estimated at 35^{o}C (95^{o}F) based on biological and sedimentary evidence.

The sinkhole deposit is located on the fourth terrace above the modern bed of Fall River (fig. 3). The Mammoth Site sinkhole is roughly an elliptical feature measuring 150 by 120 feet (~46 m by ~37 m). The Spearfish Formation walls are very steep, measuring greater than 60^{o} slopes. A large spring conduit was identified in the northeast section of the deposit, with minor conduits in the south-southwest and north-northwest areas of the sinkhole.

In 1978, the South Dakota Geological Survey drilled three test holes in the sinkhole fill (fig. 4). The deepest hole (test hole no. 3) was stopped at 65 feet (~20 m) below the drill surface. At that depth, bones and fill sediment were still being retrieved. We do not currently know the total depth of the fossiliferous fill deposits. Three recognized episodes of fill are classified in the deposit; phases I, II, and III. Phase I is the initial collapse including marginal gravels derived from river terraces incorporated as the walls fell in. Phase II sediments reflect a pond environment with fine-grained, laminated depositional units. Phase III reflects a declining water table-probably due to lateral migration to the entrenched Fall River. The sinkhole sedimentation was reduced, and the depression became essentially a bioturbated mud hole (fig. 5).

Late Pleistocene fauna are included in all phases of sedimentation (fig. 6). The trap was a burial place for late Pleistocene mammoths, plus 47 associated fauna (7 extinct, 40 extant). Worldwide there is no comparable deposit known as a repository for mammoths. To date, we have identified 50 Columbian mammoths (*Mammuthus columbi*) and 3 woolly mammoths (*Mammuthus primigenius*) in the excavations that represent approximately 40% of the known sinkhole fill area (fig. 7).

There is a paucity of reported Pleistocene sites in the Black Hills. As a result, paleoenvironmental interpretations for the Black Hills are limited. In summary, the Black Hills are an important but inadequately understood region, and thus an ideal place to study the invertebrate and vertebrate faunas of the present as well as the recent glacial past. The approximately 26,000 yr B.P. faunal remains recovered from the Mammoth Site provide a rare glimpse into the middle Wisconsinan environmental conditions in the northern Great Plains/Black Hills southwest of the Laurentide ice sheet.

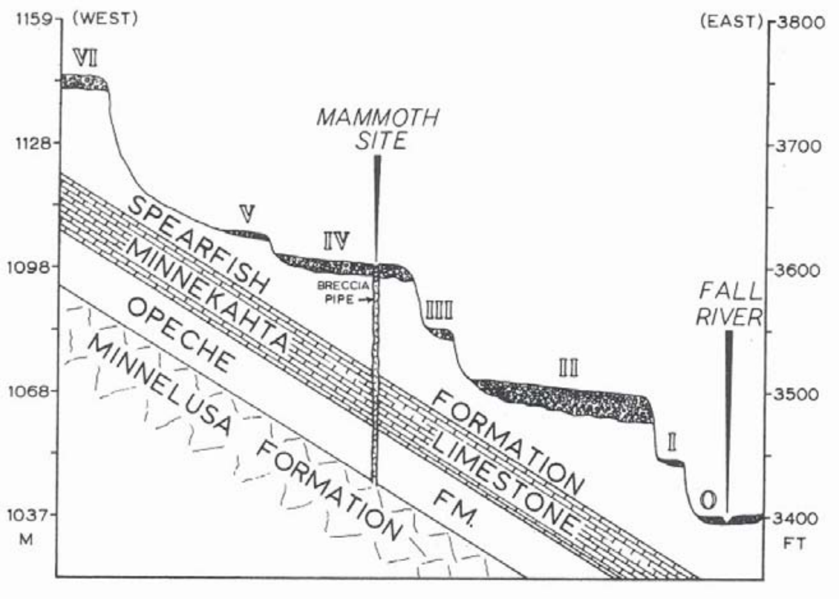


Figure 3. Simplified geologic and physiographic setting of the Mammoth Site sinkhole. Terrace 0 is the present floodplain of Fall River. The city of Hot Springs is built on all six terraces. Horizontal distance not drawn to scale. From Laury (1980).

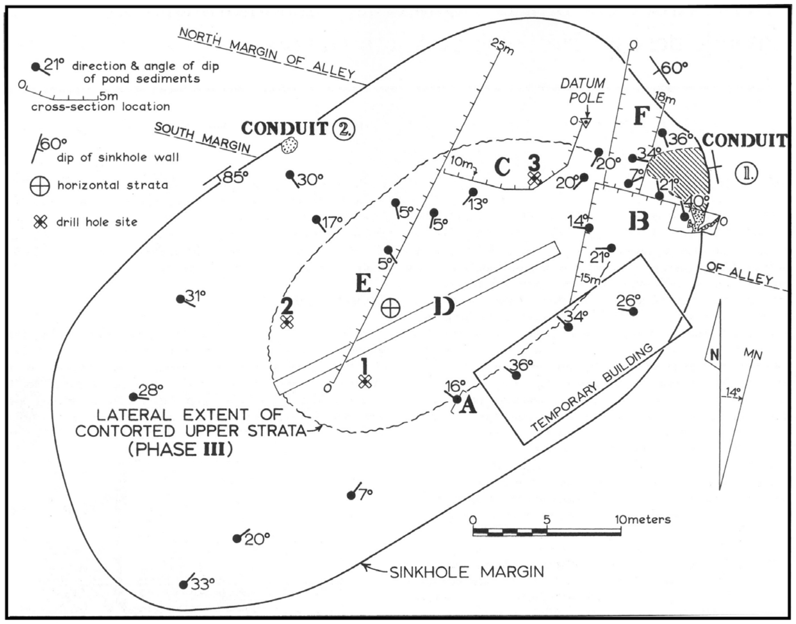


Figure 4. Map of the Mammoth Site sinkhole located in the Spearfish Formation, showing dip of pond sediments, slope of sinkhole wall, and drill-hole sites. (From Laury, 1980).

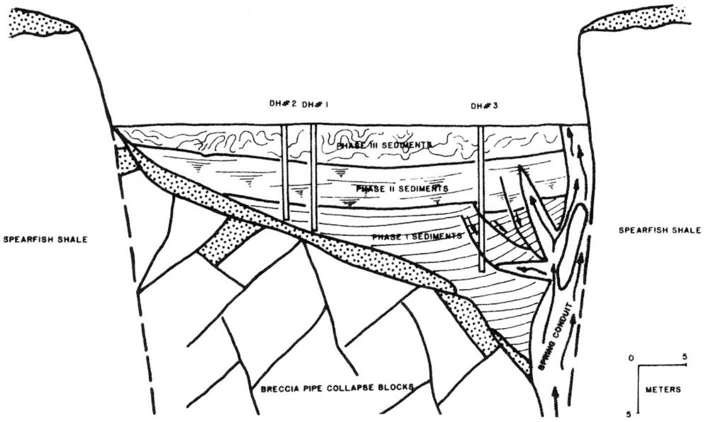


Figure 5. Schematic showing the physical character of the Mammoth Site sinkhole hydraulics, sedimentary fills, and host breccia pipe. From Agenbroad (1994).

