Field Trip Guide 3 for a Self-Guided Trip to Karst Features of the Western Black Hills, Wyoming and South Dakota, Karst Interest Group Workshop, September 12-15, 2005

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ABSTRACT

There are many interesting karstic features to be seen in Wyoming and South Dakota in the western Black Hills between the Vore Buffalo Jump (Stop 9, Field Trip Guide 2, Epstein, Davis, and others, 2005, this volume) near Sundance, Wyoming, and Custer, South Dakota. While time was not available to include this area in our regular two days of Karst Interest Group field trips, it is presented here for those who wish to devote a day to examine some additional localities in both carbonate and evaporite-bearing rocks.

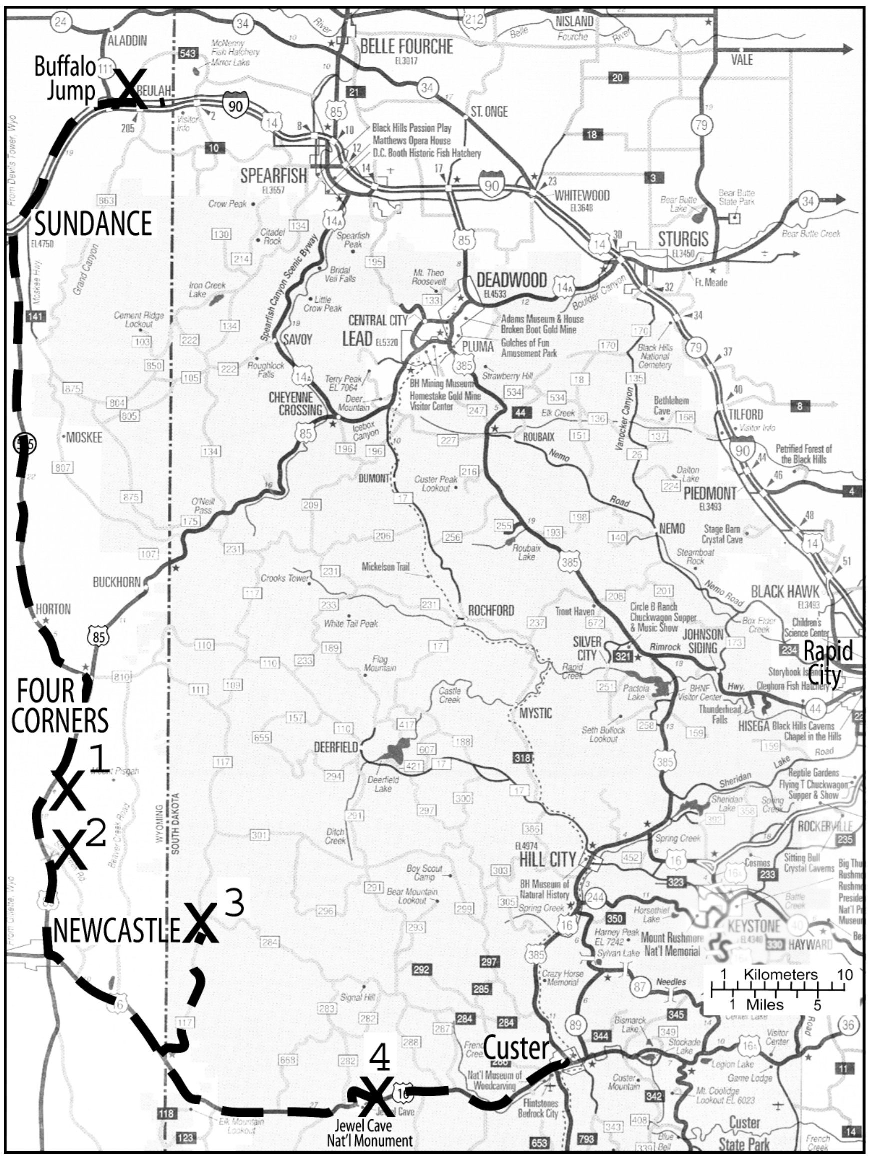

Figure 1. Map showing trip route and stop locations.

Field trip originates at the Vore Buffalo Jump, Stop 9 of Field Trip Guide 2, Epstein, Davis, and others, 2005, this volume.

0.0 **0.0** Turn left from parking area of the Vore Buffalo Jump and continue west on US 14.

