

Mapping Jewel Cave – From the Surface

Natural caves are extremely sensitive to disturbances of the ground surface and drainage. Cave resources are subject to destruction by blasting, and alterations in the percolating water supply can affect the development of speleothems and other structures. Even more susceptible to influence is the unique subterranean biota, whose survival can be endangered by changes in cave temperature and moisture. Thus, in planning new roads, buildings, wells, and waste facilities, it is important to ensure that an underlying cavern environment will not be jeopardized.

Toward this end, we tested a promising geophysical technique in Jewel Cave National Monument (JCNM) – a technique that could assess the possible existence of undiscovered caverns beneath a proposed construction area. Earlier surveys using the natural-potential (N-P) method had demonstrated its effectiveness in areas of low relief; the much more severe terrain of the Black Hills provided an especially rigorous test of this procedure.

Geologic and Hydrologic Background

JCNM is situated 21 km west of Custer, SD. The known cave – over 132 km (82 miles) – lies beneath a 5 km² area (2 land sections) of a broad plateau, dissected by steep-walled Lithograph and Hell Canyons (Fig. 1). Average elevation is 1600 meters (5200 feet), with about 120 m of relief. Hilltops form broad, flat meadows, while the slopes are typically forested with Ponderosa pine. Neither canyon maintains a stream flow, even during the heaviest rains.

The cave-bearing formation is a buff, massive dolomitic limestone (Pahasapa of Mississippian age), about 120 m thick. Unconformably overlying this unit is the lower third of the Pennsylvanian Minnelusa formation, containing 60 m of red sandstone, limestone, and thin beds of chert and shale. Both units occupy the vadose zone.

Jewel Cave is a 3-dimensional rectilinear maze (Fig. 2) of phreatic origin (pertaining to that layer of rock or soil through which water may enter wells or from which



Figure 1. Reading the natural potential on a slope of Hell Canyon directly outside the natural portal of Jewel Cave.

springs and seeps may emerge). Its 5 distinct levels have developed generally within the upper half of the limestone. Most of the known passages lie beneath the Minnelusa cap and are completely dry. The Minnelusa apparently prevents or retards direct seepage of rain and snow melt. Erosion has removed the Minnelusa from portions of Hell and Lithograph Canyons, exposing the Pahasapa. Galleries beneath these areas usually are dry, though dripstone testifies to past infiltration. Present-day seepage is occasional, sporadic, and extremely localized. Most water enters the cave in areas directly below the contact of the Pahasapa and Minnelusa. There, dripping generally occurs year round, although drip rates vary seasonally.

Natural-Potential Phenomena

Just as our atmosphere everywhere is filled with invisible electromagnetic waves – from radio and TV broadcasts as well as emissions of our sun and stars, so the ground contains both a.c. and d.c. electric currents. Electromagnetic signals generated by worldwide lightning and solar storms penetrate the ground to depths dependent on their frequencies.

Likewise, d.c. currents circulate through the ground from causes as diverse as chemical reactions around mineral deposits, volcanic heating, and moving groundwater. The individual sources form an assemblage of “geo-batteries” of all different sizes and orientations. The natural-potential method measures the voltages generated by these currents along surface profiles, using a roving electrode tied through a long cable and meter to a fixed base electrode.

At this point, one might wonder how a cave can produce a battery-like current. Actually there are several ways a cave can affect the natural electrical environment. In one of these, an empty cave gallery provides a locally more permeable path for infiltrating water, with the result that greater infiltration occurs over the cave roof than the surrounding rock. Because of the electrokinetic, or streaming, phenomenon (Ishido and Mizutani, 1981), the cave ceiling becomes positively charged relative to the ground surface, while the surface zone overlying the cavern becomes more

negatively charged than its surroundings (when the fluid chemistry is basic). Thus, a negative potential anomaly develops locally over the cavern (Lange and Quinlan, 1988). In Jewel Cave, where drippage pH averaged 8.35 (Bakalowicz et al. 1987), the cave ceiling measured almost 250 millivolts (mV) more positive than its corresponding point on the surface, 40 m over-head.

Because the voltage anomalies observed over caverns can be small – on the order of 5 to 50mV, meticulous data collection procedures and precision instrumentation are required. The end result is a computer-drawn graph of voltage and elevation vs. horizontal distance along each profile (Fig.3) and where lines are closely spaced, a plan map of potential contours.

The Jewel Cave Survey

Prior to using any geophysical method as an exploration tool for extending a cavern system beyond its known limits, one should test the method over at least one mapped passage, to see whether the technique can resolve the underlying void. Fortunately, at Jewel Cave a detailed map of the system was available, and passage depths had been established. Thus, four lines, ranging up to 840 m in length, were laid out in a NNE direction so as to cross the “grain” of the maze at nearly right angles (Fig.2).

