The Origin of Jewel Cave and how it supports cave management decisions

Mike Wiles

Jewel Cave National Monument
South Dakota, USA

Introduction

With over 175 miles of passages, Jewel Cave is the third longest cave in the world. This paper documents the intimate relationships between the cave and present-day geologic structure, contacts, and topography. It presents a conceptual model for further investigation of the origin Jewel Cave.

Principles of Cave Development

Carbonate caves typically form in three stages: 1) fracturing, 2) phreatic dissolution, and 3) vadose enlargement. Vadose activity only occurs after the cave drains and begins to pirate surface streams – something which didn't occur in the Black Hills area. Moreover, the dissolution of caves depends on the existence of a natural mass transfer system. Movement of mass from location to another requires: 1) a solute (limestone), 2) a solvent (acidic solution), 3) a transport medium (groundwater), 4) a continuous flow path, and 5) an energy gradient (elevation difference between recharge and discharge areas).

Geomorphological Framework

Jewel Cave stays in the upper 250 feet of the Pahasapa Limestone, which is locally 430 feet thick. Its passages strongly correlate with the modern surface topography: they are large and mazy beneath the hillsides, but diminish in size and complexity as they approach the drainages; so the processes that shaped the topography must also have been responsible for forming the cave at the same time.

Also, the cave exhibits a strong correlation with the geological structure, as it exists today. Hell Canyon is aligned with the axis of a south-plunging syncline, and the cave itself wraps around a curved strike, dipping toward the plunge of the syncline.

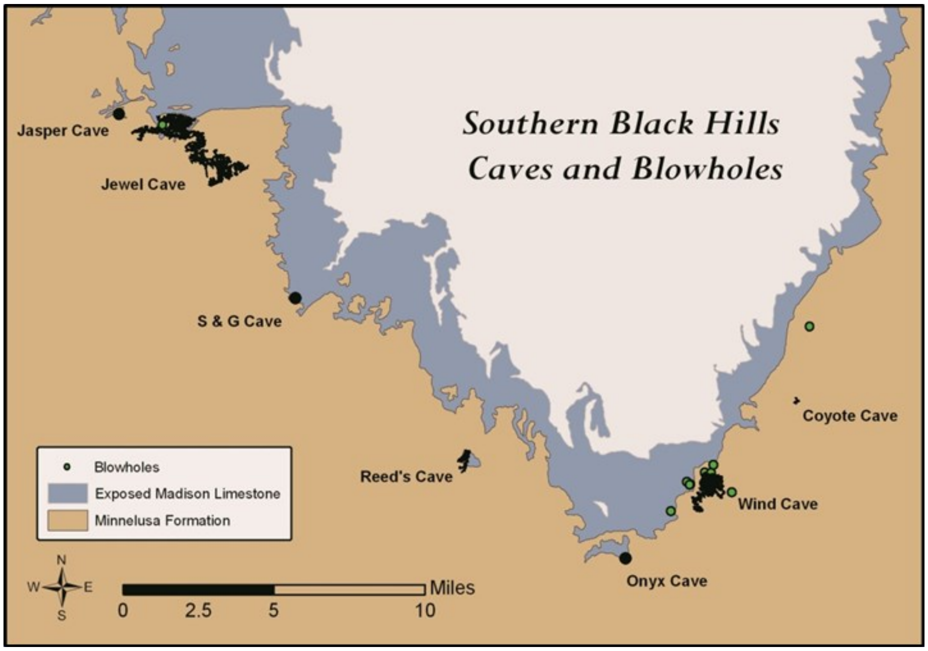


Figure 1 - Large caves are found only beneath the Minnelusa cap.