0.2 **0.2** Large sinkhole on right.

0.5 **0.3** Another large sinkhole on right.

0.7 **0.2** 600-foot-wide sinkhole in the Spearfish to the right (See fig. 9d , Stop 9, Northern Field Trip, this volume).

1.1 **0.4** Another large sinkhole to right.

1.5 **0.4** Minnekahta Limestone overlain by 4-foot-thick gypsum bed. Ten miles farther east this interval comprises about 1.5 feet of thin interbedded red shale and impure gypsum, indicating that this gypsum layer pinches out in that direction.

2.1 **0.6** Minnekahta Limestone supplies crushed stone to quarry on left. The Minnekahta is a valuable aggregate resource throughout the Black Hills.

2.7 **0.6** Many silicified and case-hardened sandstone boulders of the Lakota Formation are residual remnants of erosion of about 1,000 feet of sediments overlying the Minnekahta. Geomorphic features to the north show that the boulders are an end result of a series of erosional processes (figure 2).

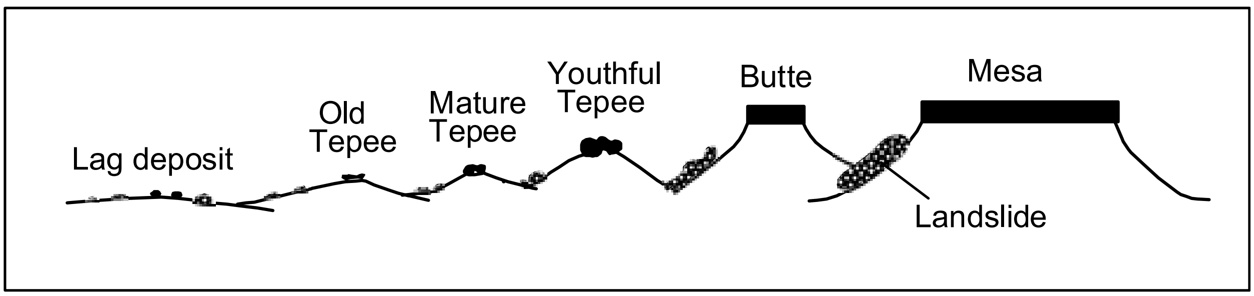

Figure 2. Stages in the development of lag boulders derived from the Lakota Formation in the northern Black Hills. Mesas, and then buttes, develop by isolation from the original tableland capped by the Lakota. Sandstone blocks, which form by continued disruption of the Lakota along joints and by landsliding, protect the underlying shale as a series of progressively lowering "tepees". Individual boulders in a lag deposit result at the final stage of erosion.

3.6 **0.9** Intersection with WY 111. Turn left towards I-90.

3.8 **0.2** Turn right onto I-90 west.

6.4 **2.6** Red Valley widens to two miles because of gentle dips in the Spearfish. In the distance to the north the sandstone outcrops of the Inyan Kara Group also widen forming the Bear Lodge Mountains.

7.8 **1.4** Sundance Mountain straight ahead, a laccolith comprising syenite porphyry (Darton, 1905).

10.0 2.2 Pine-covered rounded hill straight ahead is Green Mountain, a domal structure capped by the Minnelusa Formation, rimmed by small ridges of the Minnekahata and by gypsum in the Spearfish. It is undoubtedly underlain by an intrusion similar to Sundance Mountain.

13.0 3.0 Green Mountain to left.

14.0 1.0 Note contact metamorphism in hill to right.

15.2 1.2 Exit 187. Turn right to Wyoming 585.

15.6 0.4 Stop sign. Turn left on Wyoming 585 south towards Newcastle.

15.9 0.3 Pass under I-90. Sundance Mountain to right, view of Green Mountain to left.

