Cave and Karst Resources Summary

Montezuma Castle National Monument

Arizona

Compiled by Limaris Soto & Dale Pate

December 30, 2013

Geologic Features and Systems Branch - Geologic Resources Division
National Park Service - Natural Resources Stewardship and Science

Location & Area

Montezuma Castle National Monument (Monument) is located in the south-central part of the Verde Valley in Yavapai County, Arizona (Tweet et al. 2008) and consists of two distinct units: the Montezuma Castle Unit and the Montezuma Well Unit. The Montezuma Castle Unit encompasses 276 ha (734 acres) and the Montezuma Well Unit encompasses 111 ha (276 acres) for a total combined area of 408 ha (1,010 acres) (NPS 2006; Matthew Guebard, Chief of Resource Management written communication 10 February 2014).

Geology

Both units of the Monument are part of the Central Highlands of Arizona. The Central Highlands is a transition zone between two physiographic provinces: the Basin and Range to the south and west and the Colorado Plateau to the north and east. A distinctive feature of the Central Highlands is the Mogollon Rim, which extends more than 321 km (200 mi) from the White Mountains in eastern Arizona to the headwaters of the Verde River on the western side of the state (NPS 2006).

Stretching for many miles throughout the Verde Valley are dazzling white, flat-lying limestone beds that have been dissected by the Verde River and its tributaries. Ancient cliff dwellers built their homes in the projecting shelves of the limestone bluffs that border the rivers and they farmed the fertile lowlands below (Sense 1958). Pre-historic communities flourished within both units of the Monument.

The Monument preserves rocks from late Cenozoic (66 million years ago) and younger events. Most of the rocks at the Monument are limestone and other lake rocks of the Verde Formation (Middle Miocene-Pliocene) (13.8 million years ago) and Quaternary (2.6 million years ago) terrace gravel and alluvium from Beaver Creek (Tweet et al. 2008).

The Middle Miocene-Pliocene Verde Formation is a heterogeneous formation formed from a combination of tectonics, volcanism, and the action of the Verde River, with much of its deposition due to the river being tectonically dammed and turned into a lake (Nations et al. 1981; Tweet et al. 2008). The deposition of the formation began in the Miocene (23 million years ago) with unfossiliferous clastic material leading to limestone, dolomite, and evaporites later in the Miocene, followed by mostly limestone deposition in the Pliocene (5.3 million years ago). Spring deposits, as at Montezuma Well, are also present.

Caves and Karst

Montezuma Castle Unit: The large prehistoric structure known as Montezuma Castle was built within a large shelter cave or alcove that was formed and enlarged via spalling of the rocks from the ceilings and walls. Spalling is associated particularly with wet periods (Tweet et al. 2008).

Montezuma Castle (NPS Photo)

Montezuma Well Unit: The one cave known within the Monument (Swallet Cave) is found within the Montezuma Well Unit (Ek, 2001). This cave is directly associated with Montezuma Well, which is a significant karst feature. Montezuma Well is a natural spring and is located within a circular, collapsed travertine spring mound that maintains a near constant environment with warm temperatures, high alkalinity, and high concentrations of dissolved carbon dioxide (CO_2) (Blinn and Oberlin 1996). The well encloses an area of 0.76 ha (1.8 acres) with a diameter of 112 m (367.4 ft.) and a mean depth of 6.7 m (21.9 ft.) (Wetzel et al. 1999). Montezuma Well contains a lake which in 1947 at its deepest point was 16.8 m (55 ft.) and contained white sand that probably marked the source of the water flowing into the lake. Most of the lake bottom was covered in mud and ooze (Lange, 1957).

In the Verde Formation, the Well is unusual among karst features of western United States because it is one of the few large solution cavities formed in relatively recent limestone (Lange 1957). The spring emanates from volcanic fluvial and lacustrine deposits of the mostly calcareous Verde Formation (Wetzel et al. 1999). The raised rim surrounding Montezuma Well limits materials from outside the well from entering the system. The deposits through which water flows before entering the well yield high concentrations of dissolved solids. Water exits through a sidewall opening (swallet and solution cavern) at the southeastern margin, then traverses the cave that extends approximately 60 m (196.8 ft.) through travertine deposits before emerging 5 m (16.4 ft.) lower into an irrigation ditch originally constructed by prehistoric inhabitants (Wetzel et al. 1999). Over the years, the ditch has become cemented with calcium carbonate (Lange 1957).

