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A MINIMUM AGE FOR CANYON INCISION AND FOR THE EXTINCT MOLOSSID BAT, *TADARIDA CONSTANTINEI*, FROM CARLSBAD CAVERNS NATIONAL PARK, NEW MEXICO

Joyce Lundberg
Department of Geography and Environmental Studies, Carleton University, Ottawa, Ontario, K1S 5B6, CANADA, joyce_lundberg@carleton.ca

Donald A. McFarlane
W. M. Keck Center, The Claremont Colleges, 925 North Mills Avenue, Claremont, CA 91711-5916 USA, dmcfarla@jsd.claremont.edu

Slaughter Canyon Cave (or New Cave), Carlsbad Caverns National Park, southeastern New Mexico, opens in the wall of Slaughter Canyon, 174 m above the present level of the canyon floor. It contains bone-bearing, water-laid sediments capped by a double layer of calcite. TIMS U-Th dates on the two layers are 66.0 ± 0.3 ka and 209 ± 9 ka. Deposition of these two laterally-extensive calcite layers suggests wet periods in this currently-arid region during MIS 4 and 7. The date on the lower layer suggests that the clastic deposit was emplaced no later than MIS 8. This yields a maximum estimate for downcutting rate of the canyon of ~0.87 mm yr^{-1}during the Late Pleistocene. The clastic deposit contains bones of the molossid bat Tadarida constantinei *Lawrence 1960: the date of 209 ± 9 ka is thus a minimum age for this extinct bat.*

Introduction

Slaughter Canyon Cave (also known as New Cave), Carlsbad Caverns National Park, southeastern New Mexico, opens on the southwest wall of Slaughter Canyon (UTM 13 540848E 3553503N). The canyon is one of the many that are incised into the Guadalupe Mountains, controlled by a prominent set of NW-trending joints (Duchene and Martinez, 2000). The cave is developed in the Permian age Capitan Reef Complex (Hill, 2000) of limestone and dolostones. The cave has a simple profile along a single level now opening onto the canyon wall (Fig. 1A). A remnant of the cave can be seen at the same elevation in the opposite wall of the canyon (the Ogle/Rainbow Cave) indicating that the cave was opened when the canyon bisected it (DuChene and Martinez, 2000).

Calcite-capped, fossil-bearing clastic sediments in the cave floor were exposed by guano prospectors between 1937 and 1957. The 3 m thick deposit is mostly a bone-bearing water-lain sediment with horizons of fossil bat guano. The fossil bones show preferred orientations from water sorting. The sediments are partly cemented and capped by a thin but laterally extensive layer of calcite flowstone. Dating of this calcite thus provides an estimate of the minimum age of the deposit. The sediment-guano complex must post-date the opening of the cave by canyon downcutting. In conjunction with the geomorphological situation of the cave, and the present elevation of the canyon floor, this date allows the estimation of the rate of canyon downcutting over the Late Pleistocene. The fossils include abundant well-preserved osteological remains of *Tadarida constantinei* Lawrence 1960; thus the calcite date also allows an estimation of the minimum age for this extinct bat.

Dating

The flowstone sample, collected in 1988 from ~150 m inside the cave entrance (Fig. 1B), is ~10 mm thick, with two distinct layers separated by a depositional hiatus. The upper layer, without detrital contamination, is 4–5 mm thick and overlies the lower, somewhat detritally-contaminated, layer (Fig. 2). This lies directly on, and cements the top of the sediments. A piece of the calcite flowstone was sent to McMaster University in 1988, in the hope of generating a U-Th age by alpha spectrometry, but this was unsuccessful due to detrital contamination (D. C. Ford, *pers. comm.*, 1988). In 2003 the lower and the upper layers were U-Th dated by thermal ionization mass spectrometry (TIMS), after careful removal of material in association with the upper and middle hiatuses that may have been leached. The upper layer yielded 66.0 ± 0.3 ka and the lower layer 209 ± 9 ka (Table 1). The calcite impregnating the sediment could not be separated from the clasts and thus could not be dated.

Speleothem evidence suggests that this region alternates between arid conditions during interglacial periods and pluvial conditions during glacial periods (Hill, 1987). Musgrove *et al.* (2001) also show that speleothem growth correlates with wet periods, in central Texas. Thus the Slaughter Canyon dates are best interpreted as indicative of two wet phases separated by periods of non-deposition presumed to be arid. The fluvial activity that laid down the clastic deposit obviously occurred before the deposition of the basal calcite layer. This could have been during the marine oxygen isotope stage 8 glacial period, but obviously could have been earlier. Thus the date of 209 ± 9 ka is a minimum age for the clastic deposit. If this situation is similar to those encountered by Stock *et al.* (2005), who found that U-Th dates on speleothem overlying clastic sediments were generally considerably younger than cosmogenic $^{26}Al/^{10}Be$ burial dates on the sediment itself, then it is possible that the Slaughter Canyon

Table 1. Data from Slaughter Canyon flowstone U-Th TIMS dating (activity ratios, 2δ errors).

