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DATING RESULTS FROM CARLSBAD CAVERN AND OTHER CAVES IN THE GUADALUPE MOUNTAINS, NEW MEXICO

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Uranium-series, electron spin resonance (ESR), carbon-14, and potassium-argon methods have been used to date speleothems, bone, bat guano, and clay deposits in Carlsbad Cavern and other caves in the Guadalupe Mountains. The ages obtained confirm that the large cave passages in the Guadalupe Mountains are Pliocene-Pleistocene in age. This supports King's (1948) contention that the major rise of the Guadalupe Mountains occurred in the Pliocene-Pleistocene, and argues against Bretz's (1949) contention that the caves in the Guadalupe Mountains formed during a pre-Ogallala (pre-Miocene) exhumation of the reef.

Hill (1987) provides a detailed description of deposits in Guadalupe Mountain caves. This report summarizes only the age-dating information on the deposits and geological implications of these dates. From oldest to youngest the dated deposits are:

Clay. Montmorillonite in the Papoose Room, Carlsbad Cavern, was found to contain sufficient potassium (1.84%) to attempt potassium-argon dating. The montmorillonite clay fills solution pockets in the limestone and is truncated by (i.e. it antedates) the large cave passages. The age obtained on the clay was 188 ± 7 m.y. (Early Jurassic). This date must be considered highly speculative because of uncertainty concerning gains or losses in the open potassium/argon system that may have occurred between the Permian (when the host limestone was deposited) and the present. Reliable dates have not been achieved on montmorillonite samples hitherto (T. Bills, Geochron Labs, personal communication, 1985). However, it is interesting that the clay apparently retained a relatively high concentration of potassium in a calcium-carbonate system despite a potassium concentration of only 0.13% for the detrital feldspar component of the clay, which rules out any significant contamination from this source. Also, it is interesting that in such a karst groundwater system a significant amount of argon was retained.

Spar. Clusters of calcite spar crystals 10 cm or so in length are also found in some of the solution pockets that are believed to antedate the main cave-forming event or events. The spar occurs at all levels in the cave. Uranium and thorium concentrations were investigated in ten specimens. ^{230}Th and ^{234}U were in secular equilibrium in all cases except sample 6, implying that the spar is definitely older than 350,000 ybp. Further, ^{234}U and ^{238}U are in secular equilibrium (within measuring error) in all examples. This indicates that all specimens could be older than the 1,250,000 to 1,500,000 years required to bring excess ^{234}U into equilibrium with ^{238}U.

The ESR method was applied to five spar samples. Three were saturated, implying that they are significantly older than 100,000 ybp. Given the uncertainties of the ESR method (Grun, 1985) this unsupported result must be treated with caution. However, it is broadly concordant with the U-series results.

Cave Rafts. Cave rafts are thin, planar deposits that form on the surfaces of cave pools or the water table. There are three episodes of raft formation in Carlsbad Cavern: (1) well-cemented rafts exposed in the cave walls overlying siltstone, (2) partially cemented rafts that make up cave cones (conical piles of raft debris accumulated beneath drip points in the ceiling), and (3) rafts forming on the surfaces of cave pools today.

Hill (1987) interpreted Type I rafts to have formed at the paleo water table and to be the result of its early fluctuations that antedated the final enlargement of the large cave passages. U-series and ESR dates on Type I rafts (of siltstone-raft sequence) range from about 200,000 to >350,000 years (samples 15-20; table 1). These may all be minimum ages due to the fact that at least 80% of the mass of Type I cave rafts is post-depositional cement material that was introduced at some time after the rafts themselves had formed. The Type I raft results attest to the fact that the large cave passages most probably formed at the water table during the present erosion cycle and not in an earlier, pre-Ogallala cycle as postulated by Bretz (1949).

Type II rafts, such as make up the huge (4 m high) cones in the Lake of the Clouds area (the lowest point in Carlsbad Cavern), are believed to be the result of the last speleogenetic events in the cave. Cones on the Balcony of the Lake of the Clouds have U-series dates that range from about 250,000 ybp at the base to 50,000 ybp at the top (samples 37A–37E). The 50,000 yr date may represent the time when the regional water table receded from Carlsbad Cavern, or possibly it may represent late raft deposits forming on a perched water body. If the latter was the case, then the perched water surface must have been exceedingly stable. Cones on the Balcony are located only a few meters below the local cave ceiling; for them to have formed between 250,000 and 50,000 ybp indicates that the water surface could not have fluctuated more than the few meters between ceiling and cones for a duration of 200,000 years (Ford and Hill, 1988). In contrast, the present Lake of the Clouds (a perched water body located about 80 m below the Balcony) is known to have lowered 31.27 cm between 1966 to 1986.