Montezuma Well (Google Earth image accessed 13 February 2014).

Archeological/Cultural Resources

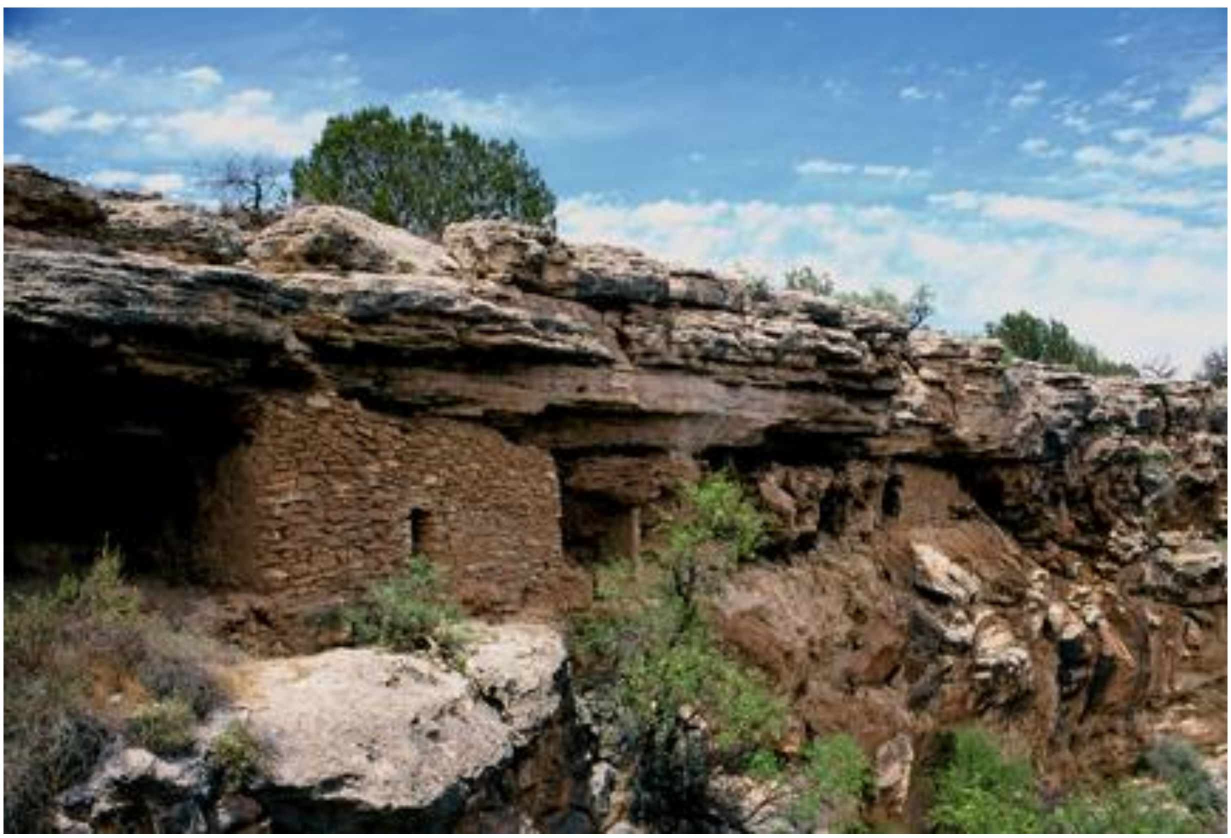
Montezuma Castle National Monument preserves 12th to 14th century Sinagua culture cliff dwellings and artifacts (Tweet et al. 2008; Matthew Guebard, Chief of Resource Management written communication

10 February 2014). The primary archeological sites at MOCA are located in cliff dwellings in the Verde Formation.

Montezuma Castle Unit: In 1896, Cosmos Mindeleff conducted the first archeological survey at Montezuma Castle.

In 1933 and 1934, a cliff dwelling west of Montezuma Castle was excavated. The two-part report describes the excavation of nine rooms and explains that the cliff dwelling may once have had as many as 45 rooms arranged in five tiers (Jackson et al. 1954; Kent 1954).

