Prepared in cooperation with the National Park Service

Groundwater Characterization of the Madison Aquifer near Jewel Cave National Monument, South Dakota

Introduction

Jewel Cave National Monument in the Black Hills of southwestern South Dakota (fig. 1) has more than 200 miles (mi) of mapped cave passages (figs. 2–3; https://www.nps.gov/jeca/index.htm) and several subterranean lakes ("cave lakes") that have been discovered since 2015 (Anderson and others, 2019; U.S. Geological Survey, 2019). Jewel Cave is one of the world's longest known caves (Long and others, 2019). Its natural beauty and unique natural cave features led U.S. President Theodore Roosevelt to designate the cave as a national monument in 1908 (KellerLynn, 2009). Jewel Cave was naturally formed in the regionally extensive Madison Limestone, which is characterized as a carbonate karst environment (containing caves and sinkholes) with extensive subterranean cave networks and losing streams at the land surface (Long and others, 2019). The Madison aquifer is a major aquifer in the Black Hills area and generally occurs in the upper karstic part of the Madison Limestone, where numerous fractures and solution openings are present (Carter and others, 2002).

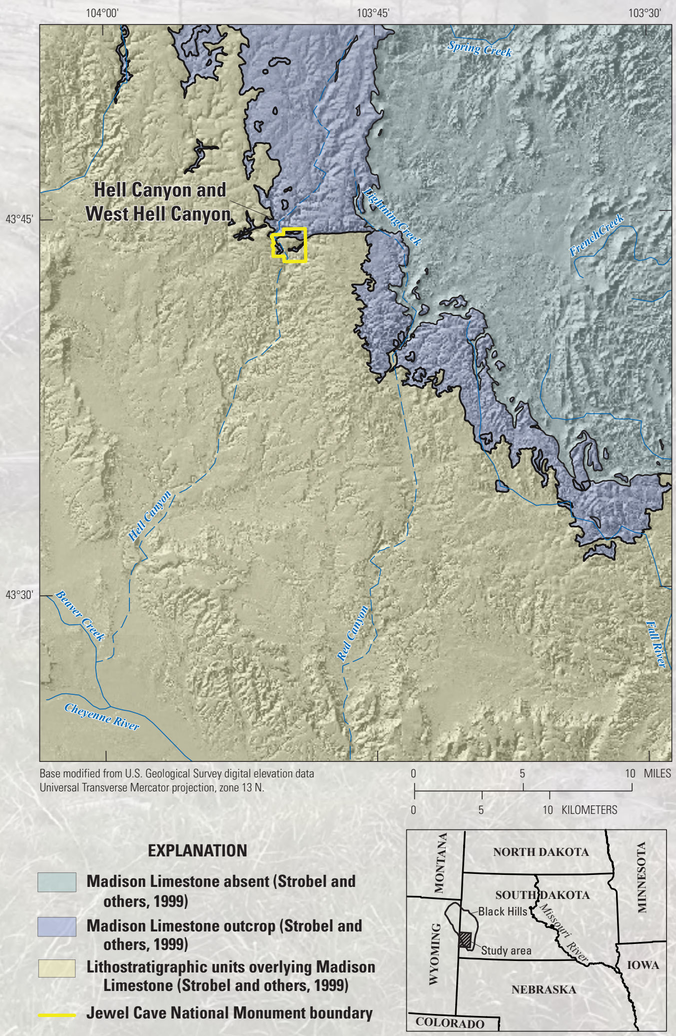

Figure 1. The study area showing the Jewel Cave National Monument park boundaries and areas where Madison Limestone is exposed at the land surface, South Dakota (modified from Anderson and others, 2019).

Figure 2. Cave explorers celebrate the mapping of the 200th mile in Jewel Cave National Monument in 2018. Photograph courtesy of the National Park Service.

Preserving and protecting the cave is an important element of the National Park Service mission (https://www.nps.gov/aboutus/index.htm). Understanding the hydrogeologic connection between the surface and the subsurface is essential for ensuring the preservation and protection of the cave for future generations. The National Park Service and U.S. Geological Survey have partnered to better characterize the hydrogeologic network near Jewel Cave and to highlight the interconnection between the surface water (fig. 4) and groundwater of the area. The highly interconnected surface-water and groundwater resources make the area highly vulnerable to aquifer contamination from human activities at the surface (Long and others, 2019). Improved understanding of groundwater flow and vulnerability of the Madison aquifer allows scientists, park managers, the visiting public, and the surrounding communities to better manage, protect, and preserve the site and its unique natural features.