17.2 1.3 Darton (1909, Plate 10) pictured a cave in the Spearfish Formation somewhere in the immediate area to the west (figure 3). The cave appears to be about 10 feet high, judging from the height of the individuals in the photograph. The water flows on a gypsum bed, possibly 6 feet thick. Above that is a zone of red beds intruded by gypsum stringers. An attempt to locate the cave in 2005 was unsuccessful, but Gene Gade (Crook County Cooperative Extension Service, written communication, 2005) reported that a local resident "...went into the sinkhole-cave complex south of Sundance a dozen or so times 30 years ago.... He confirmed that the entrance was... about a mile south of town. It apparently is (was?) over the hill and out-of-sight from Hwy 585. He said the entrance was a rather small, elliptically-shaped opening in the bottom of a sinkhole depression, shaped rather like "lips" of gypsum. One had to crawl or slide the first few feet. The cave angled down from west to east, away from the Sundance Mountain igneous intrusion, as you might expect. Once inside, the cave widened and made a bend to the right (south) and then dipped back to the east. The diameter of the cave varied from 6 to about 15 feet. At some points he had to bend over to proceed, at others he could easily stand up and walk without bumping his head. He said that a small stream came in from the side near the entrance and flowed fairly gently, indicating only a moderate dip, to where it was no longer possible for a person to proceed. The stream was shallow (probably one to several inches deep), but steady and about 5 to 6 feet in width. You had to cross back and forth, wading or stepping on rocks. At one point it slid or dropped over an incline of 2 to 3'...not really a waterfall, but probably what was pictured in your old photo. The cave continued to dip toward the east and continued for several hundred yards and had a few relatively small, short side-branches. He was convinced it was long enough to extend under Hwy 585."

20.5 3.3 Four-foot gypsum bed in Spearfish on left.

24.4 3.9 A sinkhole was observed by Trotter and Grinnell (1958) to the right of the highway. They noted that many sinkholes and subterranean streams formed by solution of gypsum beds in the lower Spearfish.

26.3 1.9 Inyan Kara Mountain three miles distant at 2 o'clock. *Inyan Kara* is a Dakota Sioux name than means "stone-made", probably referring to the hard igneous rock (syenite porphyry; Mapel and Pillmore, 1963) that forms the mountain.

Figure 3. Cave in gypsum near Sundance, Wyoming (Darton, 1909, Plate 10).

26.7 **0.4** Minnekahta Limestone in an undulating dip slope exposed for next several miles with red beds of the Spearfish covering it in many places.

27.8 **1.1** Depression in field to left may be a sinkhole.

29.1 **1.3** Inyan Kara Mountain to right.

29.9 **0.8** Historical marker on left. The Custer expedition camped here in July, 1874. General Custer climbed Inyan Kara Mountain and carved his name there. Minnekahta Limestone dips towards sign.

32.8 **2.9** Crushed stone quarry in Minnekahta on left.

33.7 **0.9** Enter Weston County. Strawberry Mountain on right, a probable Tertiary intrusive capped by the Minnelusa Formation.

34.2 **0.5** Gentle undulating slopes on Minnekahta Limestone in broad valley.

43.5 **9.3** Stop sign; intersection with US 85; turn right, south. Several sinkholes are present in the Minnekahta Limestone about one mile to the east (figure 4).

Figure 4. "Sink hole in Minnekahta Limestone, southeast of Boyd, Wyo" . From Darton, N.H., 1909, Plate 8B. The Boyd cemetery now locates the abandoned town.

44.1 **0.6** Minnekahta Limestone.

44.9 **0.8** Spearfish Formation.

45.8 **0.9** Minnekahta Limestone.

47.3 **1.5** Gypsum in Spearfish.

48.2 **0.9** Red Butte ahead on left (figure 5). Thick gypsum bed at top believed to be in the Spearfish Formation of Triassic age by Darton (1905). However, its position above red beds of the Spearfish suggests that it is the Gypsum Spring Formation of Jurassic age (Mapel and Pillmore, 1963).

Figure 5. Red Butte. White gypsum bed of the Gypsum Springs Formation (Jurassic) caps red beds of the Spearfish Formation (Triassic).

48.6 **0.4** Abundant gypsum veinlets, creating a secondary porosity in the Spearfish Formation at road level below Red Butte.

49.0 **0.4** Red Valley narrows due to increased dip of the Spearfish Formation.

51.2 **2.2** Stockade Beaver Shale Member of the Sundance Formation overlain by the Hulett Sandstone Member.

51.4 **0.2** Historical Marker. Cambria Salt Mine. The presence of salt (sodium chloride) in the Minnelusa is confirmed by more than five percent NaCl in the water of Salt Spring, 8.5 miles north of Newcastle, WY, reported by Darton (1904), and by about four percent salt reported by Brobst and Epstein (1963).