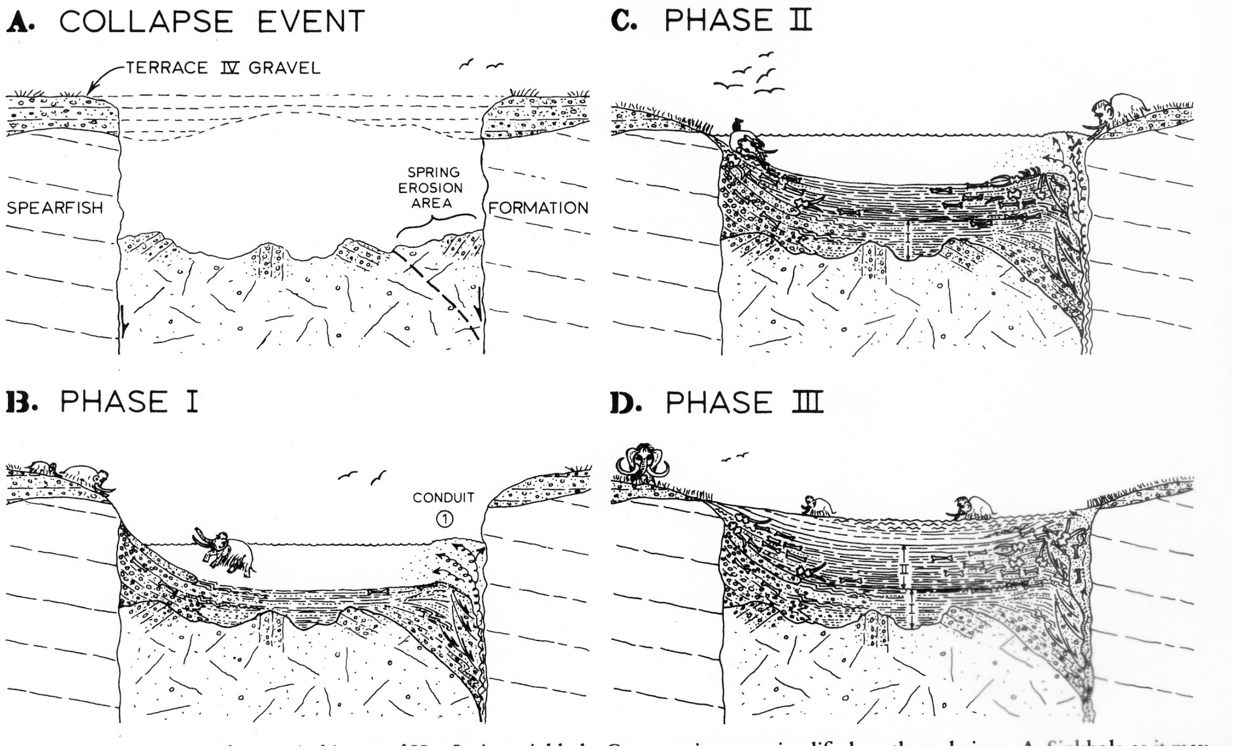


Figure 6. Sequence of events in history of the Mammoth Site sinkhole. Cross sections are simplified northward views. A, Sinkhole as it may have appeared immediately after breccia-pipe collapse. B, End of Phase I sedimentation, a period of rapid wall erosion and pond sedimentation. C, Near end of Phase II sedimentation, a longer period of sedimentation than Phase I in which more mammoths were trapped. D, Late Phase III sedimentation. The water table had dropped during renewed Fall River entrenchment, spring discharge virtually ceased, and the pond was reduced to a mud puddle. (From Laury, 1994).

Figure 7. Distribution of bone in the Mammoth Site sinkhole.

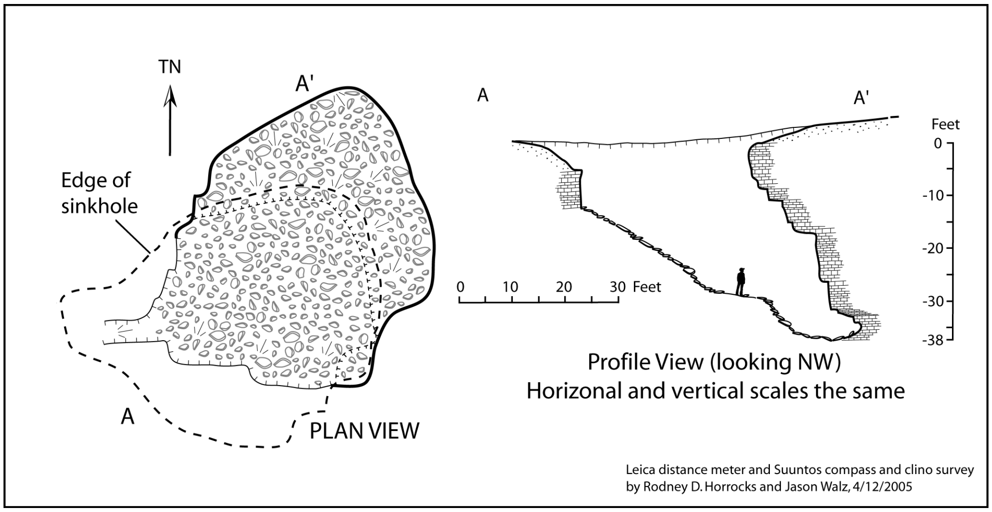
65.0 0.5 Resume driving. Leave Parking lot, turn left on truck Route US 16.

65.4 0.4 Route 71 towards Cascade Springs, turn right. Red beds of the Spearfish Formation overlain by Sundance Formation, including pinkish beds, on the higher slope, capped by sandstones of the Inyan Kara Group on left.

67.8 2.4 Pull off to side of road.

STOP 3: MINNEKAHTA SINKHOLES; WHAT IS KARST?
Leaders: Jack Epstein and Rod Horrocks

The Minnekahta Limestone is 40 feet thick in this area, comprising laminated gray limestone with a purplish tinge (light gray, N7 to light reddish gray, 10R 7/1). Three sinkholes are present at this locality, the most prominent one is 60 feet in diameter (fig 8, 9). The depth of the hole is 40 feet and it probably encompasses the entire thickness of the Minnekahta. Two other sinkholes within 100 feet to the west are about 20 feet in diameter with about 4 feet of Minnekahta exposed, and another is 50 feet in diameter with no limestone exposed. It is doubtful that the sinkhole is due to solution within the limestone because the hole extends below the Minnekahta. The shape of the hole is partly controlled by intersecting joint trends, mainly N. 78^{o} E., N. 10^{o} E., and N. 62^{o} E. A sinkhole about 400 feet to the south across the road is about 300 feet in diameter and about 35 feet deep. The sinkhole was probably formed by cover collapse due to anhydrite removal in the Minnelusa Formation, more than 200 feet below. Sinkholes in the Minnekahta are not common in the Black Hills, except locally (Epstein, Davis, and others, 2005, *this volume*, fig. 22). Other sinkholes in this formation have been reported by Darton (1909), see fig. 10) and Gries (1963). The sparce soil cover associated with these sinkholes is quite different from that in much of the humid eastern United States (fig. 11) where sinkhole formation is generally the result of piping and subsidence of soil or unconsolidation overburden (the “plug” that fills or covers the void.



Leica distance meter and Suuntos compass and clino survey by Rodney D. Horrocks and Jason Walz, 4/12/2005

Figure 8. Map and profile of sinkholes in the Minnekahata Limestone at Stop 3. The base of the Minnekahata is probably immediately below the bottom of the pit.

Figure 9. Steep sided sinkhole in Minnekahata Limestone. The hole is 40 feet deep and encompasses the entire thickness of the formation.

Figure 10. Sinkhole near Four Corners, Wyoming, northwestern Black Hills (Darton, 1909), similar to the one at Stop 3. The hole extends down through the entire Minnekahta.

Figure 11. Typical sinkhole in the humid eastern United States. This one developed by collapse of the residual soil cover in the Beekmantown Formation of Ordovician age in eastern Pennsylvania near a quarry whose pumping has significantly lowered the water table.

Karst is defined as "A type of topography that is formed over limestone, dolomite, or gypsum by dissolving or solution, and that is characterized by closed depressions or sinkholes, caves, and underground drainage" (Gary and others, 1972). At this stop, and especially at Stop 4, we will discuss whether the sinkhole in the Minnekahta as well as other collapse features are truly "karst", according to the above definition.

Resume driving. Continue south on Route 71.

67.9	**0.1**	Large sinkhole to left.
69.2	**1.3**	Skeletal remains of cow on slope to right (2004).
72.8	**3.6**	Disembark from bus; buses proceed and park at Cascade Springs at 73.1.

STOP 4: CASCADE SPRINGS: HYDROLOGY, GYPSUM SHENANIGANS, PULL APARTS, BIOLOGY. LUNCH

LEADERS: Andy Long, Jack Epstein, and Larry Putnam

73.1	**0.3**	Buses park at Cascade Springs.