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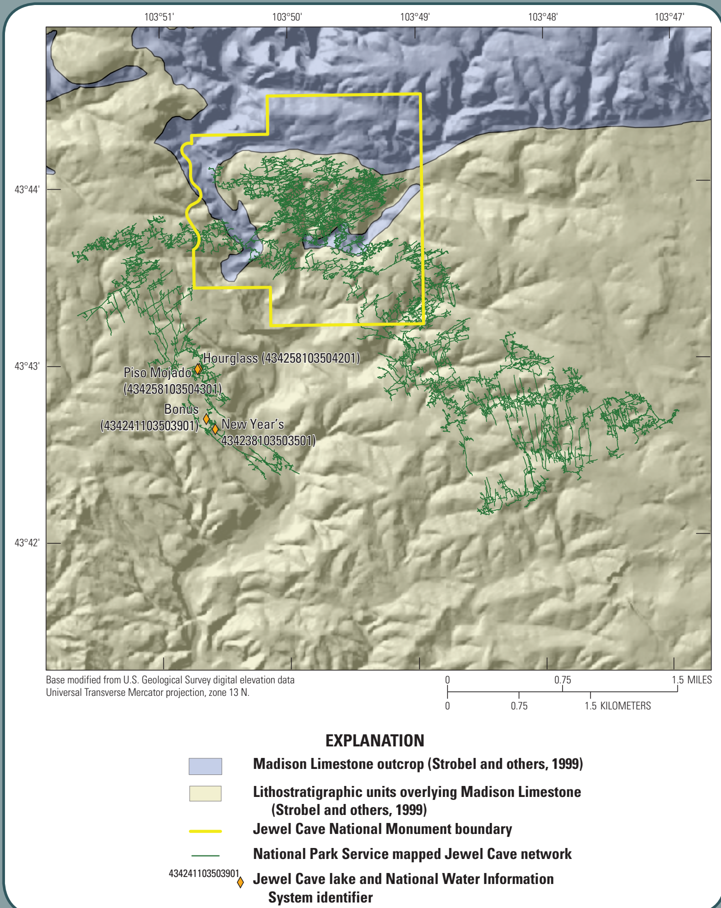

Figure 3. The mapped cave network and subterranean cave lakes near Jewel Cave National Monument, South Dakota (modified from Anderson and others, 2019).

Figure 4. Prairie Dog Spring near Jewel Cave National Monument. The background shows evidence of the August 2000 Jasper Fire that ignited just west of Jewel Cave and burned nearly 84,000 acres within the surrounding forest. Within Jewel Cave National Monument, it burned about 90 percent of the land and destroyed about one-half of the trees (https://www.nps.gov/jeca/learn/nature/jasperfire.htm). Photograph courtesy of the National Park Service.

Background and Discoveries

The study area is in the southwestern Black Hills in southwestern South Dakota and includes about 1,000 square miles surrounding Jewel Cave National Monument (fig. 1). The Madison aquifer has been researched extensively by others including regional maps published by Downey (1984) and local maps published by Strobel and others (2000), Carter and others (2002), Putnam and Long (2007, 2009), and Long and Valder (2011). With each completed study, scientists learn more about the Madison aquifer, which aids in preserving and protecting the important natural resources in the Black Hills.

For more than 60 years, volunteers for the National Park Service ventured into Jewel Cave to continue exploration and discovery, and until 2015, no cave lakes had been discovered. The first cave lake, Hourglass Lake (fig. 5), was discovered on October 10, 2015. Since then, several additional cave lakes have been discovered as cavers continue to explore uncharted parts of the cave (figs. 6 and 7). The discovery of cave lakes within the primarily dry passages of Jewel Cave has afforded a unique opportunity to study the Madison aquifer. Understanding groundwater conditions near Jewel Cave is a primary step taken to better characterize the interactions between the aquifer and the network of cave passages.

Figure 5. Discovery of the first cave lake, Hourglass Lake, in Jewel Cave National Monument. Photograph courtesy of the National Park Service.

Wind Cave National Park (https://www.nps.gov/wica/index.htm), which is about 20 mi southeast of Jewel Cave, has several subterranean lakes in the Madison Limestone. The Wind Cave National Park lakes were discovered in the 1960s, and continued monitoring and modeling of nearby precipitation data and cave lake levels have yielded valuable information about the hydrologic properties of the Madison aquifer (Long and others, 2012, 2019). The additional discoveries of cave lakes at Jewel Cave allow more comprehensive studies to be completed in the southern Black Hills to better understand the high interconnectivity of surface-water and groundwater resources of the Madison aquifer.

Figure 6. Discovery of New Year's Lake in Jewel Cave National Monument. Photograph courtesy of the National Park Service.