CAMBRIA SALT MINE HISTORICAL MARKER

"In the early days of the development of the Black Hills, the nearest railroad was nearly 100 miles away, Wagon transportation costs to the mines were high, so a bulky, yet necessary, commodity like salt had high value. Springs with a heavy salt content were discovered by Europeans in the canyon below on July 8. 1877. In November, 1878, James LeGraves came to the area to produce salt for the growing Black Hills mining market. He erected a furnace with two evaporating pans, the larger of the two being six feet wide and sixty feet long. For the next six years LeGraves produced salt by evaporation off spring water during the summer months and shipping his product to the mining districts. Some of the salt went to the general stores of Deadwood and Lead but its chief use was in chloridizing the gold and silver ores mined in the Black Hills.

N. H. Darton reported in 1904 that the spring along Salt Creek flowed at the rate of about I gps (gallon per second) and the water contained a little more than 5% sodium chloride (salt). According to Darton's calculations, about 35,000 pounds of salt were produced every 24 hours. The Cambrian Salt Company was organized in 1907 and prepared to manufacture and refine salt for the large western market. In an unsuccessful effort to locate the bed of rock salt from which the brine comes, several wells were drilled, one having a depth of 825 feet, The evaporation and purifying plant, arranged for coal fuel, was located over the divide to the west near the Cambria coal mine and the brine was pumped to it.

The Cambria Salt Company failed. The company's equipment was sold at a bankruptcy sale May 11, 1909 essentially ending salt production at the Salt Mine."

51.6 **0.2** Gypsum of the Gypsum Spring Formation overlies the Spearfish Formation.

51.9 0.3 STOP 1. SINKHOLE IN THE SUNDANCE FORMATION

Carefully pull off to the side of the road.

Figure 6. Sinkhole cutting flat-lying beds of the Hulett Sandstone Member of the Sundance Formation, east of US 85, ten miles north of Newcastle, Wyoming.

While karstic features are found in soluble rocks in the Black Hills (carbonates and evaporites), many sinkholes and breccia pipes are found in non-soluble rocks, the source of subsidence believed to be in the Minnelusa Formation at depth. Some pipes extend as much as 1,000 feet up into the Lakota Formation (Bowles and Braddock, 1963). This sinkhole is in the Hulett Sandstone Member of the Sundance Formation (figure 6), about 800 feet above the top of the Minnelusa. Interbedded gypsum below the Sundance, aggregates as much as 100 feet thick in the Gypsum Spring and Spearfish Formations, and as much as 200 feet of anhydrite and some salt is present in the Minnelusa, below which are the carbonate rocks in the Pahasapa Limestone. The red soil in the sinkhole is probably derived from the red beds in the Lak Member that overlies the Hulett. The vertical extent of the sinkhole has not been determined.

For the next few miles the road traverses the Sundance Formation, climbing up into Cretaceous rocks

53.9 2.0 Red shale of the Lak Member of the Sundance Formation to right overlying the Hulett Sandstone Member.

55.7 1.8 STOP 2. SALT CREEK OVERLOOK

Pull off to parking area to left.

HISTORIC MARKER

"The Black Hills. named after the dark green carpets of pines that cover the hills are a geological wonder. Covering some 125 miles north to south and 65 miles east to west, the Hills rise 3.000 to 4.000 feet above the red valley floor. Below you are Salt and Beaver creeks where the bur oak grows. Above the valley floor, ponderosa pine and aspen groves cling to the limestone cliffs, clay soil and red sandstone.

History, geology and wildlife are alive and well in the Salt Creek Valley. The Sioux believed the Great Spirit lived in these hills. Pioneers came here to mine for coal and oil. Small towns, like nearby Cambria, sprang up as fast as they were deserted. Tales of gunfights. stage robberies and gambling are kept alive by those who never left.

White-tailed deer roam through the pines and aspens. Wild turkeys scratch through leaves and needles along the creek bottoms in search of acorns and seeds. Brought here from New Mexico in 1948, turkeys are now the most widespread game bird in northeastern Wyoming. These shy, elusive birds don't let humans get too close. At night, they roost in treetops and return to the ground at daybreak to forage. Watch closely and you could see one of these magnificent birds!"

About 6 miles to the southeast the near-vertical rocks of brecciated Minnelusa Formation can be seen forming flat-irons in the Fanny Peak monocline. Just beyond, out of sight, are karst features in the Minnelusa that will be seen at Stop 3.