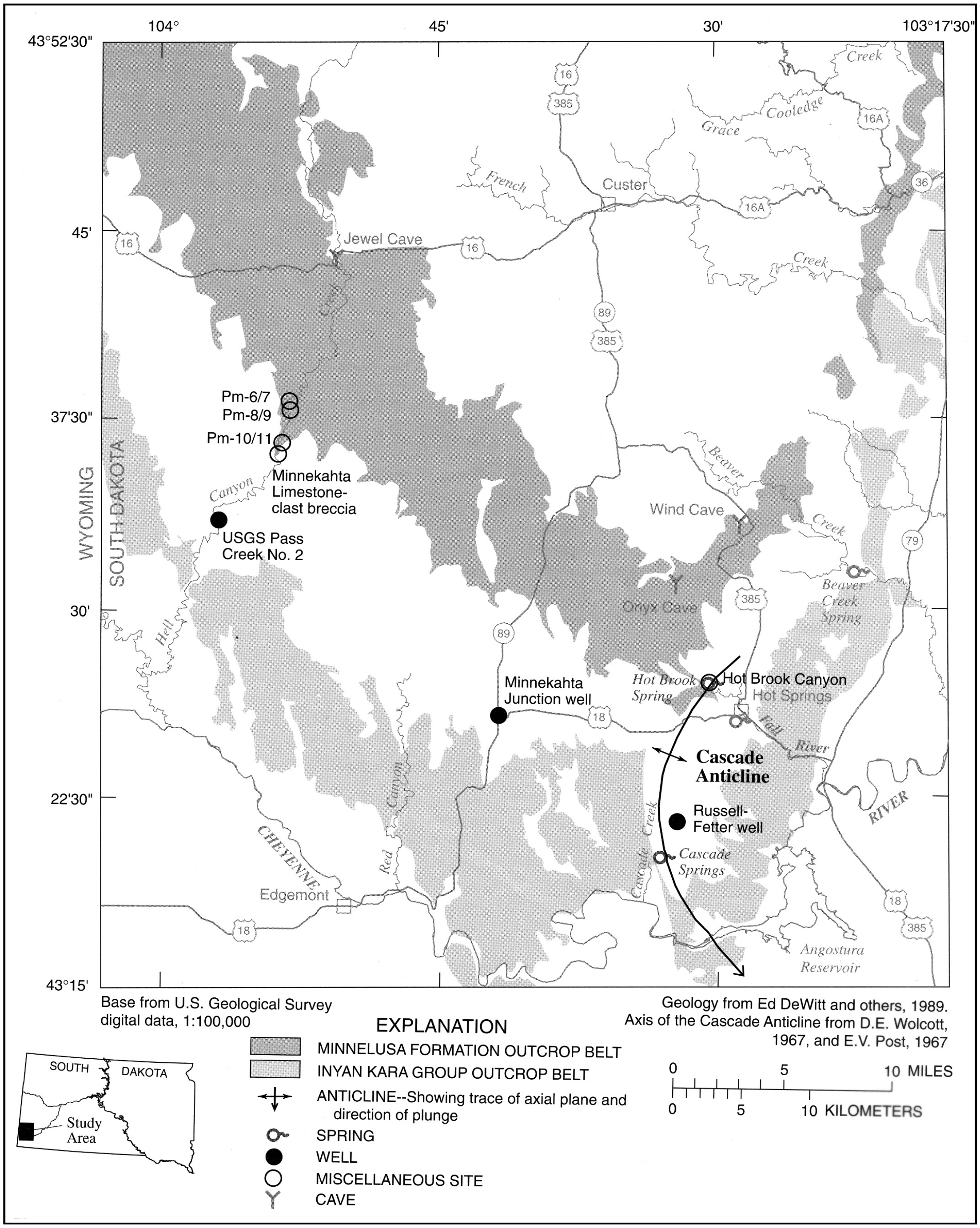
This stop is located along the west limb of the Cascade anticline at the south end of the Black Hills uplift (fig. 12). First we will examine structures in gypsum in the Spearfish formation along SD Highway 71 (fig. 13*A*), followed by a 100-foot vertical hike to see large fractures in the Minnekahta Limestone (fig.13*B*), and contemplating whether this is related to karst. Then we will discuss the hydrology, origin, and biology of Cascade Springs (fig. 13*C*).

A. Gypsum Shenanigans

In the cascade springs area the Spearfish Formation is 330 feet thick, comprising interbedded red beds and gypsum, the gypsum totaling about 70 feet (Post, 1967). The beds dip moderately to the west on the west limb of the Cascade anticline, ranging between 15 and 50 degrees (fig. 14), the steepest dips are 2,000 feet to the northwest along the highway.

The bottom of the roadside exposure at locality ***A*** is about 75 feet stratigraphically above the base of the Spearfish Formation; the top of the Minnekahta Limestone lies in a ravine just north of the road. About 50 feet of interbedded gypsum and red siltstone and shale are exposed. About 30 feet above the road there is a 2-foot bed of non-calcareous greenish-gray-weathering (5GY6/1) siltstone to fine-grained sandstone. The gypsum is contorted and many veinlets, generally less than one inch thick, extend from the parent beds (fig. 15*A*). The shale at the base of the exposure is highly fractured and bedding is not readily discernable. These features combine to create a secondary porosity in the Spearfish at this locality.

Post (1967) and Hayes (1999) noted two breccia pipes in this exposure; the easternmost one is shown in figure 15*A*. Hayes believed that breccia pipes extending up from the Minnelusa Formation are the conduits for the artesian springs at Cascade Springs. The gypsum bed in figure 15*A* is thickened and downwarped and is immediately underlain by about five feet of breccia containing blocks more than 1 foot long, some of which appear to have risen from below (fig. 15*B*) . To the side of this structure the red siltstone is highly fractured and contains a continuous 4-inch-thick bed of light-olive gray (5Y6/1) siltstone that is incorporated as clasts in the red shale of the breccia and is at a higher position than to the side. The beds immediately above the structure are flat, lying athwart the structure, and do not appear to have subsided. Beds below consist of minutely fractured and brecciated siltstone which is traversed by gypsum veinlets.



Base from U.S. Geological Survey digital data, 1:100,000

Geology from Ed DeWitt and others, 1989. Axis of the Cascade Anticline from D.E. Wolcott, 1967, and E.V. Post, 1967

Figure 12. Location map showing Cascade Springs, other nearby springs, and miscellaneous rock and ground-water sampling sites (from Hayes (1999).

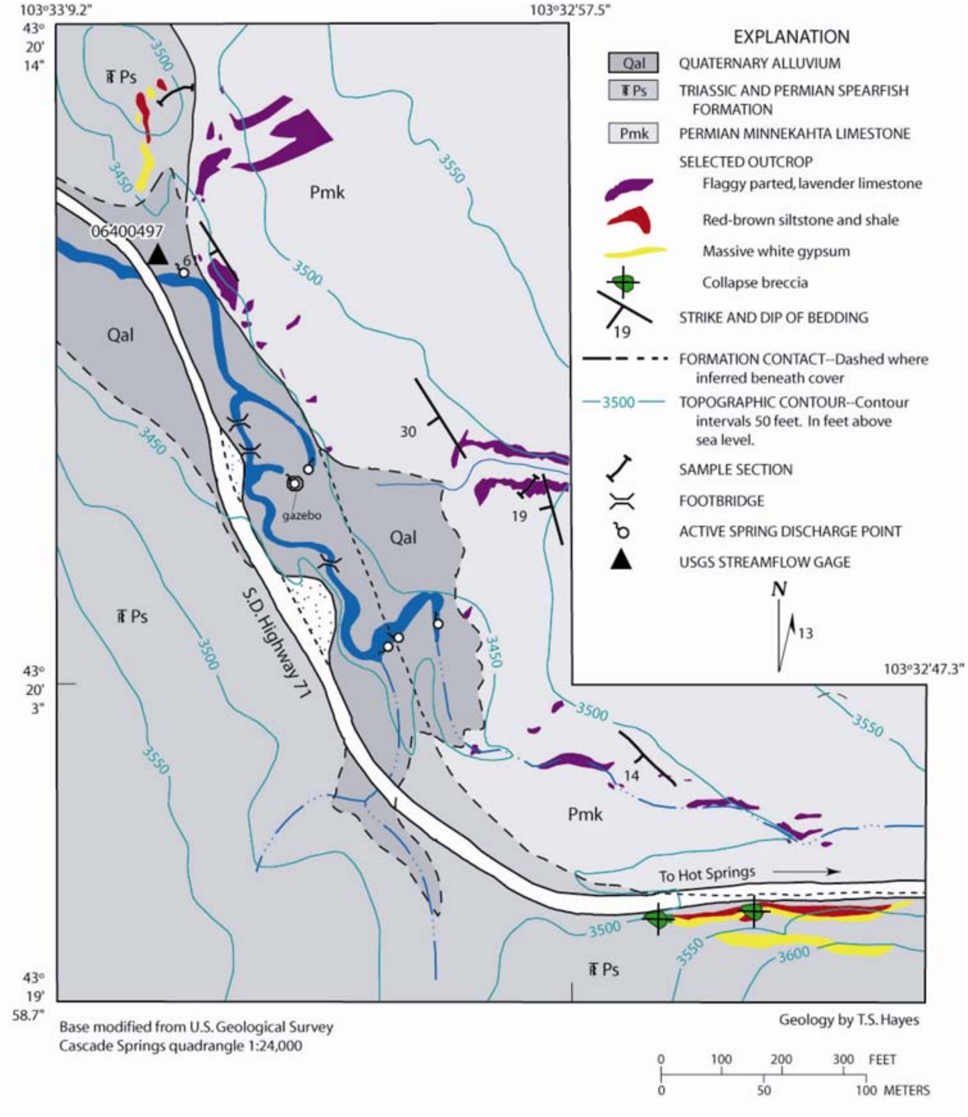


Figure 13. Stop locations at Cascade Springs showing general geology, location of springs and breccia pipes (from Hayes, 1999).

