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DATING OF SPELEOTHEMS IN KARTCHNER CAVERNS, ARIZONA

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Uranium-series dates on calcite travertine samples collected from Kartchner Caverns range from ~200-40 Ka. These dates span from the Illinoian glacial to the Wisconsin glacial, but the majority cluster within the wetter Sangamon interglacial. Petromorphic vein quartz (>35 Ka from alpha spectrometry and >1 Ma from $^{234}U/^{238}U$ ratios) dates from an earlier thermal episode associated with Basin and Range faulting. All that can be surmised about the time of cave dissolution from these dates is that it happened >200 Ka.

Kartchner Caverns is in the Whetstone Mountains, ~13 km south of Benson, Arizona, USA, just west of Arizona State Highway 90. The cave developed in a downdropped block of Mississippian Escabrosa Limestone. It is a wet, 'live' cave, >3 km long, which features a wide variety of multicolored speleothems. Kartchner Caverns is Arizona's 25th and newest State Park.

Thirty uranium-series dating analyses were attempted on calcite travertine collected from different areas in Kartchner Caverns (Fig. 1), of which 19 were successful (Table 1). An attempt was also made to date the vein and needle quartz by alpha spectrometry. For an explanation of the principles of the uranium-series dating technique, refer to Ford (1997).

Dating of the calcite and quartz material was hindered because of two factors: (1) many of the samples proved to be 'dirty' (i.e., they contained much mud that contributed detrital, non-radiogenic thorium); and (2) the samples were low in uranium (<<1 ppm), making them difficult to measure accurately. Due to these factors, a number of the sample dates were 'lost'. The oldest date obtained on the calcite was ~194 Ka, and the youngest was ~41 Ka. This span of time includes the uranium-series date (80 ± 6 Ka) on travertine encasing the sloth bones in the "Bison" Room, analyzed by J. Mead and C. Johnson (pers. com.). For a correlation of travertine dates with pollen analyses, refer to Davis (1999).

URANIUM-SERIES DATING OF CALCITE TRAVERTINE

Twelve of the 18 successful analyses of travertine were of samples at significant sediment sites in the cave (Fig. 2). The other six samples were collected at locations where key information about the cave's geologic history might be obtained. For example, it was hoped that the 'Fallen Stalactite' in the Mud Flats of the Big Room would yield an early date that might indicate the time when the water table first descended through the room (i.e., the central, oldest part of this stalactite might have started growing just after the cave became air

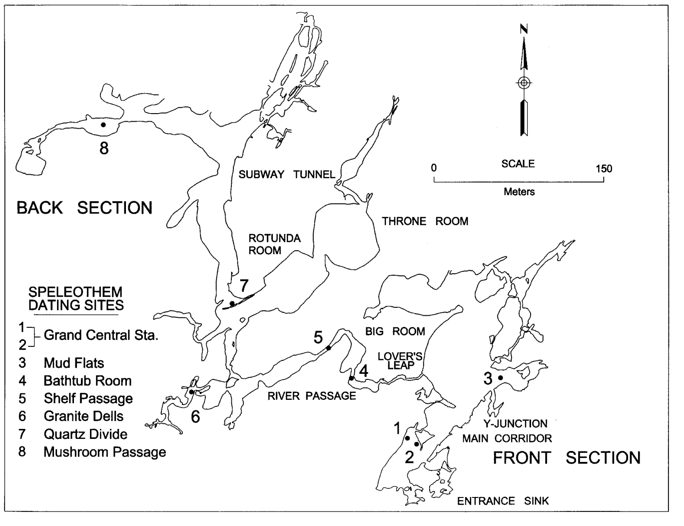


Figure 1. Map of Kartchner Caverns showing the location of speleothem samples collected for dating (black dots) and other places named in the text.

filled). However, the ages obtained on the Fallen Stalactite range from ~83 - 70 Ka (Table 1), are much younger than the travertine in Grand Central Station, and so indicate that this speleothem did not start to grow until long after the de-watering of the passage.