Speleothems. Different types of speleothems in Guadalupe caves have ages that vary between approximately 600,000 ybp (as estimated by $^{234}U/^{238}U$ ratios) and 20,000 ybp. In Lower Cave, Carlsbad Cavern, ~600,000 yr old travertine directly overlies paleomagnetically-reversed silt (>730,000 years but probably <900,000 years). As discussed by Hill (1987), maximum and minimum growth of speleothem travertine can be correlated with glacials and interglacials over the past 500,000 years or so.

'Popcorn' is the popular name given coralloidal or botryoidal clusters or nodules growing by evaporation on cave walls, etc. In the Big Room and Left Hand Tunnel of Carlsbad Cavern they are abundant below a sharp line on the walls ('the popcorn line') but entirely absent from similar host surfaces above it. Popcorn samples were dated to help determine whether the line formed as a 'water line' (paleo water table) as suggested by Jagnow (1977), or whether it is an atmospheric phenomenon caused by cool, dry, evaporative air moving into the cave along the floor and warm, moist, corrosive air moving out of the cave near the ceiling. Dates on the popcorn vary between 33,000 ybp and >350,000 ybp in Left Hand Tunnel (samples 28–32). In the Big Room near the Lion's Tail, the popcorn shows a systematic decrease in age from underlying stalagmitic traveltine (102,000 ybp) to the outermost popcorn nodules (45,000 ybp, sample 32A). All of the popcorn dates can be taken to refute a 'water line' origin for the popcorn line in Carlsbad Cavern. It is a micro-climatic phenomenon of great stability.

Iceberg Rock is the largest piece of breakdown in Carlsbad Cavern. The time of its settling away from the ceiling can be bracketed from the dates (samples 33–36, 45). Tilted stalactites on Iceberg Rock (tilted by its settling) have a U-series date of >350,000 ypb and a maximum ESR date of 513,000 ybp. Dates on vertical stalagmites on collapse breakdown (i.e. travertine deposited after the rock's fall) have been dated at 180,000 or younger (samples 36, 45). Therefore Iceberg Rock fell sometime between about 500,000 ybp and 200,000 ybp.

Bone. Bones of the ground sloth *Nothrotheriops* have been found in Lower Devil's Den, Carlsbad Cavern. The U-series date of 111,900 ybp (sample 42) probably signifies the time when the sloth had died in the cave and its bones were first exposed to uranium-bearing ground water. It can be assumed that uptake of uranium by the bone was relatively rapid and reached some saturation level after a time span which is short compared with the age of the bone. The 111,900 ybp date is consistent with a 58,000 ybp date for calcite crystals that later grew inside the already badly weathered bone (samples 41–43). This U-series date of approximately 112,000 ybp is the oldest absolute date ever obtained for *Nothrotheriops* (Hill and Gillette, 1987), and implies that the entrance to Carlsbad Cavern may have been open for at least that long.

Bat guano. Bat guano has been dated by the carbon-14 dating method and minimum ages of up to 32,500 ybp have been obtained. Thus, bats have occupied Guadalupe caves for at least this long and probably for much longer.

CONCLUSIONS

Based on the dating results it can be concluded that the lower levels of Carlsbad Cavern (Lower Cave and the Big Room) dissolved at least 750,000–850,000 years ago or earlier. Assuming a constant water table lowering rate of 0.05 cm/yr (derived from ages and elevation differences between speleothems at different levels) it is estimated that the upper Bat Cave level of Carlsbad Cavern is at least 1.2 m.y. old. And, if one also assumes a constant rate of uplift and water-table lowering throughout the entire Guadalupe Mountain area, then caves in the southwestern, higher parts of the Guadalupe Mountains are roughly 3–5 m.y. It is thus concluded that Guadalupe caves are Pliocene-Pleistocene in age.