It is interesting to compare this "pipe" with those seen in the Minnelusa at Hot Brook Canyon, Stop 1. The exposure that Post (1967) saw (fig. 15*C*) was different from the one seen now because of subsequent road widening, suggesting that we now see only the edge of the pipe. Post describes the feature thus: "High radioactivity, as much as 35 times background, was noted at a bleached and structurally disturbed zone in the Spearfish Formation on the south side of State Highway 87 in the SW1/4 SE1/4 sec. 20, T. 8 S., R. 5 E. (See fig. 87--*Post's figure*). This disturbed zone is approximately 15 feet wide and extends vertically up the face of the roadcut. Bedding in the zone is obliterated. The rock consists of a mass of disoriented fragments of siltstone, gypsum, and black mudstone. The siltstone, which is the major constituent, has been bleached to a moderate greenish gray from its normal, reddish-brown color. The character of this disturbed zone, its proximity to the hot springs at Cascade Springs, and the presence of caverns in the gypsum at the top of the roadcut just to the east of this zone suggest that the structural disturbance and bleaching were caused by a hot spring similar to those presently active at Cascade Springs. The disturbed zone may, in fact, be the upper part of a breccia pipe similar to those described by Bowles and Braddock (1963)."

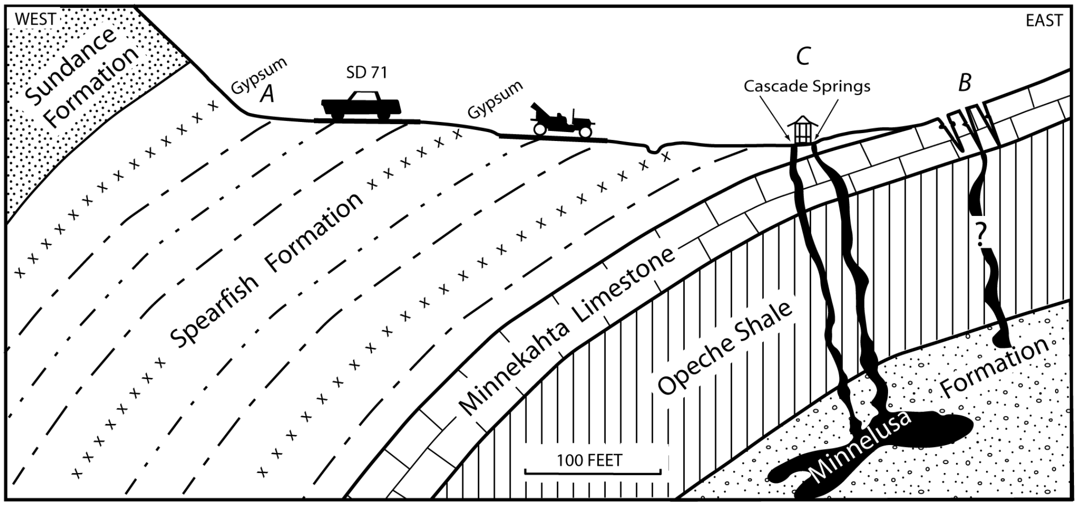


Figure 14. Cross section through the area of the gazebo at Cascade Springs showing localities to be examined, and breccia pipes, believed to be former conduits for the springs, extending up from dissolution cavities in the Minnelusa Formation at depth. Fractured Minnekahta shown in figure 16 lies about 100 feet above the gazebo at locality B. Green shale of the Stockade Beaver Member of the Sundance Formation caps the Spearfish west of S.D. highway 71.

The other "pipe", about 150 feet to the west as noted by Hayes (1999), is characterized by a gypsum bed that is downwarped a few feet, and beds above and below are not affected.

The many veinlets represent a zone where much gypsum has been removed by solution and/or have been intruded into the surrounding rock from the parent bed by processes not fully understood. Broken beds of gypsum several feet thick merge laterally into gypsum-red bed breccia (fig. 15*C*) and veinlets. The impression is that the original bedded gypsum at this locality has been modified by solution removal, injection into veins, contortion by expansion, and brecciation. It is possible that much of the original mass of gypsum has been removed. Also, anhydrite, which may have been the original form of calcium sulfate, when converted to gypsum, may have expanded considerably to create the force for vein injection and bed crumpling. However, several beds at the northernmost end of the exposure along SD 71 were X-rayed and no anhydrite was found in veins or beds, only gypsum (John Johnson, USGS, pers. comm.).

B. Fractures ("pull apart") in the Minnekahta Limestone

Walk several hundred feet to the west along the highway and pass through an open gate before the parking lot at Cascade Springs and climb up the slope. Bedding in the Minnekahta wobbles a bit, but the dip averages about 20° to the southwest. Many large fractures (fig. 16 are found in a zone between 70 and 100 feet vertically above the base of the slope in an area about 150 feet long. The fractures are more than 10 feet deep in places, and probably extend the entire 40-foot thickness of the Minnekahta. They are as much as 10 feet wide and have various orientations, including N. 35° E., E.-W., N. 5° E., and N. 70° E., following prominent joint directions. There are three possible origins that might be considered for these structures: (1) subsidence due to solution of gypsum below, (2) gravity sliding on the soft sediments of the Opeche Shale, and (3) a combination of sliding and weakening of material below by solution. An initial impression is that these fractures are caused by tension due to downhill sliding. An interesting comparison with similar fractures in the Moenkopi Formation related to dissolution of salt at depth in the Holbrook basin (Epstein and Johnson, 2003) will be made. There are many small-scale structures, folds and faults, such as those described at mileage 4.5, that have been attributed to gravity sliding, believed to have occurred after erosion had exposed the surface of the Minnekahta (Epstein, 1958; Brobst and Epstein, 1963).

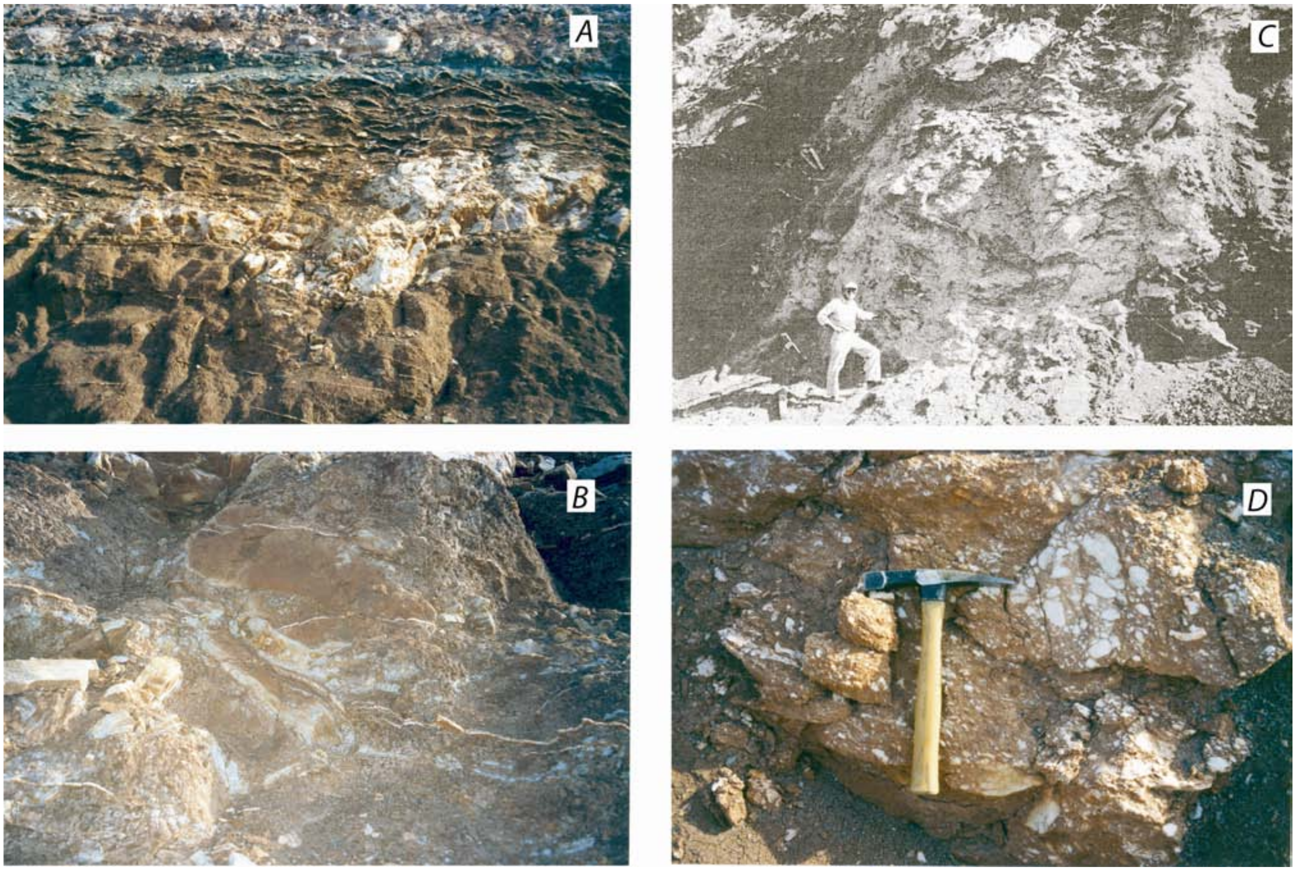


Figure 15. Structures in gypsum in the Spearfish Formation at locality A.