Two other dates came as somewhat of a surprise: the age of the flowstone collected in Granite Dells and the bevel-related age of 'The Mushroom' in the Mushroom Passage. Three samples were investigated from the Granite Dells material. Two proved too dirty to give reliable dates. The third gave an age of around 176 Ka, but this is also suspect because of detrital contamination. If correct, the flowstone age from Granite Dells is surprising because the gravels in this area look as if they were washed into the cave during a quite recent event. Possibly the Granite Dells flowstone formed in the passage before the major influx of granite pebbles and cobbles there, or

Table 1. Uranium-series dates on calcite travertine and quartz vein, Kartchner Caverns.

Speleothem and Location	Date (Ka)	Occurrence
Big Room		
·Fallen Stalactite, Mud Flats		Stalactite that fell from ceiling and broke cross- sectionally
	83±18	T#6 = crystalline core
	72±18	T#7 = middle of ringed outer sequence
	70±15	T#8 = base of ringed outer sequence
Granite Dells		
·Calcite travertine	176±62	T#16 = flowstone with included pebbles
Mushroom Passage		
·The Mushroom stalagmite		Thin layer of flowstone growing over bevel
	54±7	T#18B = base of flowstone
	41±7	T#18T = top of flowstone
Grand Central Station		
·Travertine from t1 event, west wall		A 30 cm long stalactite embedded in pebble gravel (pg1) directly above contact with blocky clay
	194±50	T#3C = core of stalactite
	166±38	T#3T = top of stalactite
	129±25	T#3B = base of stalactite
·Travertine from t2 event, 'hanging' stalagmite, west wall		Stalagmite grew over pebble gravel (pg1) and was engulfed by pg2 sediment
	95±20	T#1,2C = core of stalagmite
	114±22	T#2O = outside of stalagmite
·Travertine from t3 event, east wall		Flowstone overlying pg2 and t2 travertine
	120±22	T#4B = base
	101±11	T#4M = middle
	90±9	T#4U = upper
·Travertine from t2 event, east wall		Flowstone underlying pebble gravel (pg2)
	107±25	T#5T = top
Bathtub Room		
·Travertine flowstone		Flowstone overlying silt
	119±38	T#11M = middle
	78±8	T#11T = top
Shelf Passage		
·Travertine flowstone		Flowstone overlying sediment
	94±30	T#12
Quartz Divide		
·Quartz boxwork	>350	Vein of petromorphic quartz which intruded the rock before the dissolution of the cave

perhaps the gravels are much older than has been assumed.

The Mushroom in the Mushroom Passage is a very massive, pristine-looking stalagmite sharply beveled by a former back-up or ponding of unsaturated water (Fig. 3). It was expected that The Mushroom bevel might be very young, as very little travertine has grown since the beveling event. However, from the youngest date of ~40 Ka on calcite that has grown over the bevel, it appears that the beveling event happened long ago and that even the most youthful-looking travertine in Kartchner may not have formed in the very recent past.

The oldest travertine dated from the cave was a piece of broken stalactite (t_1) located just above the blocky clay unit in Grand Central Station (Figs. 2 & 4). This stalactite started growing about 194 Ka and was possibly broken by, and incorporated into, the pebble gravel (pg1) influx at about 110 Ka. Since this is the oldest date that indicates an air-filled passage environment for the growth of subaerial travertine, all that can be surmised about the time of cave dissolution (when the cave void itself formed) is that it happened sometime before ~200 Ka.

The ages of the calcite travertine combined with the paleomagnetic dating of sediment (Hill 1999) can be used in conjunction to obtain a rough sequence of events for deposits in Kartchner Caverns. All of the sediment in the cave is paleomagnetically normal; that is, the age of the sediment appears to be <780 Ka, before the Brunhes/Matuyama magnetic reversal.

Figure 3. The beveled 'Mushroom' in the Mushroom Passage. Age of the beveling event was ~40 Ka. Photo by Bob Buecher.