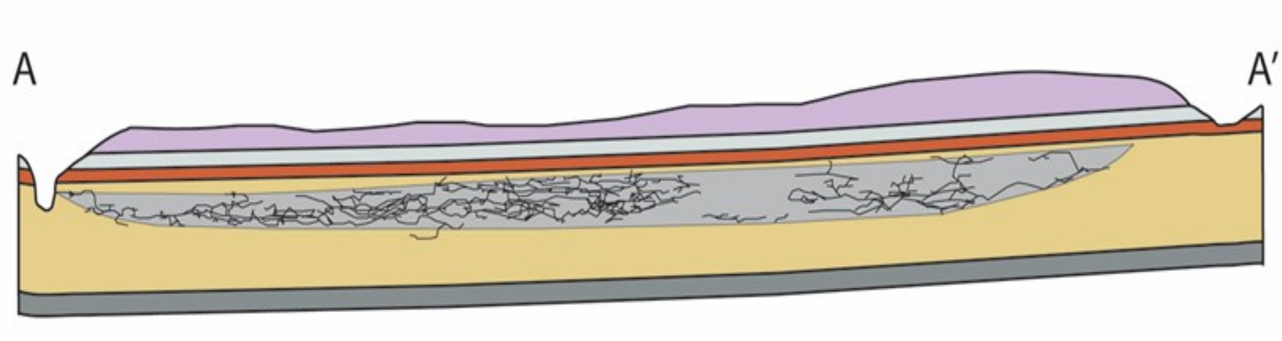


Figure 2 - Cave passages form a lens shape that thins where it approaches surface drainages.

Additionally, nearly all cave passages in the southern Black Hills lie beneath a Minnelusa cap (Figure 1), so it is obvious that the Minnelusa once played a role in forming the passages. There no large caves (remnants of large cave systems) in the uncapped portions of limestone, and none are greater than 500 feet in length. Therefore, the large cave systems could not have formed until *after* the Minnelusa cap eroded back to its present configuration.

Finally, the shape of the solutionally enlarged fractures is a lens that thins out as it approaches the surface drainage at each end (Figure 2). Throughout the Black Hills, it is common for cave passages to diminish in complexity and rise up when they approach surface drainages.

Paleohydrology

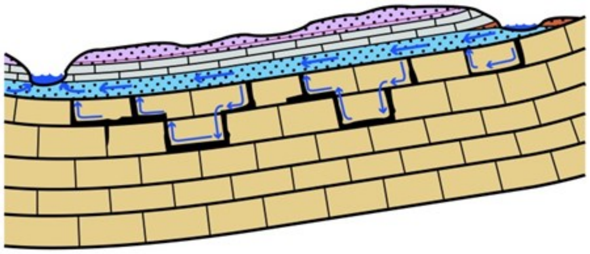
The Englewood Limestone underlies the Pahasapa, but the lower 15 feet is actually impermeable red shale, which prevents water rising from below. The presence of 15 feet of red shale above the Pahasapa precludes the direct infiltration of meteoric water into the fractures of the Pahasapa. However, a 40-foot subunit of permeable Minnelusa sandstone rests on top of the Pahasapa Limestone. A 50-foot subunit of Minnelusa limestone with interbedded clastics lies immediately above, and is overlain by the basal shale of a third Minnelusa subunit. Based on literature, the basal sandstone is assumed to have a permeability of about 10%, and could have served as an initial confined aquifer, supplying water to the developing cave system. It outcrops at Pass Creek and Teepee Canyon – assumed recharge areas, and at lower elevations in Lithograph and Hell Canyons – assumed discharge areas.

Carbonic acid is assumed to be the solute. Because the sandstone aquifer was confined, the carbonic acid wouldn't lose its aggressiveness through degassing. Therefore, it could maintain full aggressiveness over the entire distance from recharge to discharge. Additionally, the effective permeability of sandstone is 3-6 times greater than the cave-sized permeability in the limestone. So the dilution of the acidity in the sandstone, caused by the depleted water returning from the limestone, would be minimal.

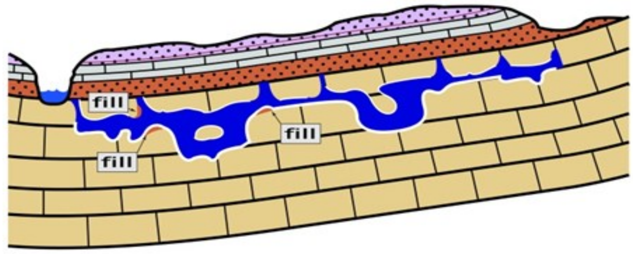
Sequence of Events

Stage 1 - Because the sandstone is much more permeable than the initial state of either limestone (above or below), the water would first flow almost exclusively through the sandstone. However, it could circulate down into the discontinuous fractures in the Pahasapa Limestone, and back up into the sandstone, as long as it emerged at a point of lower energy gradient. (See figure 3a.)