A, Downwarped gypsum bed interpreted to be part of a breccia pipe by Post (1967) and Hayes (1999). Note abundant thin veins extending into surrounding red beds. Shale and siltstone at base of outcrop is minutely fractured.

B, Brecca just below the "pipe".

C, Breccia pipe figured by Post (1967, fig. 87) at same spot as structure in fig. 15*A*. Note lack of bedding in the bleached pipe as compared to stringers sub-parallel to bedding in the surrounding rock.

D. Brecciated gypsum believed not to be sedimentary because of limited horizontal extent.

Figure 16. Fractures in Minnekahta Limestone, apparently extending down through the entire thickness of the formation, locality B, Cascade Springs, Stop 4.

C₁. Hydrology of Cascade Springs

Cascade Springs is a group of warm (~20^{o} C) artesian springs (fig. 13) with collective flow of about 19.6 ft^3/s and a surface drainage area of 0.47 square miles. The drainage area is not large enough to supply this large flow rate to the spring indicating that its source water is not local. The large springflow rate suggests that a large contribution of flow probably is supplied by the highly permeable Madison aquifer, more than 800 feet below. Hydraulic head in the Madison aquifer is higher than that of the overlying Minnelusa aquifer in the vicinity of the springs, which would result in upward flow from the Madison to the Minnelusa aquifer if adequate vertical permeability exists. Back and others (1983) examined geochemical and hydrologic data of the springs and concluded that Madison aquifer water, which is recharged in the western and southwestern Black Hills, sweeps eastward around the southern end of the Black Hills and supplies most of Cascade Springs, but they are also partially supplied from the Minnelusa aquifer. Stable isotopes of oxygen confirm the interpretation that the source of spring water is from recharge in the Black Hills many miles to the northwest of Cascade Springs (Naus and others, 2001). A spring-water sample had a δ^{18}O value of -15.4 parts per thousand, which is considerably lighter than the local recharge but is similar to water recharged on outcrops of Paleozoic rocks near the Pennington-Custer County line. Naus and others (2001) concluded that the low tritium concentrations in spring water indicate that a large proportion of greater than 40 year old ground water discharges from the springs. This long residence time is consistent with the conclusion that the recharge area is many miles from the springs. Moreover, the combination of geochemical information generally excludes substantial contribution from regional flow outside of the Black Hills (Naus and others, 2001).

A long-term response in flow from Cascade Springs may reveal some interesting aspects about karst aquifer storage. Although dry conditions and declining ground-water levels have prevailed in the Black

Hills during recent years, an anomalous increase in springflow of from 1.5 to 2.0 ft^3/s over the normally steady flow rates occurred during the spring of 2005. This could be explained by a long-term lag time in the low-frequency response component of springflow (or hydraulic head), which can occur in karst aquifers because of the unique storage properties of karst. If this is the case, the recent increase in springflow would be in response to wet conditions during the mid 1990s. An alternate explanation might be that declining water levels caused flowpaths to shift, possibly focusing more flow to Cascade Springs.

C_2. The Origin of Cascade Spring

(Summarized from Hayes, 1996 and 1999)

Beginning on February 28, 1992, a large discharge of red suspended sediment was observed from two of the six known discharge points. Similar events during 1906-07 and 1969 were documented by local residents and newspaper accounts, and a resident reported a similar reddening of the water during 2003, although not as prolific as in previous years.. This periodic sediment discharge at Cascade Springs probably results from episodic collapse that is caused by subsurface dissolution of anhydrite beds and cement in the middle and upper Minnelusa Formation, accompanied by replacement of dolomite by calcite. Mineralogic and grain size analyses support a hypothesis that many breccia pipes now exposed in outcrops of the Black Hills were, at one time, throats of artesian springs. Some of these springs have been abandoned as water levels have declined over geologic time due to the lowering of the Black Hills by erosion. The flow paths for Cascade Springs is believed to be along breccia pipes that also will someday be abandoned. Hence, the locations of artesian spring discharge points probably have been shifting outward from the center of the Black Hills uplift, essentially keeping pace with regional erosion over geologic time (Epstein, 2001, 2003). Furthermore, artesian springflow probably is a factor in controlling water levels in the Madison and Minnelusa aquifers, with hydraulic head declining over geologic time in response to development of new discharge points.

A suitable hydrologic and geochemical model for Cascade Springs involves dissolution of anhydrite accompanied by dedolomitization in the upper Minnelusa Formation, which is caused by upward leakage of relatively fresh water from the Madison aquifer (fig. 17). The anhydrite dissolution and dedolomitization account for the net removal of minerals, creating cavities that would lead to breccia pipe formation by gravitational collapse. Networks of interconnected breccia layers and breccia dikes are also common in the upper Minnelusa. These breccia structures, along with vertical fractures and faults, are likely pathways for transmitting upward flow from the Madison to the Minnelusa aquifer.

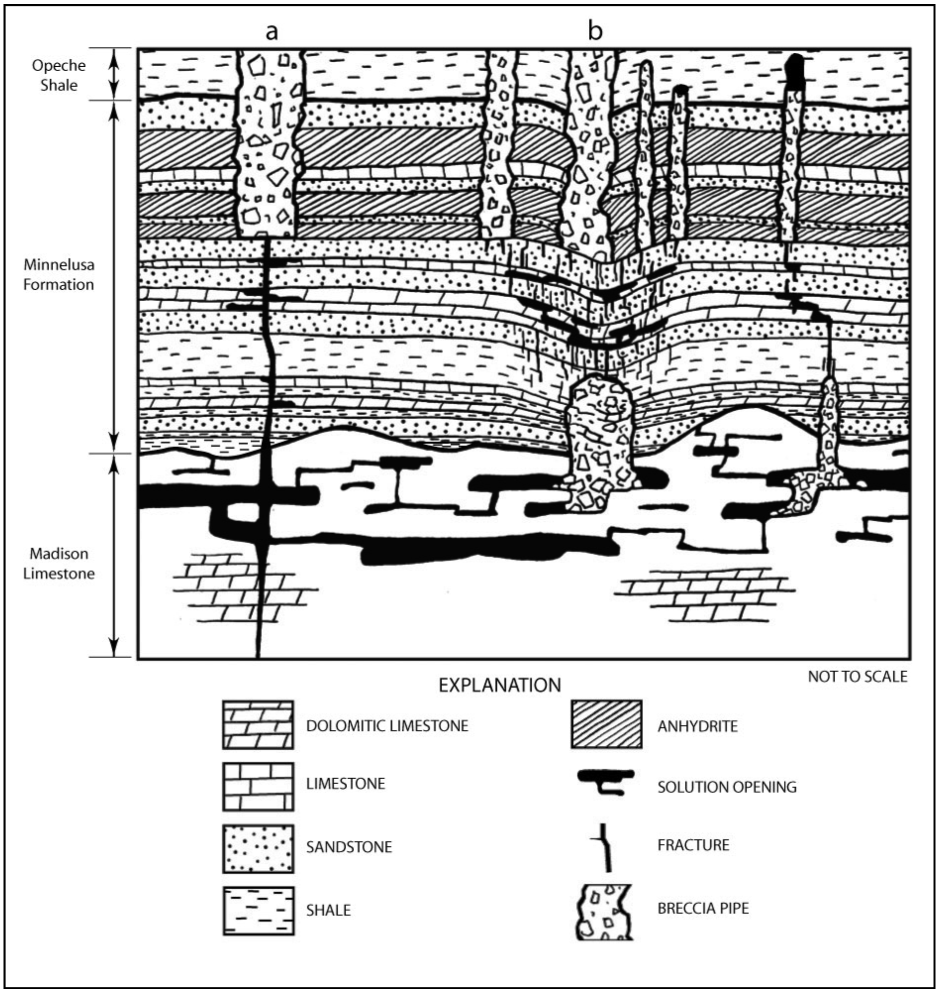


Figure 17. Geologic features that could enhance vertical hydraulic conductivity including (a) breccia pipe that formed along a fracture and (b) breccia pipe initiated by collapse of Minnelusa formation into Pahasapa Limestone cave.