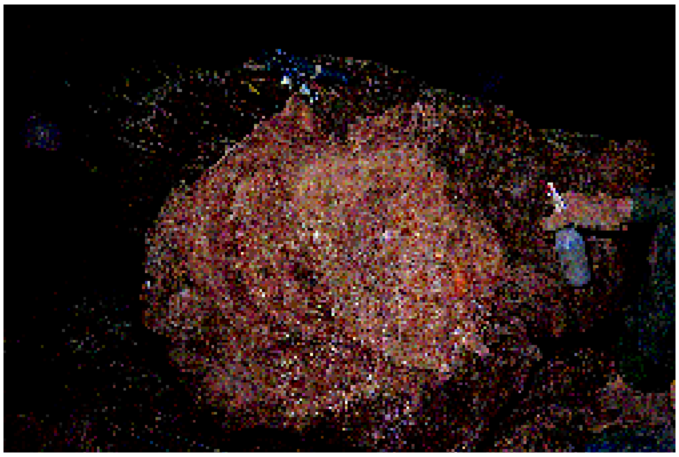


Figure 5. Naturally-broken cross-section of the Fallen Stalactite, Mud Flats, Big Room. Note the middle crystalline center (A) and outer ringed part (B) of the speleothem. This transition may represent a change in climate from wetter to drier conditions. Photo by Bob Buecher.

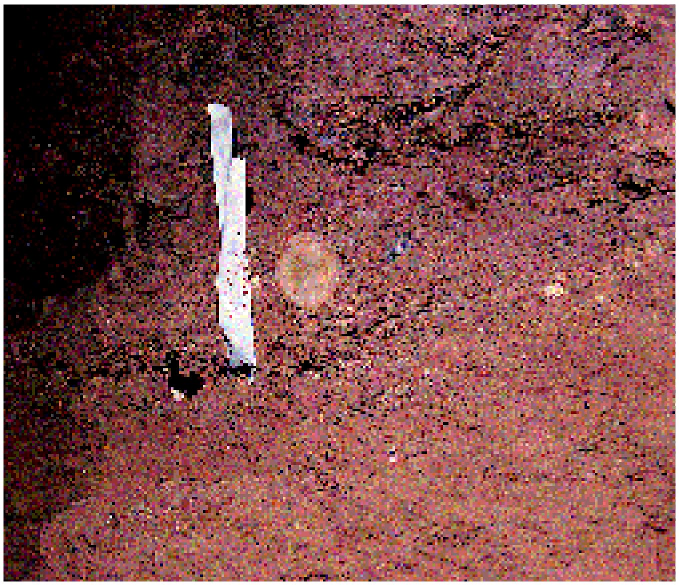
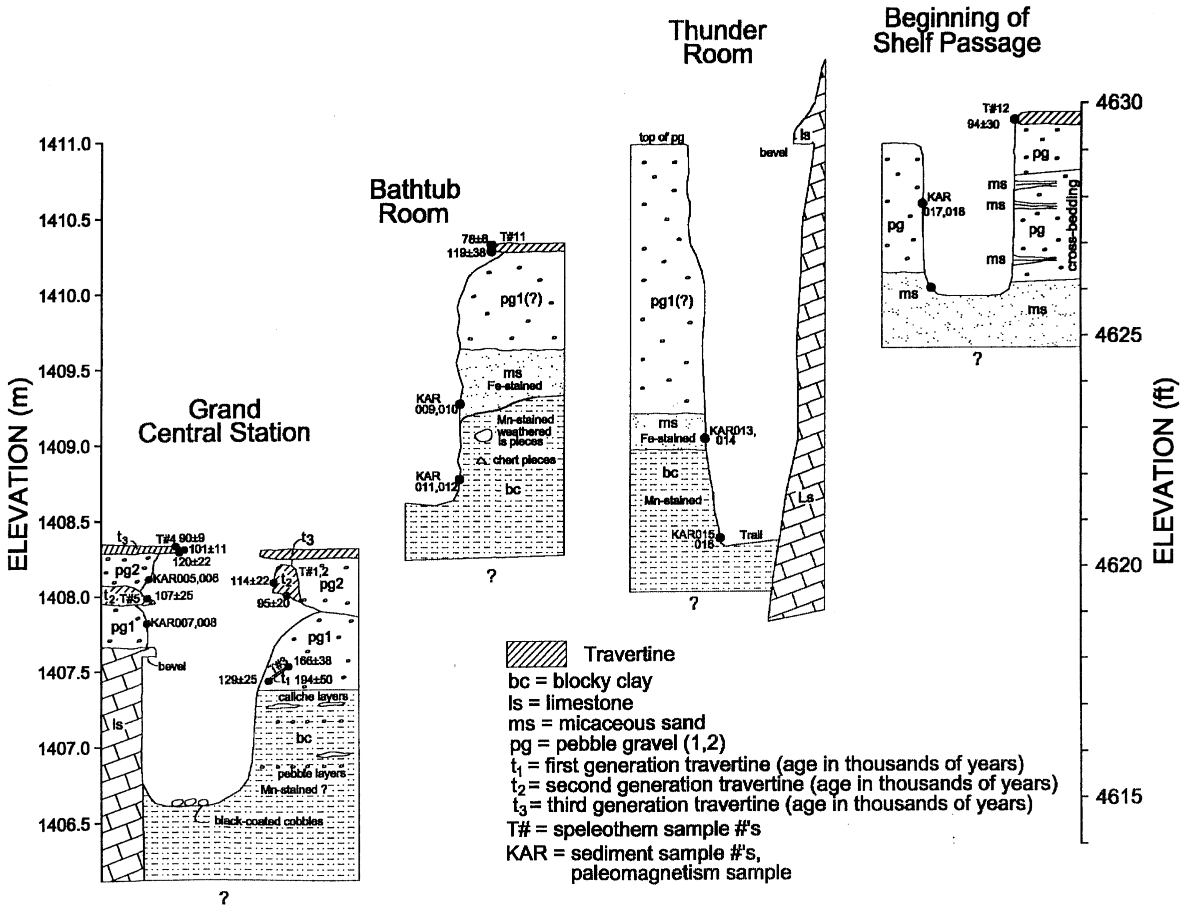


