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Geology

Extinction of Harrington's mountain goat

(vertebrate paleontology/radiocarbon/Grand Canyon)

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ABSTRACT **Keratinous horn sheaths of the extinct Harrington's mountain goat, *Oreamnos harringtoni*, were recovered at or near the surface of dry caves of the Grand Canyon, Arizona. Twenty-three separate specimens from two caves were dated nondestructively by the tandem accelerator mass spectrometer (TAMS). Both the TAMS and the conventional dates indicate that Harrington's mountain goat occupied the Grand Canyon for at least 19,000 years prior to becoming extinct by 11,160 ± 125 radiocarbon years before present. The youngest average radiocarbon dates on Shasta ground sloths, *Nothrotheriops shastensis*, from the region are not significantly younger than those on extinct mountain goats. Rather than sequential extinction with Harrington's mountain goat disappearing from the Grand Canyon before the ground sloths, as one might predict in view of evidence of climatic warming at the time, the losses were concurrent. Both extinctions coincide with the regional arrival of Clovis hunters.**

Certain dry caves of arid America have yielded unusual perishable remains of extinct Pleistocene animals, such as hair, dung, and soft tissue of extinct ground sloths (1) and, recently, of mammoths (2). Other less well known collections from the surface or shallowly buried in six caves of the Grand Canyon, Arizona, include horn sheaths, dung pellets, and dry tissue of an extinct mountain goat, *Oreamnos harringtoni*, as reported here (Fig. 1).

Beyond their significance as paleontological curiosities, the perishable remains provide high quality organic residues for radiocarbon dating (3, 4). Contamination by soil humic acids or by other sources of allochthonous organic carbon is unknown and unexpected. The scarcity of perishable material in paleontological collections, and, until recently, the small size of many samples otherwise ideal for ^{14}C dating has prevented the widespread use of keratin or dung in geochronology. Our contribution follows the advance in radiocarbon technology offered by the tandem accelerator mass spectrometer (TAMS)—in particular, its small-sample capability.

Extinction of Harrington's mountain goat and that of the Shasta ground sloth, *Nothrotheriops shastensis*, may be compared biologically as well as temporally. Compared to living mountain goats (*Oreamnos americanus*), Harrington's mountain goat was small, with a more robust mandible, a distinctive palate, and larger dung pellets (5). The extinct mountain goats and the ground sloths once occupied the same region and, at least in one case, the same cave (Rampart). Nevertheless, it is hard to imagine two more divergent large herbivores. For example, the extinct mountain goat was digitigrade, gracile, and presumably highly mobile in rough terrain, penetrating remote parts of the Grand Canyon (Stanton's, Tse'an Bida, Tse'an Kaetan, and Stevens Caves) inaccessible to the plantigrade and ponderous Shasta ground sloth. Living mountain goats are gregarious rather than solitary, unlike living relatives of the ground sloths. They are grazing ruminants rather than browsing monogastrics. The ancestry of the mountain goat was possibly holarctic and boreal rather than neotropical as in the case of the ground sloths. Given these differences, one might expect that under natural stress, such as that imposed by severe climatic change, the two species would not disappear at the same time. A climatic change inimical to one might well favor the other, at least initially. Instead, our findings suggest concurrent loss.

Ranging south of the living *O. americanus*, *O. harringtoni* (Rupicaprini, Caprinae, Bovidae) was described from late Quaternary deposits of Smith Creek Cave, Nevada (6).