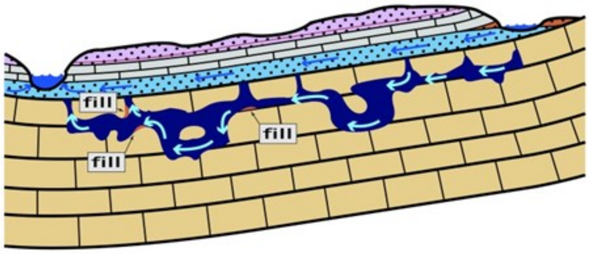
Stage 2 - The discontinuous nature of the fractures would result in isolated cells of dissolution, which would begin to coalesce as the nascent cave passages were enlarged. The basal Minnelusa sandstone would sometimes collapse into the still-developing cave passages. (See figure 3b.) This model anticipates the fill entering contemporaneously with cave development,



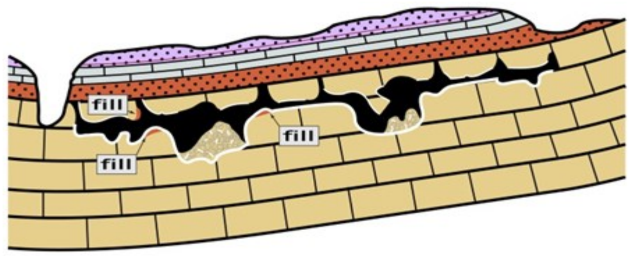
3a- **Stage 1** of cave development



3b - **Stage 2** of cave development



3c - **Stage 3** of cave development



3d **Stage 4** of cave development

Figure 3. Stages of cave development

rather than 300 million years earlier, so the fill is best described as *neofill*, rather than *paleofill*.

Stage 3 - Once Hell Canyon (and Lithograph Canyon) had cut all the way through the sandstone aquifer, the sandstone would drain and stop functioning as a confined aquifer, and the water remaining in the Pahasapa would be essentially stagnant. Unenlarged fractures may have slowly drained water from the cave. Once air entered the aquifer, the water would begin to degas. This would cause cave water to become supersaturated, and precipitate the ubiquitous calcite spar on cave surfaces. (See figure 3c.)

Stage 4 - As the water drained, buoyancy was removed, and many of the larger rooms collapsed into piles of breakdown. (See figure 3d.) With further draining, air connections became more integrated, and barometric air flow became more prominent.

Timing

Using known physical parameters and estimating hydrological and chemical properties, a calculation estimates 1.1 million years as the minimum amount of time for the cave to form. The deposition of calcite spar essentially marked the end of cave development. A pair of U/Pb dates at suggests that the spar began forming later than 26 ma, probably around 15 ma. Since the $CaCO_3$ equilibrium is controlled by dissolved CO_2, once the CO_2 was removed, the precipitation would have become irreversible, and might have taken only a few hundred years. Depending on the nature of the older dated substrate, the cave could have formed as recently as 15 million years ago.

Orthoquartzite clasts are found along the western and southern flanks of the Black Hills, but no local source has been found. The clasts are scattered across 1,500 square miles around western and southern flanks of the Black Hills, from 7,000 to 3,700 feet elevation. They crosscut several stratigraphic units, so are one of the newest features of the landscape. Three clasts have been found in Jewel Cave. One is beneath, and therefore older than, the spar. This supports a geological recent origin for the cave.

Conclusions

The model is geomorphically compatible with surface and cave features. It explains the development of cave passages with 1) no direct recharge from meteoric water, 2) no hydrothermal recharge from below, and 3) no paleokarst origins. The cave could have formed in as little as 1.1 million years, as recently as 15 million years ago.