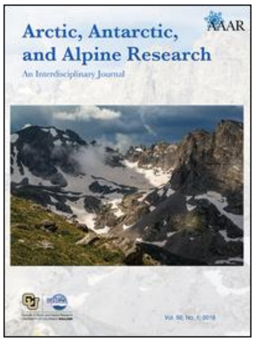

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THE ANTIQUITY OF CASTLEGUARD CAVE, COLUMBIA ICEFIELDS, ALBERTA, CANADA*

M. Gascoyne
Geochemistry and Applied Chemistry Branch, Atomic Energy of Canada Ltd.
Pinawa, Manitoba R0E 1L0, Canada

A. G. Latham
Department of Geology, McMaster University, Hamilton, Ontario L8S 4M1, Canada

R. S. Harmon
Isotope Geology Unit, Department of Geological Sciences
Southern Methodist University, Dallas, Texas 75275, U.S.A.

D. C. Ford
Department of Geography, McMaster University, Hamilton, Ontario L8S 4K1, Canada

ABSTRACT

Several sections of Castleguard Cave contain abundant, massive fossil speleothem deposits. Twenty-one samples have been dated by the $^{230}Th/^{234}U$ method. Ten of them are older than 350 ka (1 ka = 1000 yr before present). Included in this group are (1) a massive in situ flowstone in the Waterfall Chamber along First Fissure, (2) a prominent indurated stalagmite projecting through the false floor in the Grottoes, and (3) the base of a large flowstone boss near the start of Second Fissure. More recent deposits include a false floor overlying laminated clay in the Grottoes (144 ka), a flowstone veneer apparently overlying laminated silt in First Fissure (100 ka), and a similar veneer between Holes-in-the-Floor and Second Fissure (38 ka).

Speleothems (1) and (2) above have been found to be magnetically reversed, indicating an age of greater than 720 ka, but probably less than 1 ma from examination of their $^{234}U/^{238}U$ ratios.

These ages clearly demonstrate the antiquity of the cave and show that (1) First Fissure, the Grottoes, and Second Fissure were vadose by 720 ka, (2) the silt deposits along First Fissure and in the Grottoes are older than 100 ka, and if of glacial origin, must therefore be from the penultimate glaciation, or earlier, and (3) the presently active (but unexplored) drainage system of the cave is likely to be very old and, therefore, well developed.

*A version of this paper was presented orally at a symposium, "Karst and Caves of Castleguard Mountain," at the 8th International Congress of Speleology, Bowling Green, Kentucky, U.S.A., 20 July 1981.

INTRODUCTION

Calcite speleothems, in the form of stalactites, stalagmites, and flowstones, are found in almost all parts of Castleguard Cave. The first small stalactites are encountered in the effluent flood zone. Their size and number steadily increase through Helictite Passage and First Fissure, to attain maxima at the Grottoes in the center of the cave. Although there is a decrease again farther up the cave, small deposits occur in all of the older passages of the Headward Complex, and stalactites appear to be actively growing within 150 m of the glacier ice blockage (Figure 1).

The deposits display many unusual or unexpected features for an extreme alpine and subglacial situation such as this. The first is the very existence of actively growing deposits of any size beneath a permanent ice cover. Second and related is the massive size of many of the speleothems, both active and fossil. An active speleothem from the Grottoes is shown in Figure 2. Massive deposits are expected in humid temperate or tropical caves where rich vegetation cover supports enhanced CO_2 production in the soil. Groundwaters passing through it are enriched in their capacity to dissolve limestone and, ultimately, to reprecipitate it when a cave with a standard atmosphere is encountered (White, 1976).

Lastly, a number of the more massive deposits have suffered considerable re-solution, and so appear to be ancient. Re-solution of speleothems is fairly common in many caves of the world. There are two types: Type 1 re-solution occurs where the nature of the speleothem feed-water changes from supersaturated to aggressive with respect to carbonate. Having first deposited a stalagmite, flowstone, etc., the source water dissolves it away again. The corrosion creates deep microravines in the deposit. Type 2 re-solution occurs when the deposit is inundated by water from other sources, flooding the cave passage. All exposed surfaces of the speleothem may be dissolved faster than the feed-water can build them in drier periods. In Castleguard Cave, re-solution is common between P24 and the head of Second Fissure. It may extend into the Headward Complex but has not