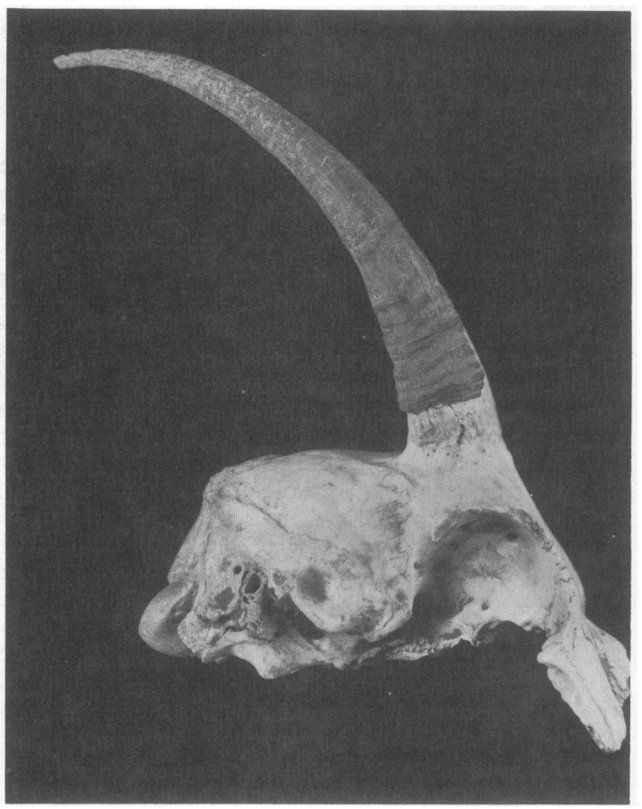

FIG. 1. Fragmented skull of *O. harringtoni* with horn sheath still attached. Measurements of horn sheath indicate that the animal was from a female ≈7 yr old. Keratinous remains of the extinct mountain goat are unique to the Grand Canyon.

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Abbreviation: TAMS, tandem accelerator mass spectrometer.

Extinct mountain goat bones occurred only in the lowest unit of the deposit (6), since referred to as the Reddish-brown Silt Zone (7). The age of this deposit falls between 12,600 ± 170 yr before present (B.P.) and 28,650 ± 760 yr B.P., or possibly older (8).

Additional skeletal remains and horn sheaths were subsequently recovered from deposits of similar age in Rampart Cave (Grand Canyon, Arizona) (9). During an archaeological project in the 1960s, bones, horn sheaths, and many thousands of dung pellets of the extinct mountain goat were excavated at Stanton's Cave (Grand Canyon, Arizona) (10, 11).

METHODS

The abundance of fresh-looking perishable remains at or near the surface of Grand Canyon caves might lead one to imagine the extinction of *O. harringtoni* happened quite recently. To test this possibility, we analyzed 23 horn sheaths (8 from Rampart Cave and 15 from Stanton's Cave) by radiocarbon dating. The specimens are easily identified; they are unlike the horn sheaths of mountain sheep *Ovis canadensis* and other artiodactyls (5). Conventional radiocarbon dating technique requires several grams of horn sheath material, an unacceptable sacrifice of these unusual fossils. Since TAMS radiocarbon dating requires only a few milligrams of carbon, the specimens suffered negligible loss.

With TAMS, ions are accelerated to high energies and then separated by electrostatic charge and mass, allowing the direct measurement of isotope ratios. Samples, prepared as iron carbide targets, yielded a large standard deviation; the precision of measurement has been greatly improved by substituting a graphite bead target. All pretreatment and TAMS analyses were performed at the National Science Foundation Accelerator Facility for Radioisotope Analysis at the University of Arizona, Tucson.

The results are presented in Table 1 along with 14 conventional radiocarbon dates, mostly obtained from large dung pellets (5, 12). The latter, 0.5 g or more in pellet weight, are typically found associated with skeletal remains of *O. harringtoni*, their apparent source. The distribution of radiocarbon dates from Stanton's Cave (Fig. 2) are biased toward the late glacial period, just prior to the extinction of the species.

Because of the number of radiocarbon ages dating < 12,000 yr B.P., we found it imperative to improve the precision of the clustering of dates and, therefore, we have used a system of averaging, weighting them according to different standard deviations (13).

RESULTS AND DISCUSSION

The oldest TAMS measurement for the extinct mountain goat is 28,700 ± 700 yr B.P. (Table 1), which is within 1 SD of the oldest conventional radiocarbon date of 30,600 ± 1800 yr B.P. From Stanton's Cave, the weighted average of three TAMS dates on horn sheaths younger than 12,000 yr is 11,510 ± 175 yr B.P. When dates are plotted to their nearest 1000 yr, all millennia younger than 25,000 and older than 9000 yr B.P. are represented, a remarkably even distribution that suggests continuity of the species in the Grand Canyon during and after the last glacial maximum (Fig. 2).