SAMPLE DESCRIPTIONS

Type of deposit	Sample no.	Location	Dating method	Age (yrs)	$^{234}U/^{238}U$ ratio	Analyses by; notes
Carlsbad Cavern, this study						
Spar	1	Entrance	U-series	>350,000	1.025±0.023	D. Ford, MU; ~4,300 ft elevation
Spar	2	Entrance	U-series	>350,000	1.046±0.08	D. Ford, MU; Weathered spar. U systematics disturbed?
Spar	3	Lower Guadalupe	U-series	>350,000	1.008±0.15	D. Ford, MU; collected by M. Queen; ~3,800 ft elevation
Spar	4	Secondary Stream Passage	ESR	–	–	G. Hennig, NLB, and R. Grun, UK; saturated; not date obtainable
Spar	5	Secondary Stream Passage	ESR	879,000 ±123,000	–	G. Hennig, NLB, and R. Grun, UK; collected 10 cm from sample 3; ~3,700 ft elevation
Spar	6A	Secondary Stream Passage	U-series	320,000 ±120,000	0.987	D. Ford, MU; problematic analysis
	6B	Secondary Stream Passage	ESR	–	–	R. Grun, MU; saturated, no date obtainable
Spar	7	Bell Cord Room	U-series	>280,000	0.99±0.05	J. Cowart, FSU, ~3,675 ft elevation
Spar	8	Left Hand Tunnel	U-series	>350,000	0.959±0.148	D. Ford, MU; ~3,650 ft elevation
	9	Left Hand Tunnel	U-series	>350,000	0.987±0.03	D. Ford, MU; adjoins sample 8
	10	Left Hand Tunnel	ESR	–	–	G. Grun, MU; manganese contamination; no date. Adjoins sample 8
Spar	11	Mystery Room	ESR	–	–	G. Hennig, NLB, and R. Grun, UK; saturated; no date
Spar	12	Lower Cave	U-series	>350,000	0.987±0.025	D. Ford, MU; collected by M. Queen just west and above Nicholson's Pit, 3,570 ft elevation
Rounded spar	13	Lower Cave	U-series	>350,000	0.982±0.45	D. Ford, MU. Adjoins sample 12
	14		U-series	>350,000	1.07±0.15	J. Cowart, FSU; found with rounded cobbles in trench; no date due to low thorium concentration

SAMPLE DESCRIPTIONS (continued)

Type of deposit	Sample no.	Location	Dating method	Age (yrs)	$^{234}U/^{238}U$ ratio	Analyses by; notes
Cave rafts of siltstone-raft sequence	15	Lower Devil's Den	ESR	257,000 ±64,000	—	G. Hennig, NLB, and R. Grun, UK; ~3,720 ft elevation
	16	Lower Devil's Den	U-series	259,500 ±40,800 −29,600	1.007±0.018	D. Ford, MU; same collection site as sample 15
	17	Lower Devil's Den	U-series	213,800 ±21,300 −17,800	1.028±0.017	D. Ford, MU; repeat of sample 16
	18	Main Corridor	ESR	—	—	G. Hennig, NLB, and R. Grun, UK; saturated; no date obtainable; ~3,675(?) ft elevation: in an out-of-place breakdown block
	19	Main Corridor	U-series	>350,000	1.086±0.234	D. Ford, MU; same as 18
	20	Main Corridor	U-series	205,200 ±52,600	1.06±0.14	J. Cowart, FSU; same as sample 18
Flowstone	21	Bell Cord Room	U-series	151,700 +8,800 −8,200	1.119±0.14	D. Ford, MU; flowstone corroded by rillen-karren
	22	Bell Cord Room	U-series	176,000	1.00±0.07	J. Cowart, FSU; collected 0.5 ft lower than sample 21
Flowstone	23	Big Room	U-series	107,600 +3,400 −3,300	1.586±0.025	D. Ford, MU; underlies silt-breccia
Flowstone	24A	Lower Cave	U-series	125,000 ±10,000 at top	1.867	D. Ford, MU; flowstone 1.5 cm thick; overlies cobbles
	24B		U-series	148,000 ±10,000 in middle	2.169	
	24C			176,000 ±25,000 at base	2,236	
	25A	Lower Cave	ESR	125,000 ±25,000 at top	—	R. Grun, MU; same as sample 24
	25B			160,000 ±32,000 at base		
Drapery	26	Bat Cave	U-series	54,000 ±2,600	2.048	D. Ford, MU; drapery slightly corroded
Drapery	27	Bat Cave	U-series	47,000 ±2,100	2.054	D. Ford, MU; drapery highly corroded
Popcorn	28	Left Hand Tunnel	ESR	272,000 ±106,000	—	G. Hennig, NLB, and R. Grun, UK; popcorn below the "popcorn line"
	29	Left Hand Tunnel	U-series	>350,000	0.931	D. Ford, MU
	30	Left Hand Tunnel	U-series	33,000 ±800	0.601	D. Ford, MU; collected about 7 m from sample 29; popcorn of "popcorn line"
Popcorn	31	Left Hand Tunnel	U-series	36,300 ±1,800	0.56	D. Ford, MU; popcorn of "popcorn line"; dirty; date may not be reliable
Popcorn overlying stalagmite	32A	Big Room (by Lion's Tail)	U-series	45,000 ±2,000	1.971 (popcorn)	D. Ford, MU; drill core in massive stalagmite covered with popcorn of "popcorn line"; core 3 cm deep; outer cm popcorn, intermediate and inner cm stalagmitic travertine.
	32B			87,000 ±6,000	2.619 (outer cm)	
	32C			102,000 +4,000	2.005 (inner cm)	
Stalactite	33	Main Corridor Iceberg Rock	U-series	>350,000	—	D. Ford, MU; tilted stalactite on bottom of Iceberg Rock
	34		ESR	513,000 ±100,000	—	R. Grun, MU; same sample as 33
	35		ESR	223,000 ±50,000	—	R. Grun, MU; aragonite core of sample 33
	36		U-series	55,000 ±4,100	2.289	D. Ford, MU; stalagmite growing on collapsed rock beneath Iceberg Rock