Figure 7. Discovery of Piso Mojado Lake in Jewel Cave National Monument. Photograph courtesy of the National Park Service.

Groundwater Characterization of the Madison Aquifer

Groundwater characterization of the Madison aquifer consisted of analyzing well hydrographs (graphs that show the variation of groundwater elevation), developing a groundwater potentiometric map (a map representing the hydraulic head, which is the elevation to which water would rise in a tightly cased well), and interpreting groundwater flow near Jewel Cave (Anderson and others, 2019). In general, groundwater conditions near Jewel Cave consist of confined and unconfined regions of the Madison aquifer. The confined region is where the Madison Limestone is overlain by a confining unit, which is a low permeability geologic unit that impedes the vertical movement of water. A confined aquifer contains water that would rise above the top of the aquifer in a penetrating well (also known as an artesian aquifer) and is where the aquifer is fully saturated. An unconfined aquifer is an aquifer in which the water table is exposed to the atmosphere through openings in the overlying materials. The Madison aquifer is under artesian pressure over most of its regional extent but does not have flowing well conditions because the potentiometric surface is below the land surface. However, the aquifer is unconfined in areas where the Madison Limestone is exposed at the land surface, and generally, for a short distance downgradient from the outcrop area. In the southwestern Black Hills, the Madison aquifer is unconfined (not fully saturated) for a distance of about 6 mi downgradient from the outcrop area (Carter and others, 2002).

Water levels measured (fig. 8) in 24 wells and 4 cave lakes are presented in Anderson and others (2019). Hydrographs of changes in water levels in four observation wells (fig. 9) represent confined and unconfined regions of the Madison aquifer and were used to develop the potentiometric-surface map (fig. 10). Water-level data from calendar years 1980 to 2019 from 24 non-observation wells in the study area were also used to construct the potentiometric-surface map of the Madison aquifer. All water-level data used for this study are available from U.S. Geological Survey (2019).

Figure 8. U.S. Geological Survey hydrologist measuring the depth to water in a well near Jewel Cave National Monument.