Layer	Age (ka)	Corr. Age[a] (ka)	U (ppm)	$^{230}Th/^{234}U$	$^{234}U/^{238}U$	$^{234}U/^{238}U_{init}$	$^{230}U/^{232}Th$
Upper	66.0 ± 0.3	N.A.	0.26	0.4722 ± 0.0002	1.807 ± 0.003	1.973 ± 0.004	253
Lower	209 ± 9	206 ± 9	0.38	0.922 ± 0.014	1.40 ± 0.02	1.911 ± 0.005	38

[a] Age corrected for detrital contamination assuming an initial $^{230}Th/^{232}Th$ activity ratio of 1.5. In this case, the corrected age is within the 2δ error, thus the detrital contamination is insignificant.

Table 2. Radiocarbon dates (conventional) associated with *Tadarida constantinei*, Slaughter canyon Cave, New Mexico.

Laboratory Code	Stratigraphy	Reported Age (rcybp)
C 898[a]	Guano, 2 feet below caprock.	>17,800
UCR 1270[b]	Guano, 8–9 inches below caprock.	>28,150
UCR 1208[b]	Guano, 90 inches below UCR-1207.	>32,500
UCR 1543[b]	Unknown.	28,800 ± 2,600

[a] Libby (1954).
[b] U.S. Park Service, Carlsbad Caverns (unpublished records).
Laboratory code C represents University of Chicago.
Laboratory code UCR represents the University of California, Riverside.

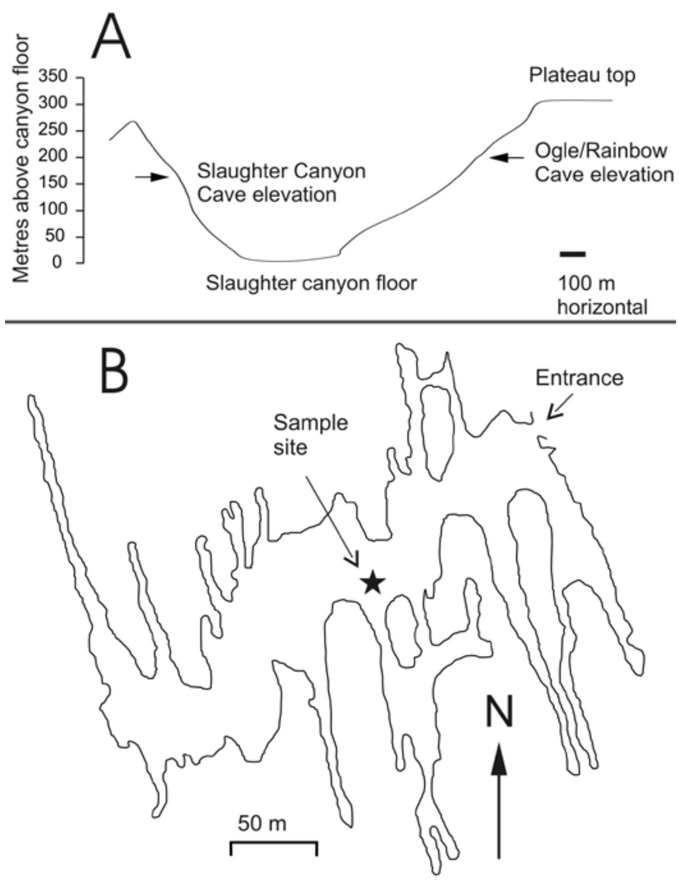

Figure 1. A. Cross section of Slaughter Canyon (from SW to NE across canyon) showing the relationship of the plateau top, the canyon floor and the caves opening into the canyon wall. The Rainbow entrance of the Ogle/Rainbow Cave is directly opposite the Slaughter Canyon Cave entrance, at an elevation of ~174 m above the canyon floor (drawn from data in US Geological Survey, 1979). B. Plan of Slaughter Canyon Cave showing location from which flowstone was collected (drawn from data in Cave Research Foundation, 1976).

Cave sediments are also considerably older than the impregnating calcite.

Downcutting Rate

The clastic deposit consists of waterlain sediments containing fossil mammal bones showing evidence of water sorting, with some horizons of fossil bat guano. It is presumed that the sediment was emplaced when the canyon floor was close to the elevation of the cave entrance.

The geomorphological setting of Slaughter Canyon Cave (New Cave) in the face of the canyon wall directly facing the Rainbow entrance of Ogle Cave in the opposite wall (Fig. 1A) suggests that the two caves had been a single system at the time of speleogenesis (DuChene and Martinez, 2000) long before the canyon began to be incised. With falling base level, the canyon has cut through the cave, bisecting it. If the calcite-capped fluvial deposit indicates the time when the canyon floor was at the level of this passage, then the difference in elevation of the passage and the present canyon floor gives a measure of how far the canyon has been incised in the last 200 kyrs or more. The level of the Slaughter Canyon Cave entrance is 174 m above the canyon floor (Jagnow, 1977). Hill (1987, p. 92) estimated the rate of downcutting at < 45 mm yr^{-1} but only had access to a ^{14}C date on the bat guano of >32,500 rcybp (Table 2). Using the TIMS U-Th date of ~200 ka on the calcite gives a new and considerably lower (but maximum) estimate of downcutting rate of ≤ 0.87 mm yr^{-1}.