Figure 4. Stalactite T#3 from t_1 event (Table 1) encased in pebble gravel (pg1), just above the blocky clay unit, Grand Central Station. Flagging is hanging just to left of embedded stalactite. Photo by Bob Buecher.

Figure 6. Natural breakage and regrowth of travertine at the Y-junction in the Big Room. The Great Sonoran Earthquake of 1887 may have caused the damage.

Figure 2.

Relative elevations of speleothems and sediments collected from Grand Central Station, the Bathtub Room, Thunder Room, and Shelf Passage. "T" numbers refer to speleothem samples collected for uranium-series dating, and "KAR" numbers refer to sediment samples collected for paleomagnetic dating.



From the travertine dates at Grand Central Station, the blocky clay unit appears to be >200 Ka (older than the travertine that overlies it), while the first influx of pebble gravel (pg1) took place at <129 Ka (the youngest age of the stalactite t_1 embedded in the pebble gravel). There was a period of ~20 Ka (115 - 95 Ka) when travertine (t_2) grew over the pebble gravel (pg1) before another influx of pebble gravel (pg2) came into the cave. Finally, the last travertine (t_3) event occurred at about 100 - 90 Ka in Grand Central Station before downcutting of the sediment-travertine series occurred without further vadose sediment deposition in this area (Fig. 2; Hill 1999).

It is not known if the pebble gravels in the Bathtub Room and Shelf Passage are part of the Grand Central Station pg1 or pg2 depositional events or if, instead, they entered via a different part of the cave along a different route at different times. The pebble gravel, micaceous sand, and blocky clay units are at different elevations in these areas (Fig. 2), so it is probable (but not certain) that the sediments are not correlative. Flowstones overlying the pebble gravels in the Bathtub Room and Shelf Passage were dated at 78 Ka, 94 Ka and 119 Ka; these dates could either indicate a pg1 or pg2 time of origin for the underlying gravels in these areas.