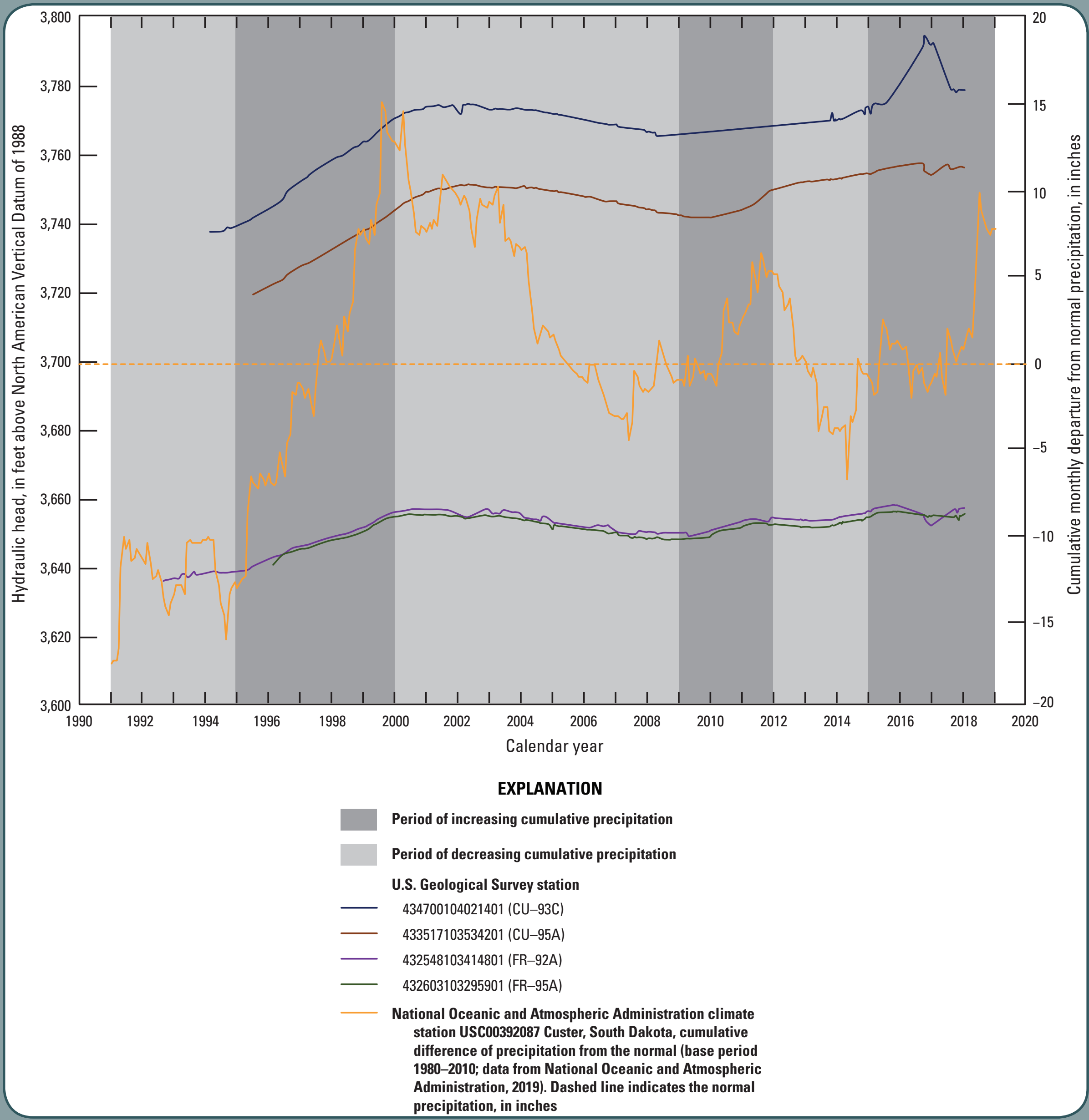

Figure 9. Water-level hydrographs for observation wells near Jewel Cave National Monument, South Dakota (from Anderson and others, 2019).

The potentiometric-surface map was used to interpret the groundwater-flow directions in the study area (fig. 10). Groundwater-flow directions are typically assumed to be perpendicular to the potentiometric contours; however, because of the extensive karst (cave) network, groundwater flow might not actually be perpendicular to potentiometric contours because of the anisotropic permeability arising from cave and fracture orientations in the karstic Madison aquifer (Greene and Rahn, 1995). The potentiometric surface and interpreted groundwater-flow directions indicate that groundwater near Jewel Cave originates from recharge to the Madison aquifer in the higher elevations in the north-central Black Hills, flows south-southwest through Jewel Cave National Monument, and then flows southeast (fig. 10; Anderson and others, 2019). Interpretation of the groundwater-flow direction is limited to the data that are available. There are areas near Jewel Cave where the inferred potentiometric contours pass through known unsaturated areas of the Madison Limestone (Anderson and others, 2019), which is likely a result of the interpolation of the potentiometric surface because of sparse data. For example, the wells at Jewel Cave National Monument are completed in the Deadwood Formation and are used as the primary source of water for the National Park because the Madison Limestone within the park is nonwater bearing (Dyer, 1961; South Dakota Geological Survey, 2019). In addition, Hell Canyon and West Hell Canyon (fig. 1), north of Jewel Cave, expose a section of the nonwater-bearing Madison Limestone at the surface (Redden and DeWitt, 2008).

The discovery of the cave lakes in 2015 has allowed the National Park Service and the U.S. Geological Survey to study the Madison aquifer near Jewel Cave, where historical information is sparse. The volunteer explorers of Jewel Cave (fig. 2) continue to discover and map cave passages further and deeper into unexplored areas. The discovery of the cave lakes continues to be an effective means for mapping groundwater surfaces and interpreting the groundwater-flow direction near Jewel Cave National Monument.