56.1 0.4 Historic marker. Cambria Coal Camp

"Coal was discovered in the lower Lakota Formation in 1888, the Cambria Fuel Company was subsequently formed, owning 17,000 acres at Cambria, two miles to the northwest. The Cambria mines produced about 13 million tons of bituminous coal with a value of $20 million during a 41-year life span. The coal was unique in that it contained small amounts of gold assaying at $2 per ton. By 1900, the coal camp reportedly employed 750 people and the population had swelled to 1,500. The coal was depleted and the town became a ghost town in 1928. A historical sketch with photographs can be found at http://www.wyomingtalesandtrails.com/cambria.html."

56.7 0.6 Shale and sandstone of the Lakota Formation to left.

58.0 1.3 Top of the "Dakota" hogback. Great Plains (Powder River Basin) to right (west). The Powder River Basin contains about half of Wyoming's oil resources, has tremendous coal reserves, and is an important uranium producer. Road descends through younger formations, from the Lakota Formation, through the Fall River Formation, Skull Creek Shale, Newcastle Sandstone, and Mowry Shale in gently southward-dipping beds in the Black Hills monocline.

59.7 1.7 "Welcome to Newcastle." Newcastle was named in 1889 by the superintendent of the Cambria coal mines after his old home of Newcastle-on-Tyne, England.

60.1 0.4 Westward-dipping beds in the Fanny Peak monocline can be seen straight ahead six miles away.

60.9 0.8 Sandstone and carbonaceous shale in the Newcastle Sandstone of Early Cretaceous age.

61.4 0.5 Stop light. Turn left on US 16 east. The Weston County Visitor's Center is located 600 feet to the west and north of US 16. An educational tour guide of part of the area covered by this field trip, "Beaver Creek, A Trip Through Time", is available at the center.

62.4 1.0 Highway parallels southwest-dipping rocks of the Newcastle Sandstone in the Black Hills monocline, a northwest-trending structure which intersects the northward-trending Fanny Peak monocline at mileage 66.6.

64.4 2.0 Mowry Shale crops out on left with Newcastle below.

64.5 0.1 "Hand-dug Accidental Oil Well" attraction on left. The 24-foot well was dug with a pick and shovel in 1966. Steeply-westward dipping rocks in the Fanny Peak monocline straight ahead.

64.7 0.2 Mowry Shale and Newcastle Sandstone to left.

65.9 1.2 Near-vertical beds of the Minnelusa Formation in the Fanny Peak monocline to the left.

66.1 **0.2** Cross Stockade Beaver Creek.

66.6 **0.5** Outcrop to the right in near-vertical and faulted beds in the Fall River and Lakota Formations of the Inyan Kara Group in the Fanny Peak monocline near the intersection with the Black Hills monocline (Brobst and Epstein, 1963). The bend in strike from north to east in the Minnekahta Limestone at the intersection of the two monoclines can be seen to the left.

67.2 **0.6** The route takes us back into the Red Valley and the host Spearfish Formation. Aggregate quarry in the Minnekahta Limestone to left. Canyons cut into the Minnekahta expose red shale and fine sandstone of the Opeche Shale and sandstone, dolomite, shale, and limestone of the Minnelusa Formation below. Landslide debris litters the slope beneath the hogback to the right.

69.8 **2.6** Passing through the southward dipping Minnekahta Limestone in the Black Hills monocline.

70.1 **0.3** Turn left onto Boles Canyon Road (FS 117).

70.2 **0.1** Entering South Dakota. Redbeds in the Opeche Shale underlie the Minnekahta Limestone.
70.7 **0.5** Purple zone to left in the upper 13 feet of the Opeche Shale (see Stop 10 of the Northern Field Trip for a discussion of this zone). Numerous intraformational folds and faults in the Minnekahta can be seen along the cliff face in the limestone (figure 7). These have been ascribed to gravitational sliding (Epstein, 1958; Brobst and Epstein, 1963).

Figure 7. Intraformational overturned fold passing into thrust fault in laminated and thin-bedded Minnekahta Limestone, typical of many such structures in Redbird Canyon and surrounding area.

71.2 **0.5** Purple zone at the top of the Opeche. Bedding undulations in the Minnekahta probably caused by subsidence in the underlying Minnelusa Formation due to anhydrite dissolution.