C_3. Biology of Cascade Spring

(Summarized from various materials provided by The Nature Conservancy, Black Hills Ecoregion, 8100 Sheridan Lake Road, Rapid City, SD 57702, Phone: (605) 342-4040, Fax: (605) 348-6060 http://www.nature.org/wherewework/northamerica/states/southdakota/preserves/art9147.html)

The springs support a unique warm riverine system that includes four rare plant species – tulip gentian, beaked spikerush, southern maidenhead fern, and stream orchid found nowhere else in the Black Hills or the surrounding Great Plains. Their presence in the Black Hills is due in large part to the warm water of Cascade Springs, which allows for their survival during severe winters. Tulip gentian (*eustoma grandiflorum*) requires a fairly high water table in moist open fields and meadows underlain by sandy alluvial soils. Its habitat has been reduced to the point that it is now rare over much of its former range. Beaked spikerush (*eleocharis rostellata*) is an obligate wetland species that occurs in many types of alkaline wetlands, including hot spring edges. It typically occurs on sand bars and along stream edges in saturated soil. Also, beaked spikerush can occur in marl beds, which are formed from calcium-carbonate precipitates. Southern maidenhair fern (*adiantum capillus-veneris*) owes its localized occurrence along Cascade Creek to the warm, limey waters of Cascade Springs. Stream orchid (*epipactis gigantean*) grows on calcareous, porous substrates or thin, partially decomposed, wet organic substrates and is more common in the open than in forests.

This area contains prime mountain lion habitat, with a nearby active den, and it includes an unusual Townsend's big-eared bat nursery roost. Because Cascade Creek remains ice-free throughout the year, it's a valuable winter fishery and provides an important water source for wildlife - especially birds. This unique riverine system has received The Nature Conservancy's second-highest biodiversity ranking, making it an outstanding example of an extremely rare natural community.

Resume driving. Leave parking lot, turn left on Route 71 back towards Hot Springs.

81.0 **7.9** Intersection with Truck Route US 18 East, turn right.

81.7 **0.7** Turn left on US 385 North into Hot Springs.

82.6 **0.9** Stop light, intersection with US 16, continue straight following US 385.

83.4 **0.8** Three-way stop sign. Turn right, continuing on US 385 North.

83.5 **0.1** Gypsum in Spearfish Formation to left.

83.6 **0.1** Fire tower atop Battle Mountain to right.

HISTORIC MARKER

The historic sign states: “According to tradition, American Indians were stricken with an epidemic known as "fell disease" about the middle of the 16th century that threatened to obliterate the tribes. A Messenger arrived from the Great West with news of a wonderful water which, he said, had been touched by the finger of the Great Spirit and would cure all manner of diseases. Indians came to these springs by the thousands.

After a lapse of more than 200 years, the Cheyenne took possession of the springs and built an immense tipi city covering hundreds of acres.

In the following years, the Sioux migrated west and disputed the ownership of the springs. This culminated in a fierce conflict in about 1869, the memory of which is preserved in the name of the eminence to the east, Battle Mountain, where the besieged Cheyenne established fortifications. The Sioux won the battle and possession of the springs which they called wi-wi-la-kah-to (Springs - hot). They called the area Minnekahta (Water - hot) and termed the Black Hills a great "Medicine Home".

After the Battle Mountain fight, tradition says the Sioux and Cheyenne agreed to allow the springs to be a health sanctuary to give their sick and lame the benefit of the healing waters. Around 1880, pioneers began to settle the area”.

84.1 **0.5** Quarry located in the Minnekahta Limestone to left. The Minnekahta is the most important source for aggregate in the Black Hills. We are riding in the Red Valley comprising weak beds of the Spearfish Formation, straddled between the Dakota hogback on the right and hills of the Minnelusa on the left.

86.2 **2.1** Entering Custer County.

88.8 **2.6** Minnelusa Formation in gulley to right.

89.5 **0.7** Entering Wind Cave National Park. Keep an eye out for bison, coyotes, and prairie dogs.

89.6 **0.1** Undulating Minnekahta Limestone at entrance to park. Poorly exposed, progressively older rocks are encountered traveling north through the park, including the Minnelusa Formation, Pahasapa Limestone, and Deadwood Formation, and Precambrian rocks.

92.5 **2.9** Turn left to Park Visitor Center.

93.2 **0.7** Park at Visitor Center.

STOP 5. WIND CAVE NATIONAL PARK: CAVE AND KARST VULNERABILITY

LEADERS: Rod Horrocks and Marc Ohms

Significance of Wind Cave:

- Most boxwork of any known cave
- The most complex rectilinear maze cave known in the world
- 4th longest surveyed cave in world (over 117 miles currently surveyed)
- One of best paleokarst exposures known anywhere
- One of the strongest blowing barometric wind caves
- Diverse mineralogical assemblage
- Diverse and unusual speleothem types
- Intersects the water table

Cave/Karst Vulnerability:

The National Park Service built the infrastructure to facilitate visitors viewing Wind Cave within an erosional window through the Minnelusa Formation and on top of the Pahasapa Limestone and adjacent to the natural entrance of the cave. This is, arguably, the worst place such structures could have been built. Since the Park can not remove these historic Civilian Conservation Corps (CCC)-era structures, it is now attempting to mitigate the impact from these structures on sensitive cave resources.

Sewage systems, roads, parking lots, fire suppression, and buildings change the quality, direction, and amount of water entering Wind Cave. To better protect Wind Cave, the old leaking sewer lines above the cave were replaced with dual-contained HDPE sewer lines in 2001. The inner, primary line was surrounded by an outer, secondary line, which captures and contains any leaks that may arise from the primary line. Visual inspection ports were built into the system, allowing the park to quickly and easily monitor the line for leaks and fix them before any spillage occurs.

To stop contaminated runoff from the parking lot from entering Wind Cave, the park replaced the asphalt lot with concrete in 2004. The concrete has mitigated the effect of dripping gasoline and antifreeze “melting” the asphalt and releasing hydrocarbons which were washed into the cave in as little as 6 hours. It is also no longer necessary to conduct annual chip sealing of cracks in the asphalt, a major hydrocarbon source. In addition, the new concrete lot captures all runoff and funnels it through an oil and grease separator before releasing it into Wind Cave Canyon.

Due to decades of fire suppression and planting of trees by the CCC during the 30’s, the area above Wind Cave contains many more trees than it historically did. This second overgrowth has reduced the amount of water entering the cave. The park has initiated an active prescribed fire program to reintroduce fire back into the ecosystem.

Artificial entrances to Wind Cave have impacted the cave's climate by allowing increased or unnatural airflow. When warm summer air enters the cave, it cools and water condenses on the walls of the cave.

When cool, dry winter air enters the cave it warms up and evaporates water. When the cave is expelling air due to barometric pressure changes, as much as 16.1 gallons of water is lost per hour out the natural entrance (Nepstad, 1986). The most dramatic effect of climate change on the cave were three collapses that occurred near the walk-in entrance that were caused by frost wedging. To help control these changes, a revolving door was added to the Walk-In Entrance and airlocks were added to the two elevator landings. We are currently monitoring and studying the cave climatology to help us better understand the whole system and to determine if further actions are necessary to restore natural climatological conditions.

The developed tour route portion of Wind Cave is impacted from construction-generated dust, dust from tours traveling over unpaved trails, dust tracked into caves on shoes or brought in on clothes, lint accumulations, and other materials shed from humans. Human visitors shed a plethora of materials into caves including lint, hair, dandruff, mites, microbes, shoe rubber, and pet animal fur (Jablonsky 1994). Lint and dust removal projects are conducted in Wind Cave to restore natural conditions, prevent unnatural speleothem dissolution, remove artificial food sources, eliminate unnatural odors, and to restore visual scenes. Many of these concerns, although seemingly unrelated, are part of a bigger picture. The relationships between animals, plants, fire, water, the cave and people are all interconnected. No one part of the ecosystem is separate from another. We try to understand, conserve, and interpret all aspects of Wind Cave National Park as this is the mission of the National Park Service.

Barometric Breathing Cave:

The strong barometric wind coming from or blowing into the natural entrance of Wind Cave is one of its defining characteristics and the reason for the name of the cave. This wind is a reaction to changing atmospheric pressure conditions. When there is a high pressure outside, air rushes inside towards the lower pressure. This exchange happens because the cave is fairly well sealed by the overlaying Minnelusa Formation and because of the small number of entrances (2) and blowholes (6). Wind speeds up to 25 miles an hour have been reported through the natural entrance. Airflow has been documented flowing in the same direction (out or in) for up to 32 hours, thus indicating a very large volume for the cave (Pflitsch, 2002).

The barometric airflow through the natural entrance provides an opportunity to determine the approximate volume of Wind Cave. In the mid 1960's, Herb Conn built an instrument to measure the wind flow through the Natural Entrance. He calculated that Wind Cave had a volume of 56,000,000 m^3 (Conn, 1966). The current surveyed portion of the cave has a volume of 1,400,000 m^3, a little over 2% of his estimate (However, it should be pointed out that a significant percent of this volume may be in cracks too tight for humans to enter or in-between breakdown blocks). Conn's research was repeated by Daniels in 2001, this time taking into account the Snake Pit entrance and more accurate and precise instrumentation.