Montezuma Well Unit: Before being acquired by the National Park Service, extensive excavations had been made in ruins found in Swallet Cave, which is located under the rim of Montezuma Well. A study by the NPS in Swallet Cave showed that the site was occupied from after 1160 to about 1275 and certainly ending by 1300. Included in the excavations were human burials, stone implements, chipped stone tools, miscellaneous items of stone, bone implements, shell ornaments, pottery, and miscellaneous unworked animal and vegetal material (Ladd 1964; Matthew Guebard, Chief of Resource Management written communication 10 February 2014).



Pre-historic structures built in shallow shelter caves known locally as alcoves, below the rim of Montezuma Well. (NPS Photo)

Biological

There are at least seventeen species of bats known from both units within the Monument. This includes the Brazilian free-tailed bat (*Tadarida brasiliensis*), pallid bat (*Antrozous pallidus*), big brown bat (*Eptesicus fuscus*), spotted bat (*Euderma maculatum*), Allen’s big-eared bat (*Idionycteris phyllotis*), twestern red bat (Lasiurus blossevillii), eastern red bat (*Lasiurus borealis*), hoary bat (*Lasiurus cinereus*), southwestern myotis (*Myotis auriculus*), California myotis (*Myotis californicus*), eastern small-footed myotis (*Myotis leibii*), little brown bat (*Myotis lucifugus*), fringed myotis (*Myotis thysanodes*), cave myotis (*Myotis velifer*), yuma myotis (*Myotis yumanensis*), western pipistrelle (*Pipistrellus Hesperus*), and Townsend's big-eared bat (*Plecotus townsendii*) (NPSpecies website).

A biological study of the bat occurrence and use of archeological sites at the Monument was conducted by Bucci and others (2011). Results show that bats are using archeological sites mostly as night roosts, as indicated by the presence of small accumulations of guano.

<u>*Montezuma Castle Unit:*</u> A recent unpublished study has shown that there is some damage to wood and earthen architecture at Montezuma Castle cliff dwelling (Matthew Guebard, Chief of Resource Management written communication 10 February 2014). There was no evidence that bats, bat urine, or bat guano have damaged the structural integrity of the sites. The data also indicated that bats used the site mainly during the summer months (May through September) when bat activity was highest. The largest accumulation of guano was found in the five-story cliff dwelling and the study recommended the removal of guano each year to prevent a large build-up that could potentially compromise the structural integrity of the site (Bucci et al. 2011).

<u>*Montezuma Well Unit:*</u> Montezuma well contains unique organisms which have evolved in response to the unique mineralization of water (MOCA website). Montezuma Well has a nearly constant environment, which creates a very stable biotic community and contains 94 invertebrate taxa. The diversity of species is low, however, with a few abundant taxa dominating invertebrate densities, which might be due to the unusual physicochemical properties found in the well (Blinn and Oberlin 1996).

Dehdashti and Blinn (1986) reported a freshwater bryozoan; *Plumatella repens* L. (Ectoprocta) from Swallet Cave. The study indicates that colonies of *P. repens* flourish within Swallet Cave and feed on the constant supply of nannoplankton that continually passes through the cave. In addition, the absence of animals anywhere within the well or in the outside ditch system may have also provided an environment with minimum predation pressure on the bryozoan colonies within the cave (Dehdashti and Blinn 1986).

The aquatic annelid oligochaeta of Montezuma Well was examined from 1987 to 1996 to determine the presence of this specialized habitat. Due to the high dissolved CO_2 concentrations, fish have never been reported from the well. Results show over 500 specimens of oligochaetes representing 11 taxa and three families. All 10 identified species represented new records for the state of Arizona. The occurrence of *Varichaetadrilus angusti- peni* also represents the westernmost locality for this rare Nearctic species (Wetzel et al. 1999).

Hydrological

A Baseline Water Quality Data Inventory and Analysis study was completed for both units of the Monument. Results of the water quality criteria screen found three parameters that exceeded screening criteria at least once within the study area. Copper exceeded the Environmental Protection Agency (EPA) acute criterion for the protection of freshwater aquatic life. Arsenic and lead exceeded their respective EPA drinking water criteria. Based on the data inventories and analyses, surface waters within the study area generally appear to be of good quality, with some indications of impacts from human activities. Potential sources of contaminants include urban land use and mining operations (NPS 1995).