71.6 0.4 Turn right on FS 376 into Redbird Canyon. The rocks slowly rise as we travel up the canyon exposing rocks down into the Minnelusa Formation, and eventually into the Pahasapa Limestone.

72.0 0.4 Uppermost sandstones of the Minnelusa on left underlying 100 feet of exposed Opeche redbeds.

72.4 0.4 Brecciated upper Minnelusa on left.

73.2 0.8 View of collapse features in the Minnelusa in canyon wall straight ahead.

73.4 0.2 Ancient debris fan to right cut by present stream valley.

73.7 0.3 STOP 3. ANHYDRITE DISSOLUTION FEATURES IN THE MINNELUSA FORMATION

Entrance to ranch on left.

The Minnelusa Formation at this locality is about 700 feet thick, but ranges to about 900 feet in the subsurface where it has not been thinned by anhydrite dissolution. The Minnelusa consists of sandstone, limestone, dolomite, shale, and anhydrite. Anhydrite is more than 200 feet thick in the subsurface nearby, but is mostly absent in surface outcrops, having been removed by solution. The dissolution of anhydrite and consequent formation of voids in the Minnelusa at depth resulted in foundering and fragmentation of overlying rocks, producing extensive disruption of bedding, a regional collapse breccia, many sinkholes, and breccia pipes and pinnacles. The exposure in Redbird Canyon along the 400-foot high cliff is one of the best in the Black Hills (fig. 8), demonstrating the variety of karst features due to evaporite removal and consequent collapse (Bowles and Braddock, 1963; Brobst and Epstein, 1963; Epstein, 1958, 2001, 2003). The contrast between the brecciated rocks above the level at which the anhydrite has been removed and the undisturbed beds below is striking (see figure 1b of Stop 1, this volume, Southern Fieldtrip Guide).

The breccia in the Minnelusa contains clasts that are slightly abraded, although some of the more friable rocks are partly rounded. They consist of fragments from less than one inch long to clasts several tens of feet long. They consist of all rock types in the Minnelusa as well as some material from overlying formations. The matrix is principally fine-grained sand cemented by calcium carbonate. Many beds can be traced for distances of hundreds of feet, but the rocks are broken and may be displaced several tens of feet in a vertical direction. This crude bedding is a common feature throughout the upper part of the brecciated Minnelusa. The crude bedding may give way laterally to chaotic structure in which the rock fragments are randomly oriented and bedding layering is lost (termed “breccia sills” by Bowles and Braddock, 1963).