Representative portions and depths of cave system were selected. On each line, a base station was established near a road, and a long, color-calibrated wire was spooled out to the ends of the line. Multiple potential readings were made at station intervals ranging from 1 to 7.5 m, as data warranted, and corrections were made to remove drift due to temperature fluctuations in the soil and electrodes (Fig.1).

Jewel Cave Anomalies

Definitive negative anomalies coincided with the cave passages, wherever the test lines crossed over cave passages. Line B is typical of this correlation (Fig.3). Here, the edges of the broad central low response correspond to the north/south limits of the mapped cave. Except for the northern ends of the profile, the remainder of the line is positive. The exception occurs around the main highway junction, where a nearly east/west fault crosses the line (Deal, 1962). Although N-P expressions of faults are common, it also is possible that additional undiscovered cave galleries underlie this feature.

It is instructive to ask what would be the result of placing a drilling target over the maximum negative value of the profile. On Line B, such a drill hole would intercept a major lower level of the cave system at an estimated depth of 140 m.

The three other profiles likewise showed a definitive correlation of millivolt lows with mapped cavern. As on Line B, negative readings also expressed fault zones. All in all, the natural-potential profiles delineated more than 90 percent of the mapped cavern crossed by the lines. As mentioned above in the section on hydrology, much of the cave today remains dry, suggesting that mechanisms other than downward filtration are contributing to the anomalies observed over the cavern.

Exploration Scenario

In practice, one would not necessarily target a test hole on the negative peak. For one thing, the N-P response can express voids situated on either side of the line. In order to better resolve the target, several short potential lines would be run offset from the first to

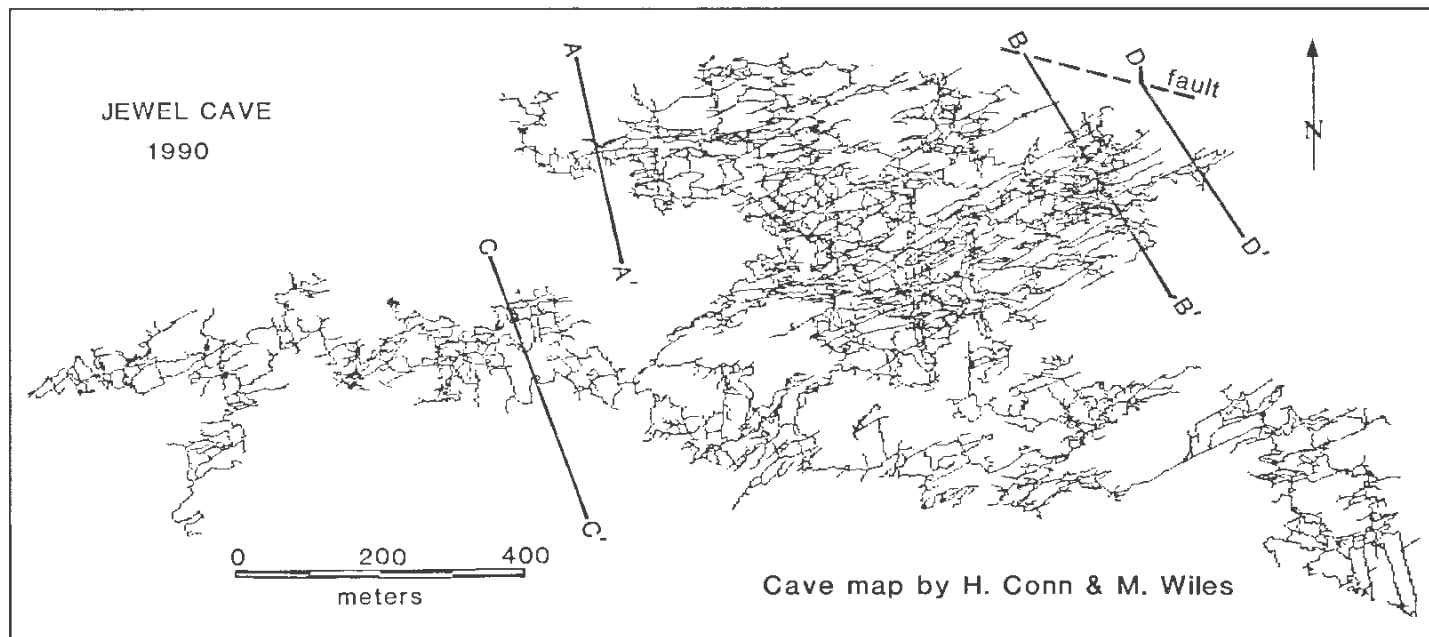


Figure 2. Computer-drawn map of the known 132-km extent of the Jewel Cave labyrinth, showing the natural-potential lines and a segment of a major fault that intercepts two of the lines.