There are numerous potential sources of error in any measurements of cave airflow. There are at least six documented blowholes near Wind Cave that are likely to be connected to the cave. The revolving door at the Natural Entrance leaks air, as does the elevator shaft and Snakepit Entrance cover. Cavers have observed airflow in high dead-end domes near the surface, possibly indicating diffuse airflow through the bedrock and overburden. All of these were not accounted for in Daniels' study, and will lead to an underestimate of the airflow. However, Daniels estimated the total volume of Wind Cave to be between 6,000,000 m^3 – 10,000,000 m^3, significantly lower than Conn's estimate. However, it is reasonable to conclude from both Conn's 1966 research and Daniels' 2001 research, that airflow indicates that there is a significant amount of cave that has not yet been discovered in Wind Cave.

Cave Potential:

A very active exploration and mapping program, which began in the 1950's, is still on-going within Wind Cave. Currently, 3-4 miles are added to the surveyed length of the cave each year. It is not uncommon to hear cavers participating in the current survey effort remark about the "endless" potential of the cave. A famous diary quote from 1891 by an early Wind Cave explorer, Alvin McDonald, said, "Have given up the idea of finding the end of Wind Cave" (McDonald 1891). This is as true today as it was then.

Many people have speculated on the potential extent of Wind Cave, even to the possible connection with the world's second longest cave, Jewel Cave, located 18 miles to the NW. Although, theoretically possible, this seems highly unlikely based on how both caves react to surface changes in barometric pressure, how network maze caves form, and upon their geologic setting. By calculating passage density within the current boundaries of Wind Cave, a minimum potential length of humanly accessible passages in the cave was determined (Horrocks and Szukalski, 2002). Based on the total density in each of five distinct regions of the cave, a minimum length of 250 miles for Wind Cave was estimated. The current 117 miles of survey represents no more than 47% of that minimum predicted length. By examining the geologic factors, a likely potential areal extent was also identified. It was determined that the current cave boundaries cover 1/8 of the likely extent of the cave. Based on the known passage density, the length of the Wind Cave survey could be as much as 1,100 miles. The current mapped 117 miles represents about 10% of that maximum potential length. The final mapped length of the cave will depend on human caving capabilities. Whether 10% or 46% of the cave has been surveyed, it is obvious that a tremendous amount of surveyable passage remains within the cave system. Based on current mapping rates, it seems probable that Wind Cave will soon become the third longest known cave in the world. It is doubtful that it will ever attain the first or second position.

Boxwork:

Wind Cave is known for its world-class displays of boxwork. Boxwork consists of thin interconnecting veins of calcite that protrude from all surfaces within Wind Cave, especially in the Middle Level and within layers of dolomite. The formation of these calcite veins pre-date the cave. Therefore, boxwork is a speleogen, a dissolution feature that formed when the surrounding bedrock was dissolved or weathered away. These veins are truncated by paleokarst features and thus predate that event and the formation of the cave. The current theory states that these veins resulted from fractures that formed when anhydrite hydrated to gypsum and expanded, fracturing the surrounding limestone soon after the rocks were deposited. These gypsum veins were later replaced by calcite when fresh water circulated through the limestone late in the Mississippian Period. Subsequent removal of the surrounding limestone left the calcite vein fillings standing in relief. The bedrock was more easily removed because it consists of calcite crystals, which are pseudomorphs after gypsum that are held together by a sparse secondary quartz cement and which became a friable sand upon partial dissolution along the grain boundaries (Palmer and Palmer, 2000).

Paleokarst:

Wind Cave is one of the best spots in the United States to view paleokarst. Between 310-320 million years ago, a karst surface was developed on the Pahasapa Limestone. Sinkholes, vertical pipes, and short horizontal caves developed within this landscape. The caves appear to have been developed under phreatic conditions in zones of freshwater-saltwater mixing. About 310 million years ago, a marine transgression filled in these karst features with layers of red sand, silt and clay, along with fragments of limestone, chert, and sandstone derived from previously overlying sediments that were entirely eroded away. These filled-in features became an important structural control during the development of Wind Cave 40-60 million years ago. Many of these features were partially or wholly excavated when the main passages in Wind Cave formed. These paleofills are readily seen on the Garden of Eden and Fairgrounds Tour Routes in Wind Cave. These features are concentrated in the upper half of the Pahasapa Limestone.

Development of Wind Cave:

(Note: The "stages" referred to below are only for convenience in this outline and include only the major events. They are not formal divisions. – Art and Peg Palmer (personal communication, 1999).

Stage 1: Deposition of the Pahasapa Limestone (Madison) on a shallow sea floor 340-320 million years ago (Mississippian Period). Low areas of the continent were covered by shallow sea water. Some of the major cave-forming limestones and dolomitesof North America were deposited at this time. Several distinct lithologic layers formed, from bottom to top: massive dolomite (route to Lakes); bedded dolomite and limestone (major boxwork zones); chert (ceiling of Ice Palace); and massive limestone (Fairgrounds, Garden of Eden). Gypsum (hydrated calcium sulfate) and anhydrite (calcium sulfate) were also deposited within some of the lower and middle layers.

Stage 2: Gypsum and anhydrite are physically and chemically unstable. Soon after the rocks were deposited (about 320 million years ago) they were uplifted slightly above sea level, allowing the following to happen:

Anhydrite hydrated to gypsum, causing expansion that formed many small cracks in the surrounding rocks, especially the dolomite beds in the middle Pahasapa Limestone. Dissolution of dolomite followed by crystallization of calcite, as well as plastic deformation of the sulfates, probably contributed to the fracturing. Subsequent calcite was deposited in the fractures.

The pressure of the overlying rocks forced the gypsum and anhydrite to migrate into fractures in the surrounding rock.

Reduction of gypsum and anhydrite in the deeper layers produced hydrogen sulfide, which migrated upward to oxygen-rich areas, where it was oxidized to sulfuric acid. The reaction of this acid with the surrounding limestone formed the earliest cave openings--generally small pockets and fissures--and the adjacent limestone and dolomite were altered to a weak, crumbly, bleached zone. The basic layout of the cave passages was determined at this time.

Some of the hydrogen sulfide combined with dissolved iron to produce iron sulfide (pyrite, etc.).

Stage 3: The climate became wetter, and considerable amounts of fresh water entered from the surface. Gypsum and anhydrite were replaced by calcite. Oxidation of the iron sulfide around the old hydrogen sulfide zones produced red and yellow zones of iron oxide in and around the cave, and the calcite deposited at this time is orange-brown as a result. This includes the veins that now protrude as boxwork fins. In the upper strata, gypsum was simply dissolved away, leaving a fractured jumbled breccia in the limestone (as in the Garden of Eden).

Stage 4: Eventually the climate became so wet that sinkholes and solutional fissures formed at the surface, and new caves were formed or enlarged forming part of the upper level of the cave, most of which were subsequently filled by sediment during stage 5. Some of the fissures extended below the chert level intersecting the cave network established in Stage 2. Much of the cave enlargement simply followed earlier openings, fractures, and altered rock zones.

Stage 5: About 300 million years ago, during the Pennsylvanian Period, a rise in sea level caused the lower part of the Minnelusa Formation (mainly sandstone) to be deposited, filling in the sinkholes, fissures, and most early caves. Much of the sandstone was deposited by rivers along the paleo-shoreline. The red sand and clay deposits in the Beauty Parlor and Garden of Eden are derived from the lowest layers of this formation.

Stage 6: Continued deposition of sediments buried the Pahasapa Limestone to a depth of at least one mile during the Pennsylvanian through Cretaceous Periods (300-70 million years ago). A layer of white calcite (dogtooth spar) was deposited on the walls of earlier cave openings.

Stage 7: The Black Hills and Rocky Mountains began to rise about 70 million years ago. Mobilization of deep fluids early in this stage caused deposition of hydrothermal minerals in some of the early caves and pockets, including quartz crystals (Crown Jewels, etc.).

Stage 8: As the Black Hills continued to rise, the sedimentary rocks were stripped off by erosion, exposing very old (Precambrian) igneous and metamorphic rock at the center of the uplift (Harney Peak, Mt. Rushmore, etc.). The eroded edges of the sedimentary rocks, including the Pahasapa Limestone, were exposed around the perimeter of the Black Hills. Groundwater moved through the rocks in considerable volume, and most cave enlargement took place during this time. Again, the enlargement was concentrated along the zones of older cave development and alteration. Except in a few places the cave does not extend to the top or bottom of the Pahasapa Limestone, nor does it extend far below the water table. Evidently the cave is not the product of simple artesian groundwater flow, infiltration from the surface, or hydrothermal water rising from depth. If it were, the cave would be largest where the water first entered the limestone. It is clearly the result of mixing between two or more of these water sources, which produced a zone of solutionally aggressive water. Its main solutional phase was about 60-40 million years ago.