continued

SAMPLE DESCRIPTIONS (continued)

Type of deposit	Sample no.	Location	Dating method	Age (yrs)	$^{234}U/^{238}U$ ratio	Analyses by; notes
Rafts (of cones)	37A	Balcony, Lake of the Clouds	U-series	50,000 ±4,000	1.009	D. Ford, MU; natural drip tube in cone; surface of cone. May represent last speleogenesis event
	37B			114,000 +123,000 −70,000	1.173	Collected 91 cm down drip tube of cone
	37C			115,000 +47,000 −30,000	1.508	Collected 122 cm down drip tube of cone
	37D			207,000 +48,000 −33,000	0.973	Collected 152 cm down drip tube of cone
	37E			254,000 +172,000 −122,000	0.978	Collected 196 cm down drip tube of cone
Rafts	38	Christmas Tree Room area	U-series	>350,000	–	D. Ford, MU; rafts overlain by sulfur crystals. Result is probably spurious due to high uranium content (U = 238 ppm)
Gypsum block	39	Polar Region, Big Room	ESR	–	–	G. Hennig, NLB, and R. Grun, UK; did not exhibit an ESR-sensitive peak
Montmorillonite clay	40	Papoose Room	K-Ar	188 ±7 m.y.	–	S. Stokowski, Geochron Labs
Nothrothiops (sloth) bone	41	Lower Devil's Den	C-14	>29,700	–	Geochron Labs
	42	Lower Devil's Den	U-series	111,900 +13,300 −11,100	0.808	D. Ford, MU; date on bone material
	43	Lower Devil's Den	U-series	58,000 +5,600 −5,100	0.787±0.13	D. Ford, MU; calcite crystals inside of weathered bone
Carlsbad Cavern, other studies						
"Texas Toothpick" stalagmite	44	Lower Cave, below Jumping Off Place	U-series	167,000 to >350,000	2.247–2.509	D. Ford, MU; stalagmite overlies paleomagnetically reversed silt; core of stalagmite might approach or exceed 600,000 yrs; core drilled by B. Ellwood, UT. Brook and others (manuscript)
"Georgia Giant" Stalagmite	45	Main Corridor	U-series	60,000 to 180,000	3.0–3.4	J. Cowart, FSU; stalagmite overlies Iceberg Rock; core drilled by B. Ellwood, UT. Brook and others (manuscript)
Soda straw	46A	Main Corridor	U-series	20,000 at bottom	–	J. Cowart, FSU; collected by B. Ellwood, UT, near "Georgia Giant" stalagmite
	46B			50,000 at top		
Aragonite moonmilk	47	Lower Cave(?)	C-14	18,000 ±580	–	"Mud wholly of aragonite" (Dunham, 1972)
Other Guadalupe caves, other studies						
Stalagmite	48	Ogle Cave	U-series	125,000 to 205,000	–	Harmon & Curl (1978)
Bat guano	49	New Cave	C-14	>17,800	–	Libby (1954) 20 cm below flowstone caprock
	50A	New Cave	C-14	>28,250	–	225 cm below flowstone caprock. Letter from R. H. Brown to Carlsbad Caverns Natl. Park (1981)
	50B			>32,500	–	
Bat guano	51	Ogle Cave	C-14	4,150 to 7,300	–	Upper level of guano, cut by miner's trench (D. DesMarais, pers. commun. 1984)

Abbreviations: FSU, Florida State University, Department of Geology, Tallahasse, Florida; UT, University of Texas, Department of Geology, Arlington, Texas; MU, McMaster University, Geography Department, Hamilton, Ontario, Canada; UK, Geologisches Institut der Universitat Koln, West Germany; NLB, Nidersachsisches Landesamt fur Bodenforshung, Hannover, West Germany.

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