No other estimates for down-cutting rates in Slaughter Canyon itself have been published, but DuChene and Martinez (2000) estimate downcutting rates for the Central Section of the Guadalupe Mountains at 0.072 – 0.022 mm yr^{-1} (median 0.046 mm yr^{-1}), using $^{40}Ar/^{39}Ar$ dates on alunites from sulfuric acid caves in the region (Polyak *et al.,* 1998; Polyak and Provencio, 2000). Dethier (2001) offers a broad estimate for downcutting in non-carbonate rocks in the general region of the south-west USA using dates on tephra deposits from the Yellowstone Caldera for the whole region west of the Mississippi River. Although no dat-

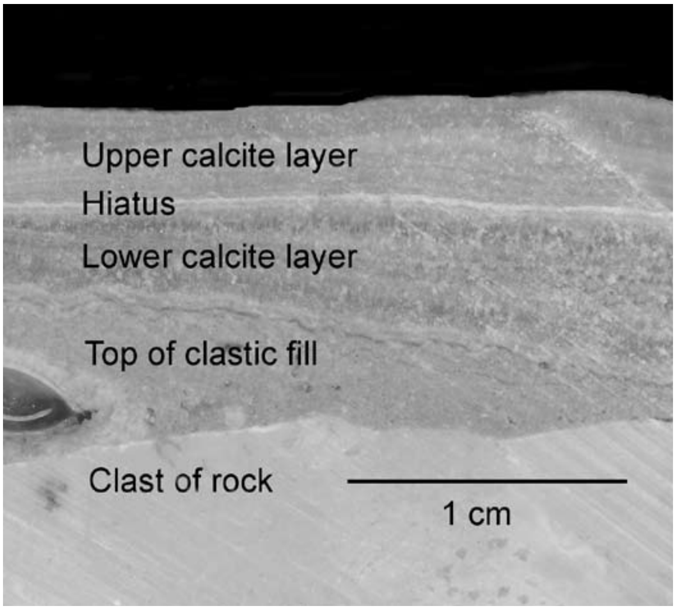

Figure 2. Section of the calcite capping the bone-bearing clastic sediment. The upper calcite layer and the lower calcite layer were U-Th dated by TIMS at 66.0 ± 0.3 and 209 ± 9 ka respectively. (The angled saw marks are artifacts from cutting.)

ed ash deposits are indicated in the immediate area of the cave, the estimated long-term incision rate over the last 600,000 years for the Guadalupe region is ~5 – 10 cm ka^{-1} or ~0.05 – 0.10 mm yr^{-1}. However, incision rate has not been constant over this time period. Although the age control is incomplete, Dethier (2001) observes that incision rates increased in the middle to Late Pleistocene by two to five times the earlier rates. Dethier's Figure 3 shows details for the Rio Grande, New Mexico, ~200 km to the west of the Guadalupe region. Overall incision rate for the last 800 ka was estimated to be ~0.16 mm yr^{-1}, but only ~0.08 mm yr^{-1} for the first 600 kyrs and ~0.38 mm yr^{-1} for the last 200 kyrs. Duchene and Martinez's (2000) estimate, 0.046 mm yr^{-1}, is considerably lower than this and our estimate, 0.87 mm yr^{-1} maximum, is higher (but a similar order of magnitude). The true incision rate is probably somewhere between the three.

Palaeontology

The molossid bat in this deposit, *Tadarida constantinei* Lawrence 1960, differs from the extant *Tadarida brasiliensis mexicana*, abundant in adjacent Carlsbad Caverns, primarily in size. Lawrence (1960) described *T. constantinei* as averaging 13% larger in length of skull, with the means of the two taxa differing by some eight standard deviations. Attempts to date the extinct *T. constantinei* deposit began early (Table 2); a sample of fossil guano from the deposit was reported on by W. F. Libby in his fifth radiocarbon date list (Libby, 1954) and found to be < 17,800 rcybp – the effective limit of the technique at that time. Subsequent efforts by the University of California, Riverside radiocarbon lab in 1981 advanced the age to 32,500 rcybp (unpublished US Park Service records), again the limit of the available technology. The new TIMS U-Th date yields a minimum age on the fossils of 209 ± 9 ka.

Our examination of a sample of crania collected from the cave in 1988 did not reveal any characters other than size that would distinguish *T. constantinei* from the extant *T. brasiliensis*. Morgan (2003) reported that *T. constantinei* differs from *T. brasiliensis* only in having a flatter skull. Given the minimum age of *T. constantinei* and the lack of any *T. brasiliensis* material of a similar antiquity, we regard *T. constantinei* as a chronospecies and junior synonym of *T. brasiliensis*.

Conclusion

A U-Th TIMS date of 209 ± 9 ka on the calcite layer capping a fossil-bearing, clastic deposit in Slaughter Canyon Cave, New Mexico, has yielded a maximum estimate for downcutting rate of the canyon of ~0.87 mm yr^{-1}. This date also represents a minimum age on the molossid bat *Tadarida constantinei*.

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