From Stanton's Cave, the weighted average of the three youngest TAMS dates on horn sheaths is 11,510 ± 175 yr B.P. If these three are averaged with the youngest conventional radiocarbon age, the average age for survival of Harrington's mountain goat at Stanton's Cave is 11,210 ± 130 yr B.P. Averaging this result with the youngest date from Rampart Cave (10,140 ± 510 yr B.P.) and the youngest date from Tse'an Bida Cave (11,850 ± 750 yr B.P., conventional), yields an apparent survival of Harrington's mountain goat in the Grand Canyon of 11,160 ± 125 yr B.P. Conceivably, the mountain goats lingered to a slightly later time (≈10,000 yr B.P.) around Rampart Cave; however, sample 593 is burdened with a large standard deviation and is not significantly different, at 2 SD, from the average obtained for all six dates. Despite the wealth of fresh-looking, preserved perishable material from the caves, and the length of the Pleistocene record, the results do not disclose Holocene survival.

Fig. 3 illustrates the TAMS and conventional radiocarbon dates on *O. harringtoni*; shown from left to right are the youngest TAMS date from Rampart Cave, the three youngest TAMS dates, and the youngest conventional date all averaged together from Stanton's Cave, the youngest conven-

Table 1. Radiocarbon dates on the keratinous horn sheaths and large dung pellets of *O. harringtoni* from the Grand Canyon

Radiocarbon lab. no. or TAMS sample no.	Specimen no. (material)	Radiocarbon date, yr B.P.	Dating method
	Rampart Cave		
593	21,961 (HS)	10,140 ± 510*	T
1839	348 (HS)	13,430 ± 130	T
1841	278 (HS)	16,690 ± 160	T
A-1278	91 (D)	18,430 ± 300	B
1842	367 (HS)	19,970 ± 290	T
1840	385 (HS)	19,980 ± 210	T
1855	87-3 (HS)	20,960 ± 320	T
1854	87-4 (HS)	22,430 ± 320	T
1856	93-94-2 (HS)	28,700 ± 700	T
	Stanton's Cave		
A-1155	20-25 (D)	10,870 ± 200	B
576	67 (HS)	11,460 ± 1050*	T
1852	NN1 (HS)	11,490 ± 180	T
A-3439	102 (HS)	11,920 ± 810*	T
1845	46 (HS)	12,300 ± 160	T
1843	98 (HS)	12,370 ± 130	T
1846	99 (HS)	12,860 ± 340	T
A-1167	25-30 (D)	12,980 ± 200	B
1849	101 (HS)	13,120 ± 130	T
1844	100 (HS)	13,290 ± 240	T
1847	97 (HS)	13,760 ± 120	T
A-1132	20-25 (D)	13,770 ± 500	B
A-1168	35-40 (D)	15,500 ± 600	B
575	60 (HS)	16,270 ± 400*	T
A-1246	55-60 (D)	17,300 ± 800	B
1850	52 (HS)	19,320 ± 380	T
574	51 (HS)	20,060 ± 930*	T
1848	89 (HS)	20,560 ± 310	T
1853	61 (HS)	22,280 ± 290	T
1851	128 (HS)	23,030 ± 300	T
	Tse'an Bida Cave		
RL-1134	Surface (D)	11,850 ± 750	B
SI-3988	Surface (HS)	12,930 ± 110	B
RL-1133	Surface (D)	13,100 ± 700	B
RL-1135	Layer 4 (D)	16,150 ± 600	B
A-2373	Layer 8 (D)	24,190 + 4300 − 2800	B
	Tse'an Kaetan Cave		
A-2835	Surface (D)	14,220 ± 320	B
A-2723	10-15 (D)	17,500 ± 300	B
A-2722	25-30 (D)	30,600 ± 1800	B

Radiocarbon laboratories: A, University of Arizona; RL, Radiocarbon Limited; SI, Smithsonian Institution. HS, horn sheath; D, dung pellet; T, dated by TAMS; B, dated by conventional β counter. All TAMS dates were provided by the University of Arizona National Science Foundation Accelerator Facility for Radioisotope Analysis.