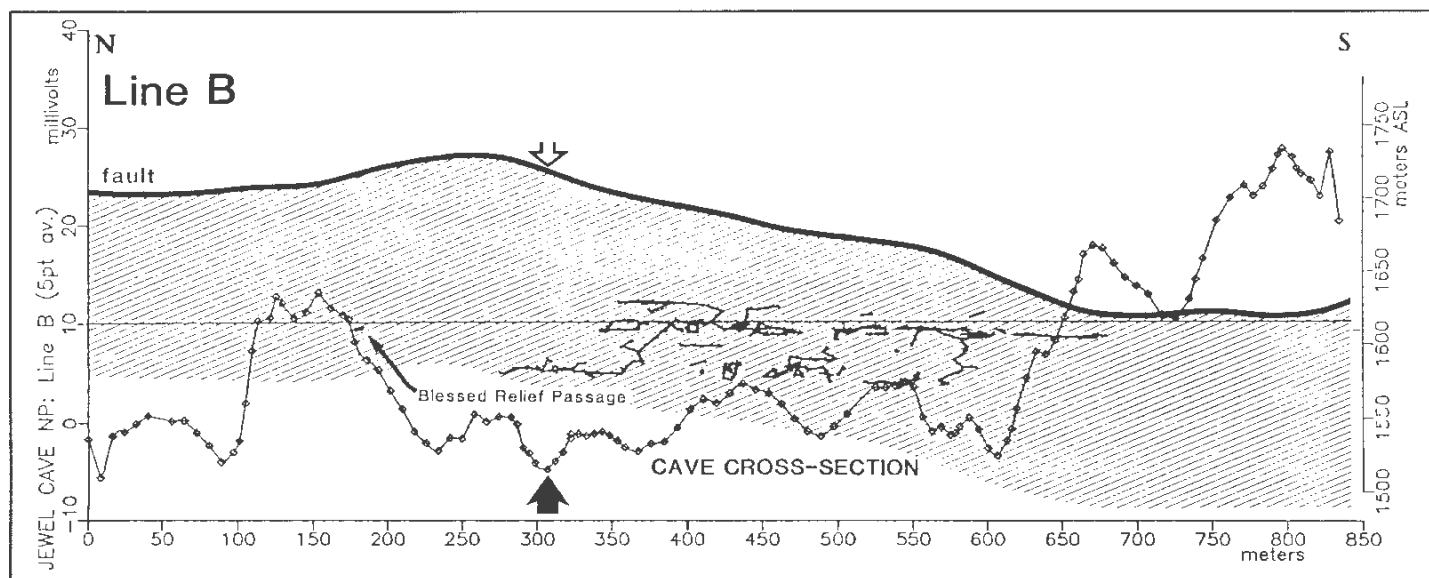


Figure 3. Natural-potential profile of Line B superimposed on a cross section of topography and cave. The major N-P low coincides closely with the region of mapped cave; a secondary low is associated with a major fault zone, which may possibly contain voids. A drill hole sighted at the open arrow, corresponding to the lowest potential value of the line (solid arrow), would intercept a cave passage at a depth of about 140 m (~460 ft).

map the response on either side.

Because N-P anomalies, both positive and negative, can arise from processes other than water movement around voids, it is advisable to test the N-P targets by means of another geophysical method. The gravity method is most appropriate since it responds directly to low density zones and voids underground (Neumann, 1967). Unfortunately, the method requires precise surveying of ground elevations, and mapping of nearby topography. In addition, it loses resolution as the target depth exceeds the width of the void, so that the deeper passages may not be resolvable. For these reasons, one would confine the gravity measurements to the N-P target zones, rather than attempting to sample the entire area.

Other Natural-Potential Tests Over Caves

The senior author began applying N-P techniques to caves in 1986 over the Ozark Underground Laboratory,

Protem, MO. Three test lines produced a strong correlation of negative anomalies with mapped cavern. Since that first trial, tests have been made in environments as diverse as the Mammoth Cave area in Kentucky (Lange and Quinlan, 1988), the Edwards aquifer of Texas, the Great Basin of eastern Nevada and desert outcrop of Kartchner Caverns State Park, AZ (Lange et al., 1990). Especially pronounced anomalies have been observed over underground streams, making "natural-potential" the logical targeting tool for siting monitor wells over groundwater conduits in carbonate terrains. Ongoing research is focusing on the electrochemical processes that generate cavern anomalies.

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