The Snowy River formation in Fort Stanton Cave, New Mexico: Results from Radiometric Dating and Hydrologic Observations of the World's Longest Speleothem

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ABSTRACT

The Snowy River formation, located in a recently discovered passage in Fort Stanton Cave, New Mexico, may be the world's longest continuous cave deposit. The formation is composed of white calcite that coats the floor of the Snowy River passage, and currently extends >7 km with its southern terminus still undefined. Core samples collected from the Snowy River deposit reveal a laminated internal structure, indicating episodic deposition of sub-millimeter scale calcite laminae during periods when the passage stream is activated. The age of the basal layer has been determined to be only 820 ± 120 years old, suggesting an abrupt change in climatic or hydrochemical conditions within the past millennium. Since its discovery, the Snowy River passage has experienced three documented periods of streamflow. During each episode, a thin layer of new calcite was deposited. Data loggers indicate an abrupt (~1 week) disappearance of floodwaters in December, 2008, suggesting a point source of recharge such as a losing stream or subterranean pool. Initial precipitation of the Snowy River deposit may correlate to a transition from perrenial streamflow in the cave to ephemeral conditions ~800 years ago due to changes in either climatic conditions or source water input.

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INTRODUCTION

Fort Stanton Cave, currently 23.8 km (14.8 miles) long, is the third-longest cave in New Mexico. The cave is formed in middle Permian San Andres limestone near the northern end of the Sacramento Mountains (Kelley, 1971). Fort Stanton Cave is located east of the igneous core of the Sacramento Mountains crest, on the south side of the valley of the Rio Bonito, which separates the Sacramentos from the Capitan Mountains batholith to the north (Figure 1). The existence of the cave has been on record since 1855 when the nearby U.S. Army fort, whose name the cave bears, was established (Davis and Land, 2006). Fort Stanton Cave is now administered by the U.S. Bureau of Land Management, which has gated the cave and controls access via a permit system. In 2009 the Fort Stanton-Snowy River Cave National Conservation Area was established to protect, conserve, and enhance the unique historic, cultural, and scientific resources of the

Fort Stanton-Snowy River cave system. The NCA includes approximately 25,080 acres that overlie the current known extent of the cave (U.S. Bureau of Land Management, 2010).

BACKGROUND

In September, 2001, a team working in the Priority Seven breakdown dig in Fort Stanton Cave broke through into a new passage. This newly-discovered section of the cave was named Snowy River because of the presence of a snow-white pool deposit that occupies an old stream channel in the passage. The Snowy River pool deposit consists of opaque white calcite with a coralloid texture that was deposited on top of red-brown mud that originally made up the bed of the stream. The mapped length of the Snowy River formation is now more than 7 kilometers, and continues to extend southward for an unknown distance (Figure 2). It has been suggested that the calcified bed of Snowy River may be the longest continuous cave formation on earth (Davis and Land, 2006).

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During the initial scientific assessment survey in July, 2003 a small fragment of the upper surface of the Snowy River formation was collected, which was subsequently dated by the University of New Mexico Radiogenic Isotope Lab using the Uranium-series method at 152 ± 61 years (Davis and Land, 2006). This young age indicates that part or all of the Snowy River Formation was deposited in historic times, during periods when calcium carbonate-saturated water was present in the stream channel.

We assume that the Snowy River Formation formed by evaporation and/or CO_2 degassing of calcite-saturated water that periodically flows through the Snowy River passage, similar to tufa deposits in surface streams (e.g., Andrews, 2006, fig. 5). However, unlike surface tufa, the Snowy River deposit has been sheltered from surface weathering processes, which accounts for its distinctively pristine appearance (Figure 3). Although the Snowy River passage was completely dry when first discovered, flowing water ~30 cm deep has been present for a few months in 2007, 2008 and 2010 in the aftermath of heavy monsoonal rainfall and extreme flooding events, flowing from south to north. Water in the Snowy River passage has always receded during dryer periods, and subsequent expeditions have found sub-millimeter thick crusts of calcite on flagging tape in the passage. Obviously, a similar crust will have been deposited on the Snowy River formation itself. It is thus clear that deposition is still occurring episodically whenever calcite-saturated water flow is present.

RESEARCH

Radiometric dating

In April and May, 2008, we collected nine cores along an 884 meter, south-north transect from the Snowy River pool deposit using a hand-held electric drill with a modified chuck fitted with a water-cooled diamond bit. The cores are all 2.5 cm in diameter and range in length from 3.2 to 9 cm (Figure 4). All but one of the cores penetrated the entire Snowy River formation, which is not as thick as we had expected. All the cores display fine, sub-millimeter-scale lamination (Figures 4 and 5), presumably the result of discrete episodes of calcite deposition during times when the passage was flooded. Wet and dry episodes in the cave passage should reflect alternating periods of abundant rainfall and drought in the northern Sacramento Mountains. The cores thus have excellent potential for providing a record of the paleoclimatology and paleohydrology of the area. Previous investigators have conducted similar studies using spleothem deposits as proxies for Pleistocene and Holocene climate change in continental interiors (e.g., Polyak & Asmerom, 2001; Spotl et al., 2002; Polyak et al., 2004; Asmerom et al., 2010). The basal layers of six of the cores have been dated with the Uranium series technique, yielding ages of 798±173, 836±217, 988±668, 928±4703, 687±426 and 1335±795 years BP, with the large errors reflecting significant quantities of detrital clays. Since layers can be traced from core to core (Figure 4), the basal age for all of these produces an internal 2σ weight-averaged age of 821±120, and a robust Tukey 95% confidence age of 916±250 years BP, indicating an abrupt change in climatic or hydrochemical conditions in the Snowy River Passage within the past millennium.