*Older method using iron carbide targets.

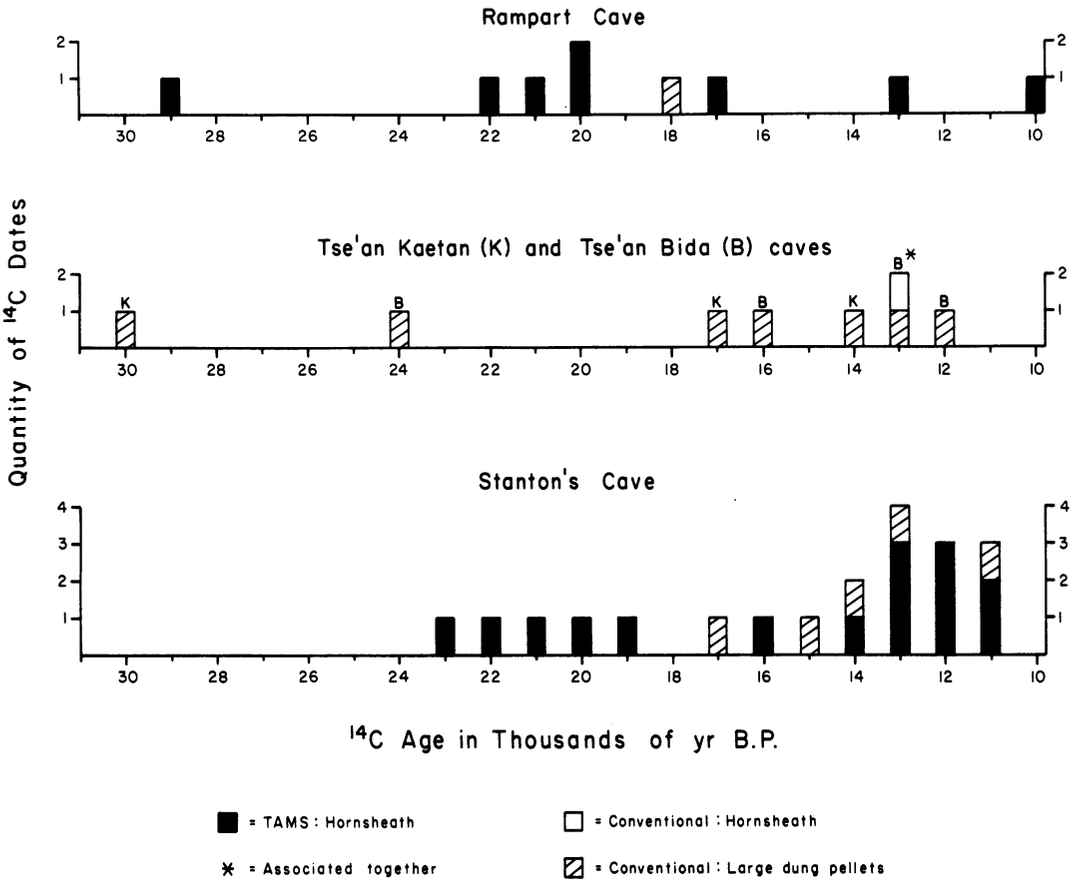

FIG. 2. Histogram of all radiocarbon dates obtained directly on *O. harringtoni* remains, as reported in Table 1. Ages reported to nearest 500 yr.

tional date from Tse'an Bida, and the total of all these dates averaged together. Also included in Fig. 3 is the average of the 14 youngest dates of the Shasta ground sloth from Rampart and the nearby Muav caves (14). The average of the six youngest dates for Harrington's mountain goat from all caves, 11,160 ± 125 yr B.P., is not significantly older than the average for the Shasta ground sloth, 11,018 ± 50 yr B.P. At 1 SD, the time of extinction of both animals in the Grand Canyon apparently fell between 11,285 and 10,968 yr B.P.