Montezuma Well Unit: The source(s) of groundwater and associated groundwater flow paths to Montezuma Well are poorly understood. Initially, it was believed that a meteor impact or a collapsed volcanic cinder cone created the well; however, as early as 1906 researchers have known that Montezuma Well is actually a limestone sinkhole (Lange 1954).

Montezuma Well is a spring-fed sinkhole on the north bank of Wet Beaver Creek (Johnson et al. 2011). The majority of the groundwater recharge in the well occurs in the topographically high area of the Mogollon Rim. Recharge through the Mogollon Rim follows fractures in the cover basalt and the underlying Permian sandstones and then flows rapidly through the karstic Mississippian (359 million years ago) Redwall Limestone at depth (Johnson and Dewitt 2009).

Johnson and Dewitt (2009) inferred that the groundwater flow and geochemistry of Montezuma Well are affected by the presence of a basalt dike underneath the Well. This basalt dike appears to be a barrier for regional groundwater flow and the focus for a component of deep-seated groundwater flowing upward along bedrock fractures. The presence of this dike and fracture system forces the groundwater flowing at depth to the surface resulting in the discharge to the Well. In addition, the fracture system appears to contribute a small amount of brine related to volcanic degassing. This brine contains carbon dioxide, salts, and trace elements such as arsenic. The increased carbon dioxide dissolves limestone at depth, which subsequently helps to maintain open fractures and probably created the cavity that forms Montezuma Well. The degassing of carbon dioxide at the surface causes travertine deposition, seen presently at the irrigation ditches (Johnson and Dewitt 2009).

Increasing population and associated residential and commercial development have greatly increased water use and consumption in the Verde Valley near Montezuma Well. Data on flow from Montezuma Well and water levels in eight wells measured in 1990 do not indicate that the ground-water system has been affected by the development. However, the mechanisms for inflow from the Verde Formation are not quite understood. The study concluded that the Verde Formation, Supai Formation, and other underlying rock units are probably the sources of water to Montezuma Well. The study concluded that more data related to system flow quantities hydraulic properties, and physical characteristics were needed before a predictive model can be developed (Konieczki and Leake 1997).

A study by Johnson and others (2011) provided data on groundwater chemistry, rock data, geologic cross sections and groundwater flow modelling of the region to better understand the source of water flowing into Montezuma Well. This information will provide new details on the groundwater flow of the area to assist in future management decisions (Johnson et al. 2011).

Paleontological

At the Monument, the Verde Formation contains fossils that are limited and mostly found in the southern Verde Basin, with diatoms in the lower Miocene beds, and algae, diatoms, plants, mollusks, ostracodes, amphibians, rodents, artiodactyls, and mammal tracks in the upper beds. The mammal tracks include "Elephant Hill" at Montezuma Castle. The fossils at "Elephant Hill" are large footprints from proboscideans, and tracks of camelids, tapirs, antelope-like artiodactyls, and other unidentified animals (McGeorge and Schur 1994; Tweet et al. 2008). By the Pliocene, fossils from the Verde Formation include algae, diatoms, various parts of a variety vascular plants, gastropods, fish, turtles, bats, rodents, rabbits, camelids, equids, and proboscideans (Nations et al. 1981; Tweet et al. 2008). In addition, the Quaternary lake deposits of Montezuma Well are also fossiliferous, indicating climatic changes in the area with evidence that the lake had been very low or dry at several times (Tweet et al. 2008).

References

Blinn, D.W. and Oberlin, G.E. 1996. Analyses of the Biota in the Aquatic Habitats of Montezuma Castle National Monument. Department of Biological Sciences. Northern Arizona University, Flagstaff, AZ.

Bucci, M., Petryszyn, Y., and Krausman, P.R. 2011. Bat Occurrence and Use of Archeological Sites at Three National Monuments in Central Arizona. Journal of the Arizona-Nevada Academy of Science 43(1): 1-5.

Dehdashti, B. and Blinn, W. 1986. A Bryozoan from and Unexplored Cave at Montezuma Well, Arizona. The Southwestern Naturalist. 31(4): 557-558.

Ek, D.A., 2001. Caves and Karst of the National Park Service. Proceedings of the 2001 National Cave and Karst Management Symposium. Tucson, AZ. p. 16-32.