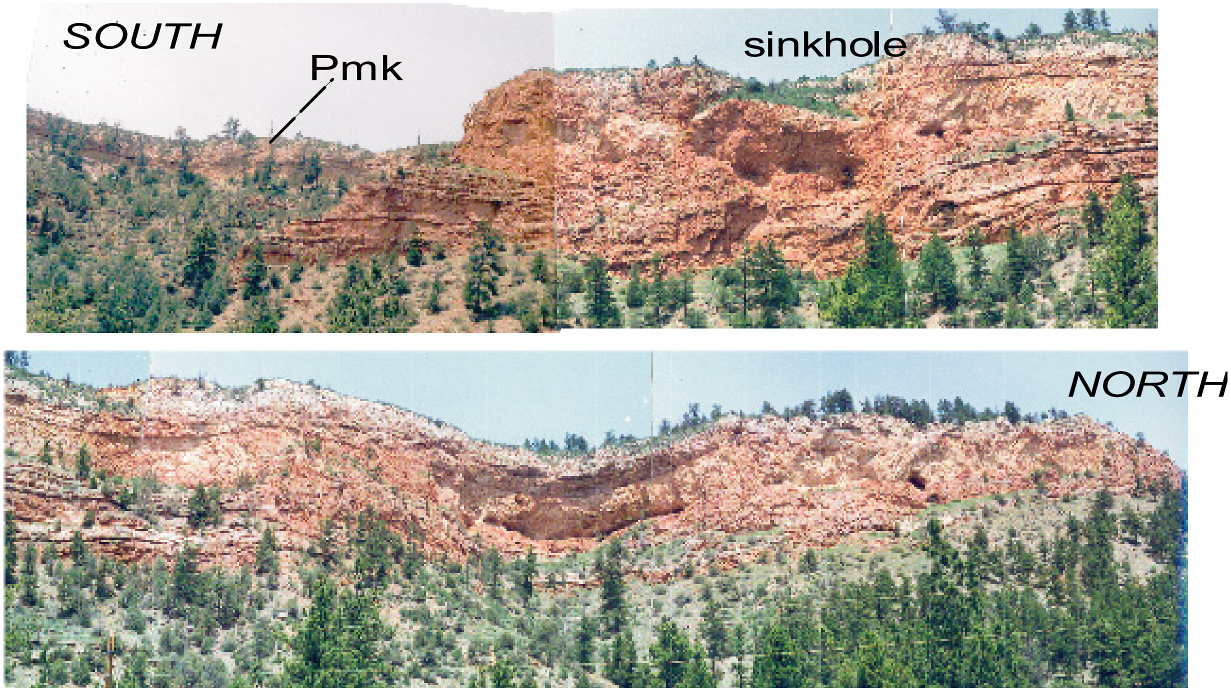

Figure 8. Minnelusa Formation in Redbird Canyon, showing abundant voids and caves due to removal of anhydrite, sinkhole collapse into solution voids, contorted bedding, and completely distorted and brecciated beds. The Minnekahta Limestone (Pmk) is warped into undulating basins and domes as seen on the canyon walls from a distance.

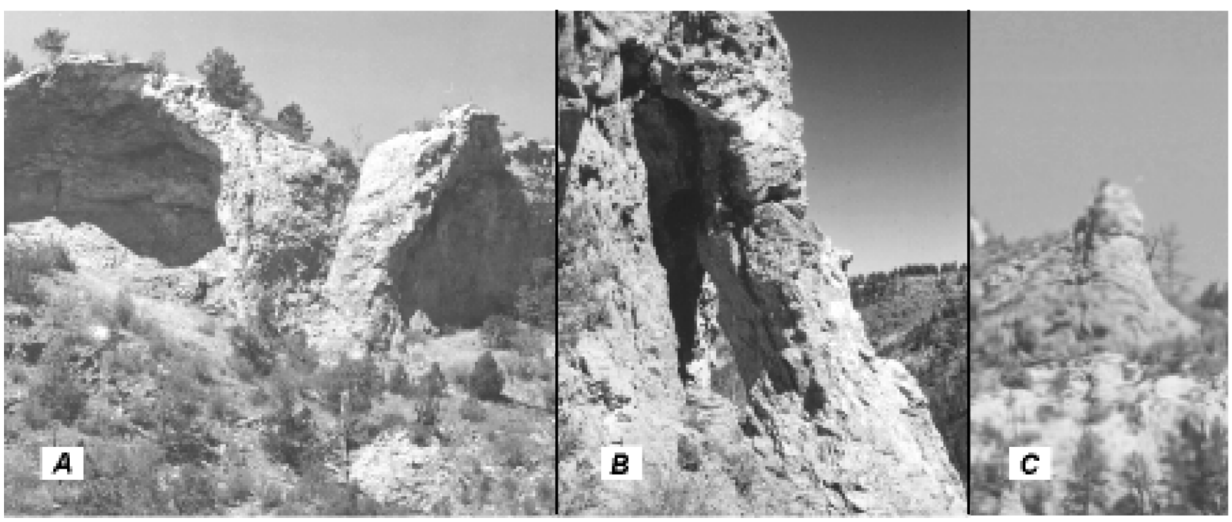

Figure 9. Breccia pipes in various stages of development in the Minnelusa Formation, Redbird Canyon and vicinity. ***A***, Calcite-cemented breccia pipe stands out in relief on the canyon wall. ***B***, breccia pipe still connected to the canyon wall. Progressive erosion will isolate it forming a pinnacle similar to the one in ***C***.