The youngest radiocarbon dates on Shasta ground sloths of

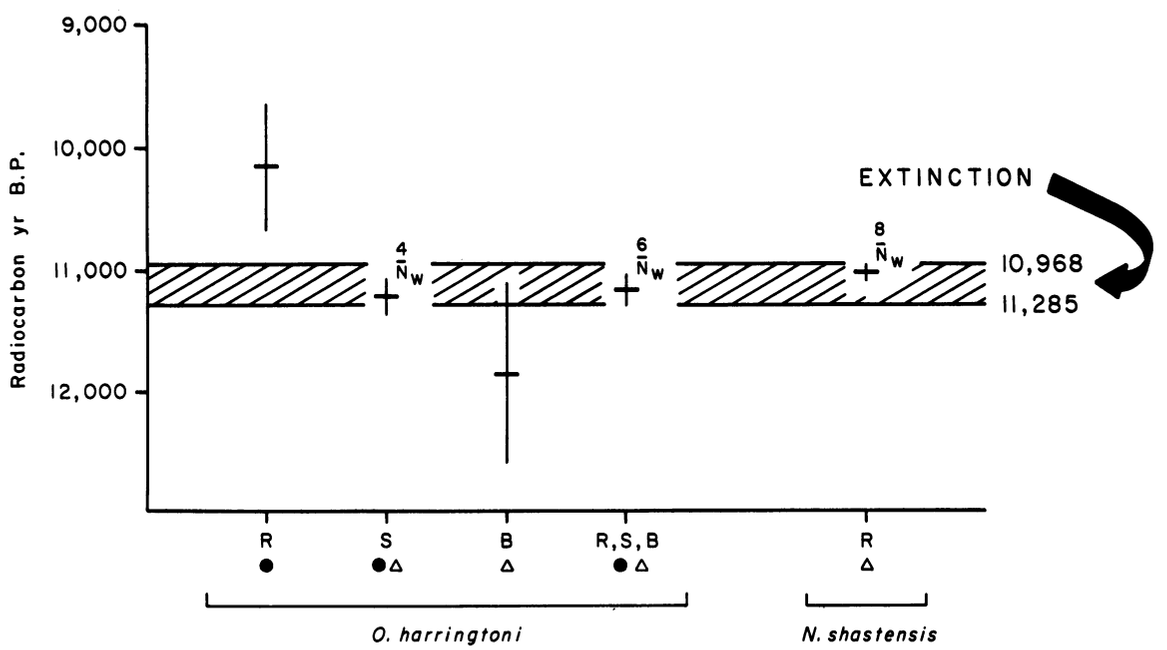

FIG. 3. Graph of the youngest radiocarbon dates obtained on horn sheaths and dung of the extinct mountain goat and the dung of the extinct Shasta ground sloth. R, Rampart Cave; S, Stanton's Cave; B, Tse'an Bida Cave. ●, Radiocarbon date obtained using the TAMS technique; △, radiocarbon date obtained using the conventional gas technique. $\bar{N}_W$, average age weighted according to criteria described by Long and Rippeteau (13). Time of inferred extinction includes 1 SD.

Arizona, Nevada, west Texas, and New Mexico also coincide in age with the youngest dates on machairodont cat (*Smilodon*, 11,130 ± 275 yr B.P.), horse (*Equus*, 10,940 ± 540 yr B.P.), and bison (*Bison antiquus*, 12,275 ± 775 yr B.P.) in southern California (15, 16). The three together average 11,200 ± 230 yr B.P. (15). Harrington's mountain goat may now be added to this group. All vanished at ≈11,000 yr B.P., a time when local plant communities were experiencing considerable turnover (17), and also when Clovis big game hunters were active in the Southwest (18). Without pursuing the matter of cause any further, the new radiocarbon results support a model of synchronous rather than sequential extinction. Evidently, the shift from boreal conifers giving way to juniper woodland (12, 17) did not force the mountain goats to withdraw in advance of the ground sloths, as one might expect (for a boreal-adapted animal) if the extinctions were driven by a warming climate.

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