Stage 9: As the water table dropped, weathering of the limestone walls took place and continues today. Most important, the crumbly, altered dolomite of Stage 2 has decomposed into a powdery sand that formed files of sediment on the cave floors and allowed the thin calcite veins (mainly the orange-brown veins of Stage 2) to protrude as boxwork. Bedrock walls have developed a thin weathering rind of fluffy powder, stained red, yellow, and black from the oxidation of minerals in the rock (such as the pyrite from Stage 2). Moist air rising from the lower levels produces condensation on the walls of the cooler upper levels and condensation erosion. This dissolution produces domes and chutes in the ceilings of upper level passages. The condensation moisture becomes saturated with dissolved calcite and seeps through the bedrock to the water table, although some of it evaporates in the lower levels to produce aragonite frostwork and popcorn. Other deposits are also formed by water seeping from the surface. Active drips fed by infiltration from surface water deposit flowstone, stalactites, etc. In zones of ponding, such as the lakes, a wall crust of calcite has formed, and calcite rafts form at the surface. This water is supersaturated with calcite and cannot dissolve limestone. Older crusts higher in the cave, including dogtooth spar in larger openings (Stage 6), have been shaved off by condensation corrosion and weathering.

Major time indicators:

Orange-brown calcite (boxwork fins); older than 320 million years. It is cut by the red paleofill and never occurs in the paleofill, except as eroded fragments.

Red sediment fill (sand and clay paleofill); about 300 million years old. This marks the well-known unconformity that separates the Mississippian and Pennsylvanian rocks throughout the western states. Be careful--many of the dolomite beds weather to red colors too, as in the Post Office. Much of the paleofill in the cave has subsided into lower levels as the cave enlarged, but this can be easily recognized by the lack of (or disruption of) the white calcite coatings and vein fillings (described below).

White calcite veins and including dogtooth spar ; between 300 and 70 million years ago, probably toward the younger end. This fills cracks and coats pockets in the red paleofill, so it is definitely younger. It is cut by the present fills and overlain by deposits such as wall crusts.

Quartz crystals ; about 100-70 million years old. In places they coat the dogtooth spar, especially along faults.

The cave itself has an origin that spans the entire period from about 320 million years ago to the present. The major solutional phase was about 60-40 million years ago, during which time the present topography developed. However, the present cave follows the patterns of the early gypsum and anhydrite zones, as shown by the fact that the orange calcite (originally gypsum) is concentrated only around the present caves. In large breakdown or blasted areas the density of calcite veins can be seen to diminish away from the cave. Therefore, the cave pattern predates the uplift of the Black Hills. The pattern seems well adjusted to the Black Hills uplift, with fractures radiating away from the center of the hills. However, the Black Hills dome has long been an area of uplift and weakness in the earth's crust, and fractures tend to maintain the same patterns and are repeatedly reactivated.

Resume driving. Leave Visitor Center returning to US 385.

93.9 0.7 Turn left on US 385 towards Custer.

94.7 0.8 Sewage lagoon on right. Minnelusa exposed on cliff face.

95.0 0.3 Poorly exposed Minnelusa littered with cobbles from the overlyingWhite River Formation.

96.1 1.1 Prairie dog mounds on right. Coyotes may be seen occasionally examining these morsels.

96.4 0.3 Junction with Route 87 north. Continue straight on US 385.

96.7 0.3 Sandstone outcrops of the Deadwood Formation in creek to right. For the next 50 miles we will be riding on a variety of Precambrian metamorphic and igneous rocks making up the core of the Black Hills. Lovely scenery, no karst, enjoy the views!

102.9 6.2 Junction with Route 89, bear right on US 385 and US 89 north towards Custer.

106.2 3.3 Mine tailings to right from feldspar workings in pegmatite.

114.2 8.0 Traffic light. Intersection with US 16. Turn right on US 16/US 385/Rte 89 into Custer.

114.6 0.4 Traffic light in Custer. Make left turn onto US 16 towards Chief Crazy Horse Mountain and Mount Rushmore.

116.8 2.2 The hills to the right are held up by the Harney Peak granite, intruded into mica schist. Chief Crazy Horse Mountain carving at 2 o’clock.

117.2 0.4 Chief Crazy Horse at 1 o'clock.

119.0 1.8 Entrance to Chief Crazy Horse Mountain (fig. 18). Chief Crazy Horse and Chief Sitting Bull were responsible for the defeat of Custer at the Little Big Horn, following conflicts with the White Man after gold was discovered in the Black Hills in 1874. The monument, carved in pegmatitic granite of Thunderhead Mountain, is the largest in the world, as tall as the Washington Monument and taller than the pyramids at Giza. Sculptor Korczak Ziolkowski was invited by Lakota Indian Chiefs to carve Crazy Horse in the Black Hills in 1939 and he began blasting in 1948. When completed the mountain carving will be 641 feet long by 563 feet high. The head of Crazy Horse is 87 feet tall or 22 stories high, and equals in volume all the heads at Mt Rushmore. His outstretched arm is nearly as long as a football field and points to “my lands are where my dead lie buried”, a quote reportedly given in response to a taunting question asked of a white man after the defeat of the Indians.

Figure 18. Chief Crazy Horse Memorial and model.

121.6	**2.6**	Cross Pennington County line.
124.9	**3.3**	Route 89/87 to right, the Needles Highway to Sylvan Lake, continue straight ahead.
125.0	**0.1**	Turn right on Route 244 East.
132.1	**7.1**	Harney Peak Granite country.
132.3	**0.2**	Enter Mt. Rushmore National Memorial (figure 19).

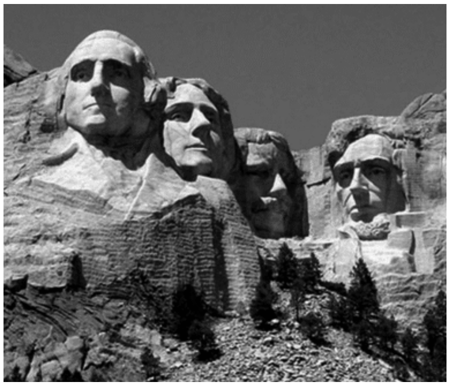


Figure 19. Mt. Rushmore National Memorial.

“The birth of our nation was guided by the vision and courage of George Washington. Thomas Jefferson always had dreams of a greater, more perfect nation, first in the words of the Declaration of Independence and later in the expansion of our nation through the Louisiana Purchase. Preservation of the union was paramount to Abraham Lincoln, a nation where all men were free and equal. At the turn of the Twentieth Century Theodore Roosevelt envisioned a great nation, a leader on the world stage, our nation was changing from a rural republic to a world power. The ideals of these presidents laid a foundation for the United States of America as solid as the rock from which their figures were carved”. (Mt. Rushmore National Park service Web Site).

133.8 1.5 Traffic light; main entrance to Mt. Rushmore national Memorial, continue straight.

Mount Rushmore National Memorial is carved into the Harney Peak Granite that intruded older Precambrian schist about 1.7 billion years ago. Sixty-foot-high heads of four presidents, representing the first 150 years of the Nation's history, are carved in bold relief: George Washington, Thomas Jefferson, Abraham Lincoln and Theodore Roosevelt. The sculptor, Gutzon Borglum, selected Mt. Rushmore because of the consistency of the granite, dominating height, and the southern exposure. Work began in 1927, funded by the Federal government, and completed 14 years later.

134.2 0.4 Nice view of Mt. Rushmore in your rearview mirror.

135.3 1.1 Junction with US 16A. Continue straight on US 16A towards Keystone.

135.7 0.4 Keystone.

138.7 3.0 Bear right on US 16 towards Rapid City.

143.7 5.0 Rockerville, a town straddled by the four-lane highway.

145.7 2.0 Entering *Touristville.*

147.1 3.4 Minnelusa on left.

148.2 1.1 Minnekahta Limestone atop Opeche red shales.

148.4 0.2 Undulating Minnekahta Limestone.

148.9 0.5 Crossing the Red Valley in the Spearfish Formation. Note gypsum ledges.

150.2 1.3 Sandstones in the Sundance formation cap hill on left.

150.8 0.6 Flat uplands on top of the Dakota hogback underlain by sandstones of the Inyan Kara Group. Great Plains in distance to the right and mountains with Precambrian rocks to left.

153.8 3.0 Entering Rapid City while descending through the sandstones of the Inyan Kara Group.

155.6 1.8 Omaha Street, turn right.

156.9 1.3 Fifth Street, turn left.

157.1 0.2 Turn left on New York Street and immediate right into Holiday Inn Parking lot. End of trip.

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