The breccia pipes are vertical cylindrical masses that transgress rocks having crude bedding and chaotic structure. They are as much as 300 feet in diameter and extend upwards from the upper part of the Minnelusa Formation more than 1,000 feet into overlying stratigraphic units (Bowles and Braddock, 1963). The pipes stand out as protuberances on the canyon walls (fig. 9***A***) or as chimney like monoliths above the ground surface (fig. 9***C***) depending on the stage of differential weathering and erosion between them and the less resistant enclosing rocks. Some are at an intermediate stage forming a window on the canyon wall (fig. 9***B***). The pipes developed where stoping was locally intense and probably formed along joints or at the intersection of joints, an ideal place for intense solution of intersected beds and lenses of subsurface anhydrite. The formation of solution chambers was followed by collapse of overlying and adjacent beds. No study has been carried out to determine the relationship between joint intensity and spacing with the occurrence of breccia pipes in the Black Hills. The limit of breccia pipes has been documented in the southern Black Hills, generally indicating the extension of subsurface dissolution of anhydrite (Gott and others, 1974). The brecciation has formed a vuggy secondary porosity, which, along with the porous sandstone, makes the upper half of the Minnelusa an important aquifer in the Black Hills. Whereas breccia pipes may extend upwards through overlying formations, one of the most obvious effects is the production of undulations in the Minnekahta Limestone. The Minnekahta is a prominent resistant unit, about 40 feet thick, forming cliffs between the underlying soft rocks of the Opeche Shale and overlying Spearfish Formation. In most places in the Black Hills the Minnekahta Limestone forms a widespread dip slope with variable domes and saddles that are undoubtedly due to settlement of the brecciated Minnelusa not far below.

Retrace route back to US 16.

77.5 3.8 Stop sign. Turn left on US 16 east.

78.2 0.7 Enter South Dakota.

79.0 0.8 Undulations in Minnekahta bedding probably due to solution collapse in the Minnelusa below.

84.6 5.6 Minnelusa Formation exposed between here and Jewel Cave.

88.0 3.4 Redbeds in the Minnelusa.

89.5 1.5 The winding road passes through the lower Minnelusa and upper Pahasapa with paleokarst collapse structures at the contact.

90.5 1.0 Enter Jewel Cave National Monument. East-west faults parallel the road with down-dropped Minnelusa on right below hills of Pahasapa Limestone on left (Darton and Paige, 1925; Deal, 1962).

90.7 0.2 Limestone unit about 100 feet above base of Minnelusa.

90.9 0.2 Basal Minnelusa redbeds; distorted bedding due to collapse into Pahasapa paleokarst. Top of Pahasapa immediately to right just below road level.

91.1 0.2 Lower limestone unit of the Minnelusa formation.

91.2 0.1 Cliffs to right in Pahasapa Limestone.

91.4 0.2 Red residual soil in Pahasapa karst. The original discovery entrance to Jewel Cave is below and to the right.

91.5 0.1 Limestone unit in Minnelusa immediately above lower redbed unit.

91.8 **0.3** Minnelusa on right down-dropped below Pahasapa to left.

92.4 **0.6** Turn right to Jewel Cave visitors center.

93.2 0.8 STOP 4. JEWEL CAVE

Park in visitors parking lot.

Jewel Cave National Monument was established in 1908. It is the third longest cave in the world, with more than 132 miles surveyed. A description of the variety of speleothems, including stalactites, stalagmites, draperies, frostwork, flowstone, boxwork and hydromagnesite balloons, can be found at http://www.nps.gov/jeca/geology/htm.

The cave occurs in the fossiliferous Pahasapa Limestone of Mississippian age (345-360 mya). During the Pennsylvania Period, about 320 mya, sediments of the Minnelusa Formation covered a karst surface that was developed on top of the Pahasapa, examples of which can be seen along the winding highway just west of the Monument entrance. Approximately 7,000 feet of sediments were subsequently piled on top of the Pahasapa through the Late Cretaceous, at which time uplift of the Black Hills began. The majority of Jewel Cave formed by increased downward-percolating rainfall, rich in soil-derived carbonic acid, about 40 million years ago. Dripping water today in the cave attests to continued cave formation.

Return to US 16.

94.0 **0.8** Turn right on US 16 east towards Custer.

94.5 **0.5** Pahasapa paleokarst sinkholes on left.

97.9 **3.4** Faulted Minnelusa on left.

99.2 **1.3** Precambrian phyllite.

101.1 **1.9** Pegmatite dikes intruding slates and phyllite.

105.3 **4.2** Enter Custer.

106.2 **0.9** Stop light at intersection with 385 and 89. Continue straight on US 16.

106.7 **0.5** Stop light. Turn left on US 16 (3:35 PM). At this point continue trip at mileage 114.6 of the Southern Field trip 1 (Epstein, Agenbroad, and others, 2005, Field Trip Guide 1, this volume).

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