URANIUM-SERIES DATING OF QUARTZ

Vein and needle quartz were analyzed by the uranium-series alpha spectrometry method. The one successfully dated quartz vein sample has a $^{230}Th/^{234}U$ age of >350 Ka (the upper limit of this dating method) and a >1 Ma date estimated from $^{234}U/^{238}U$ ratios in this sample. These greater ages were expected since quartz is a high-temperature mineral that should date from an event related to Basin and Range faulting and associated hydrothermal activity. The quartz vein material is petromorphic rather that speleothemic; that is, it formed within the rock during an earlier thermal episode and then was exposed by later cave dissolution at the water table. Thus, the veins are older than the cave passages and not related to the dissolutional development of the cave. Attempts to date the needle quartz failed because the samples were too contaminated with detrital thorium for reliable ages to be obtained.

SPELEOTHEMS AND PLEISTOCENE CLIMATE

The clustering of speleothem dates between almost 200 Ka to ~40 Ka is important to the understanding of climate changes in the southwestern United States during the later part of the Pleistocene epoch. The Kartchner Caverns dates are similar to speleothem dates in Carlsbad Cavern, New Mexico, another

Southwest cave. Brook *et al.* (1990) found maximum speleothem growth in Carlsbad Cavern to be during the latter part of the Illinoian glacial (170 - 140 Ka), the Sangamon interglacial (140 - 70 Ka), and into the Wisconsin glacial. This same trend is displayed by the Kartchner Caverns travertine. Some growth occurred during the Illinoian glacial and some in the Wisconsin glacial, but most occurred during the Sangamon interglacial. The Sangamon is thought to have been characterized by a warm, humid climate throughout the southwestern United States (Harris 1985).

A change in climate may be reflected by the Fallen Stalactite in the Mud Flat area of the Big Room. A date of ~83 Ka was obtained for the macrocrystalline, blocky-calcite center of the stalactite which indicates a period of continuous growth under wet conditions during this time (Fig. 5). Then the record changes at about 72 - 70 Ka to a ringed sequence indicative of intermittent wet-dry climatic conditions. This change may document a transition from the wetter Sangamon interglacial to the drier Wisconsin glacial.

SPELEOTHEMS AND EARTHQUAKES

Speleothems can be important indicators of earthquake activity in a region (Forti 1997). In Kartchner Caverns, a recent tectonic event is possibly recorded by broken travertine at the Y-Junction in the Main Corridor (Fig. 6) and in the River Passage just past Lover's Leap. In each of these areas the tips of some stalactites are broken off and 3-6 cm of new material has regrown since the breakage. Also, there are a number of fallen soda straws in the Rotunda Room. All of these occurrences suggest earthquake activity. While it is not possible to know the absolute age of travertine without dating it, the world-average figure for travertine growth is a few millimeters per year (Hill & Forti 1997). Using this number, one can speculate that the small amount of travertine breakage in Kartchner may correlate with the Great Sonoran Earthquake of 1887.

CONCLUSIONS

1. Although the calcite travertines in Kartchner Caverns are often 'dirty' and low in uranium, 18 satisfactory age analyses have been completed.
2. These ages range from almost 200 Ka to ~40 Ka and cluster (13 out of 18 dates) within the Sangamon interglacial (140-70Ka).
3. The transition from the wetter climate of the Sangamon interglacial to the drier climate of the Wisconsin glacial (~70 Ka) may be recorded by the Fallen Stalactite in the Big Room where there is a change from macrocrystalline blocky calcite in the inner core to a ringed sequence of calcite in the outer layers.
4. The Great Sonoran Earthquake of 1887 may be recorded by broken travertine in the cave.
5. From the uranium-series dates on calcite travertine, all that can be said about the age of the limestone dissolution that created the cave is that it took place around 200 Ka or somewhat earlier.
6. The quartz mineralization in the cave dates from an earlier hydrothermal episode that probably took place in the Miocene.

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