Jackson, E., Pierce, S.P., and Valkenburgh, V. 1954. Montezuma Castle Archeology, Part 1: Excavations. Southwestern Monuments Association. Technical Series 3(1). Gila Pueblo, Globe, AZ. http://www.nps.gov/history/history/online_books/moca/3-1/index.htm (accessed 6 January 2014).

Johnson, R.H. and DeWitt, E. 2009. The unique geology and geochemistry of Montezuma Well, a natural spring at Montezuma Castle National Monument, central Arizona. Geological Society of America Annual Meeting Portland, OR. Geological Society of America Abstracts with Programs, 41(7): 244.

Johnson, R.H., DeWitt, E., Wirt, L., Arnold, L.R., and Horton, J.D. 2011. Water and rock geochemistry, geologic cross sections, geochemical modeling, and groundwater flow modeling for identifying the source of groundwater to Montezuma Well, a natural spring in central Arizona: U.S. Geological Survey Open-File Report 2011–1063, 62 p.

Kent, K.P. 1954. Montezuma Castle Archeology. Part 2: Textiles. Southwestern Monuments Association. Technical Series, 3(2). Coolidge, AZ. http://www.nps.gov/history/history/online_books/moca/3-2/index.htm (accessed 6 January 2014).

Konieczki, A.D. and Leake, S.A. 1997. Hydrogeology and Water Chemistry of Montezuma Well in the Montezuma Castle National Monument and Surrounding Area, Arizona. Water-Resources Investigations Report 97-4156. U.S. Geological Survey, Tucson, AZ.

Ladd, E. 1964. Excavation of Swallet Cave. Project MOCA A2. National Park Service.

Lange, A. 1957. Studies on the origin of Montezuma Well and Cave, Arizona. Cave Studies. 1(9): 31-44.

Montezuma Castle National Monument, Arizona. Nature and Science. National Park Service. http://www.nps.gov/moca/naturescience/index.htm (accessed 6 January 2014).

National Park Service. 1995. Baseline Water Quality Data Inventory and Analysis Montezuma Castle National Monument. Technical Report NPS/NRWRD/NRTR-95/58. Water Resources Division. Fort Collins, CO.

National Park Service, Geologic Resources Division. 2006. Geologic Resource Evaluation Scoping Summary: Montezuma Castle National Monument, Arizona. U.S. Department of the Interior, National Park Service, Washington, D.C.

NPSpecies website. Information on Species in National Parks, Part of IRMA. https://irma.nps.gov/NPSpecies/Search/SpeciesList/MOCA (accessed 30 December 2013).

Konieczki, A.D. and Leake, S.A. 1997. Hydrogeology and Water Chemistry of Montezuma Well in Montezuma Castle National Monument and Surrounding Area, Arizona. Water-Resources Investigations Report 97-4156. U.S. Geological Survey. Tucson, AZ.

Sense, R.G. 1958. Geology of the Verde Valley, Arizona. Tuzigoot National Monument. Clarkdale, AZ.

Tourney, J.W. 1892. Cliff-and-Cave-Dwellers of Central Arizona. Science. 40(510): 269-270.

Tweet, J.S., Santucci, V.L., and Kenworthy, J.P. 2008. Paleontological resource inventory and monitoring – Sonoran Desert Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/130. National Park Service, Fort Collins, CO.

Wetzel, M.J., Oberlin, G.E., and Blinn, W. 1999. The Aquatic Oligochaeta (Annelida: Clitellata) of Montezuma Well, Arizona: A near Thermally Constant Limnocrene. The Southwestern Naturalist, 44(4): 514-518.

White-Nose Syndrome Website. http://whitenosesyndrome.org/ (accessed 6 January 2014).

Additional References (not available at the time of report)

McGeorge, R. and C. Schur. 1994. Preliminary mapping of Elephant Hill, Verde Formation. Southwest Paleontological Society, Mesa Southwest Museum, AZ. Unpublished report. On file at MOCA.

Nations, J. D., R. H. Hevly, J. J. Landye, and D. W. Blinn. 1981. Paleontology, paleoecology, and depositional history of the Miocene-Pliocene Verde Formation, Yavapai County, Arizona. Arizona Geological Society Digest 13:133-149.