Stable isotopes

Core SRS-32 was sampled for stable isotopes of carbon and oxygen (Figure 5). This data set should be regarded as very preliminary – because of the size of the bit, it was only possible to collect 22 samples from the core, thus each sample averages over a period of 3 to 4 decades of calcite deposition. Nevertheless, some broad trends may be observed in the stable isotope data, such as a pronounced negative excursion near the base of the core. More negative oxygen isotope values are often associated with periods of heavier rainfall – the "amount effect" (Dansgaard, 1964; Faure, 1986; Rozanski et al., 1993). More negative carbon isotope values could reflect the presence of C-3 dominant vegetation associated with more temperate climates (e.g., Harmon et al., 2004). However, the oxygen isotope values also reflect source of moisture, such that more negative oxygen isotope values indicate more contribution from winter (Pacific) moisture (Asmerom et al., 2010). Taken together, the more negative $\delta^{18}O$ and $\delta^{13}C$ values 74 mm below the core top could be the result of locally wetter or more winter-influenced climate conditions ~700 years BP.

Hydrologic observations

In August, 2008 a data logger was deployed at Mud Turtle Junction in the Snowy River passage of Fort Stanton Cave. The datalogger made hourly recordings of water levels and water temperature in the flooded Snowy River passage from 8/8/2008 to 4/28/2009 (Figure 6). The record shows a gradual decline in water levels in the passage from 34 to 27 cm between August 8 and December 25, 2008. Then, in the one-week period between December 25 and January 1, 2009, water levels declined to zero and remained there for the duration of the period of record. In April, 2010, water again appeared in the Snowy River passage, probably in response to record levels of snowfall in the northern Sacramentos the previous winter. Datalogger records indicate that water levels rose from zero to ~30 cm in less than one hour.

The origin of water flow in the Snowy River passage has been the subject of considerable speculation since it was first observed in 2007. The presence of water does not appear to be an annual event, but is associated with extreme summer precipitation events or very heavy winter snowfall in the northern Sacramento Mountains. Two potential end-member sources for the water include (1) diffuse flow into the passage associated with a rising water table; and (2) a point source of recharge via an upgradient sinkhole or losing stream. The sudden disappearance of water in the Snowy River passage during the last week of 2008 is more consistent with a point source model, since it seems unlikely that evaporation or the slow percolation of water into underlying sediment would occur so rapidly. Rather, the record would suggest that the water supply had been abruptly "turned off". Given the almost complete absence of suspended sediment in the water flow in Snowy River, a surface source such as a losing stream or sinkhole is also implausible. Another possible source may be a subterranean pool far to the south that periodically rises to a spill point and abruptly introduces water into the Snowy River passage.

The broader implication of the point source hypothesis is the existence of a second entrance into the Snowy River section of Fort Stanton Cave, presumably somewhere farther to the south. Whether this possible second entrance would be enterable by humans can only be determined by further exploration.

Paleohydrology

Three distinct waterlines have been observed on the banks of the stream channel in the Snowy River passage. The youngest waterline is the upper edge of the Snowy River deposit itself. However, two older waterlines are represented by dark bands of Manganese Oxide that have accumulated on the mud banks above the Snowy River deposit (Figure 7). The highest MnO_2 band occurs ~30 cm above the upper edge of the Snowy River waterline, and is assumed to represent the oldest and highest period of water level stability. These waterlines appear to be present throughout the Snowy River passage, and may represent episodes during which water levels in the channel were relatively stable for long periods of time (years to decades).

Based on observations of the water level history in the Snowy River passage recorded by these paleo-waterlines, it appears that the stream channel was a perennial stream in the past, depositing silt, sand and gravel transported in from the surface from an unknown source point, presumably far to the south. A decline in stream flow and transition to ephemeral conditions in the passage might coincide with the onset of calcite deposition ~800 years BP.

CONCLUSIONS

The Snowy River formation is evidently one of the youngest features in the passage (<1000 years old), and recent flooding events indicate that the formation is still actively growing. Hydrologic data collected during flood events suggest a single, point source of water in the passage, possibly an up-gradient subterranean pool. Preliminary stable isotope data are consistent with a wetter and/or colder climate in the northern Sacramento Mountains ~700 years BP. Initial precipitation of the Snowy River deposit may correlate to a transition from perennial streamflow to more ephemeral conditions ~800 years ago, due either to climate change or a change in source water input.

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List of Figures

Figure 1: Simplified geologic map of northern Sacramento Mountains, showing location of Fort Stanton Cave (FSC). Cp = Capitan. Rd = Ruidoso.

Figure 2: Line map of Fort Stanton Cave, surveyed length as of October, 2009 = 23.8 km.

Figure 3: Photograph of Snowy River formation. Note sharply-defined upper waterline.

Figure 4: South-north transect of cores collected from Snowy River formation.

Figure 5: Detail of Snowy River core SRS-32, showing fine-scale lamination, radiometric dates, and stable isotope values.

Figure 6: Datalogger record showing water levels in Snowy River passage at Mud Turtle Junction. The 3-day period of zero water level in October, 2008 occurred when the instrument was removed from the channel during a remediation trip.

Figure 7: Waterline on bank of Snowy River channel.