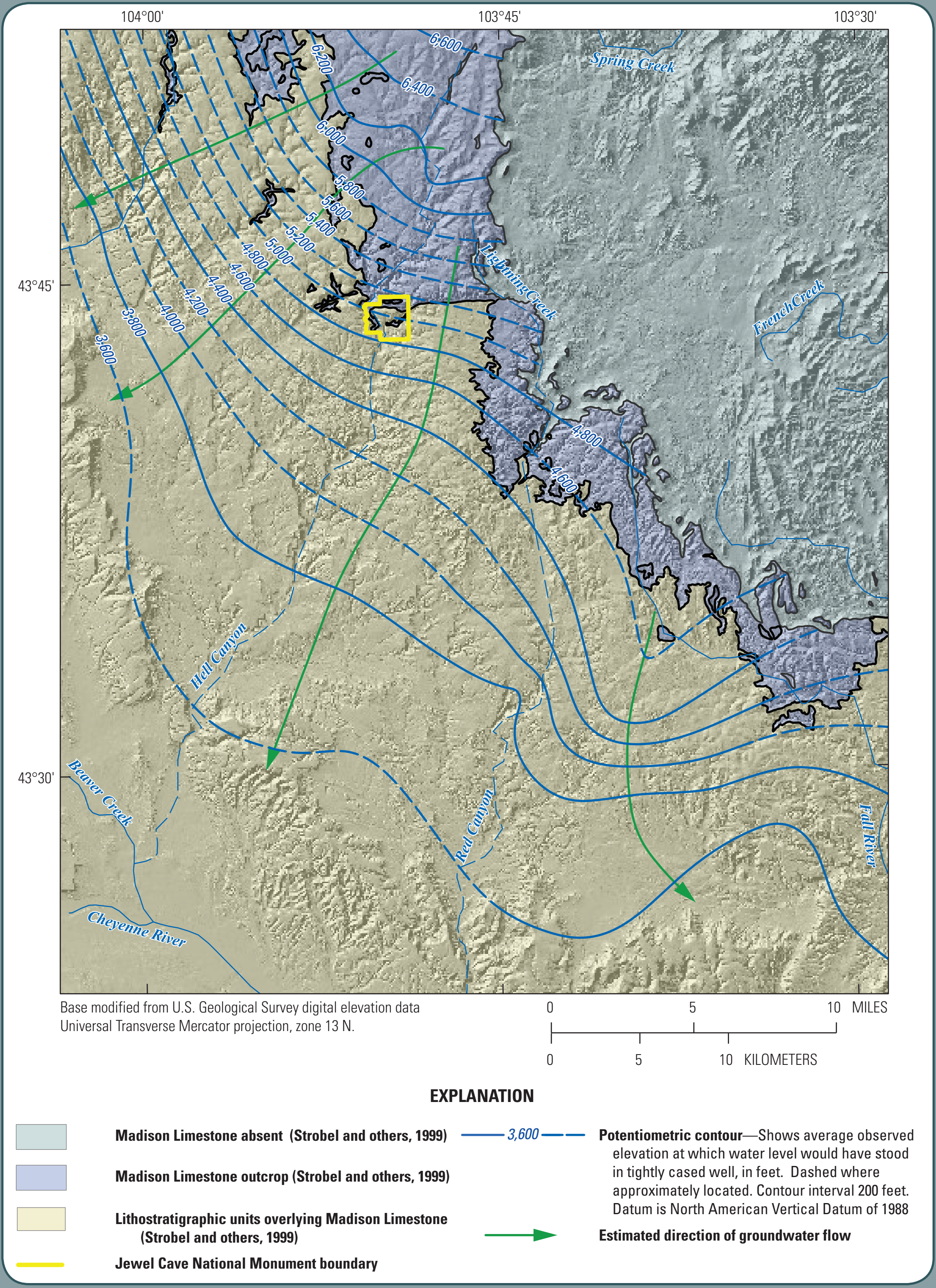

Figure 10. The potentiometric surface and direction of groundwater flow in the Madison aquifer near Jewel Cave National Monument, South Dakota (modified from Anderson and others, 2019).

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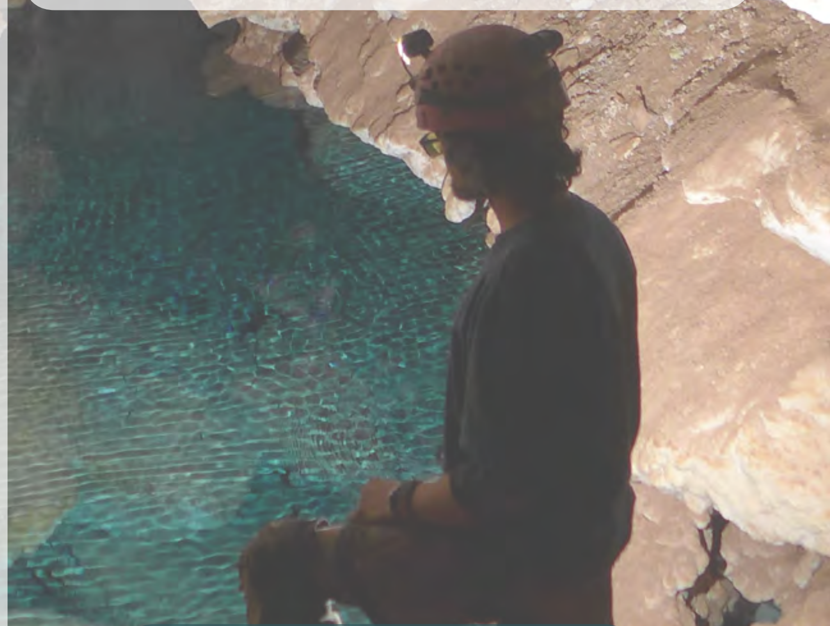

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