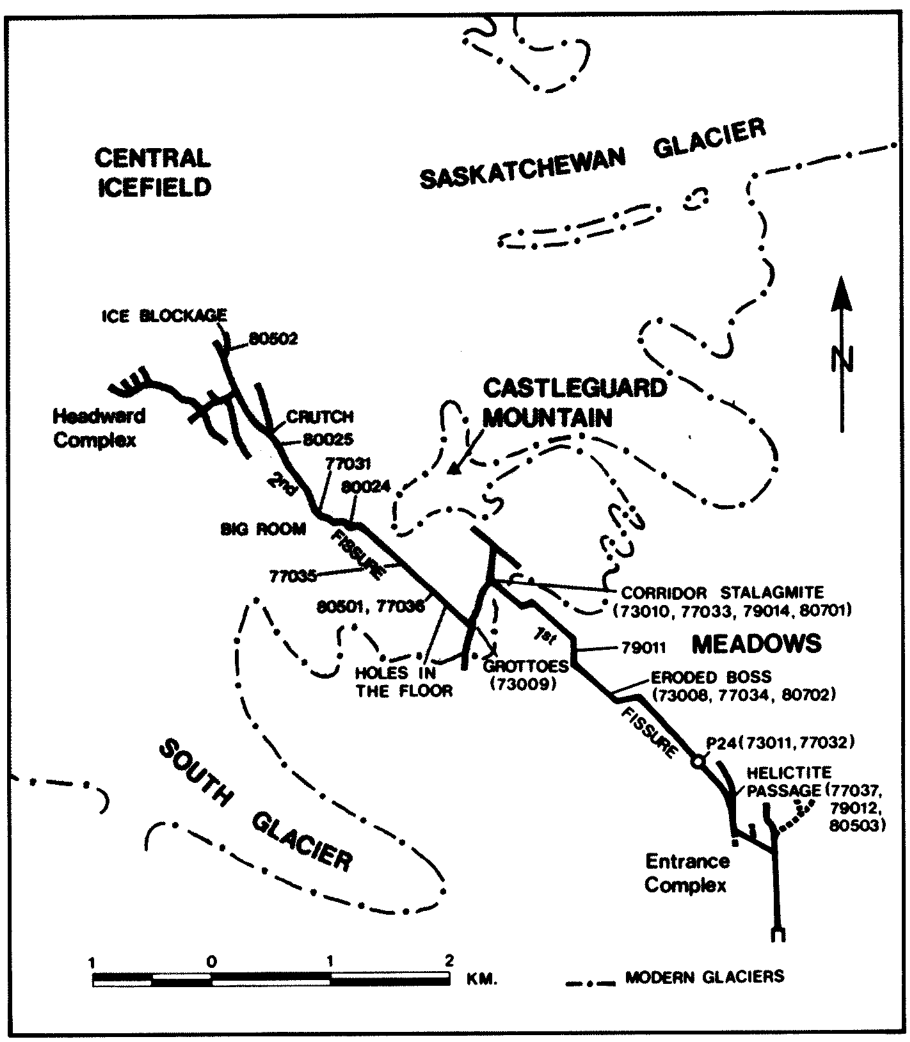

FIGURE 1. Plan of Castleguard Cave, showing the location of speleothem samples. Geographical coordinates of the summit of Castleguard Mountain are 52°06′30″N, 117°15′10″W.

been reported there. Type 1 re-solution occurs most notably at the Eroded Boss in First Fissure (see below), but Type 2 predominates. This indicates that the central cave has suffered one or more prolonged phases of inundation by aggressive waters. Figure 3 shows a typical example from the Grottoes; a large stalactitic mass has been eroded almost flush with the limestone roof, indicating complete inundation. After the floods withdrew, precipitation recommenced, to form the small stalactites seen at the lefthand edge of the older deposit. These stalactites appear to be actively growing today.

SPELEOTHEM DATING STUDIES

U-Series Dating

Uranium-series dating techniques have been used successfully to date speleothems and other carbonate deposits that formed within the Quaternary period (for a recent review, see Schwarcz and Gascoyne, 1983). The ^{230}Th/^{234}U technique is the most reliable and commonly used of these; it measures the ingrowth of ^{230}Th (initially absent from the system) by radioactive decay of ^{234}U after formation of the deposit. The age (t) is given by the equation

$$\frac{^{230}\mathrm{Th}}{^{234}\mathrm{U}} = \frac{1 - e^{-\lambda_{230}t}}{^{234}\mathrm{U}/^{238}\mathrm{U}} + \frac{\lambda_{230}}{\lambda_{230} - \lambda_{234}} \cdot \left(1 - \frac{1}{^{234}\mathrm{U}/^{238}\mathrm{U}}\right) \cdot \left(1 - e^{-(\lambda_{230} - \lambda_{234})t}\right) \qquad (1)$$

where ^{230}Th/^{234}U and ^{234}U/^{238}U are the measured radioactivity ratios and λ_{230} and λ_{234} are the decay constants of ^{230}Th and ^{234}U, respectively (in this work $\lambda_{230} = 9.217 \times 10^{-6}$ yr^{-1} and $\lambda_{234} = 2.806 \times 10^{-6}$ yr^{-1}).

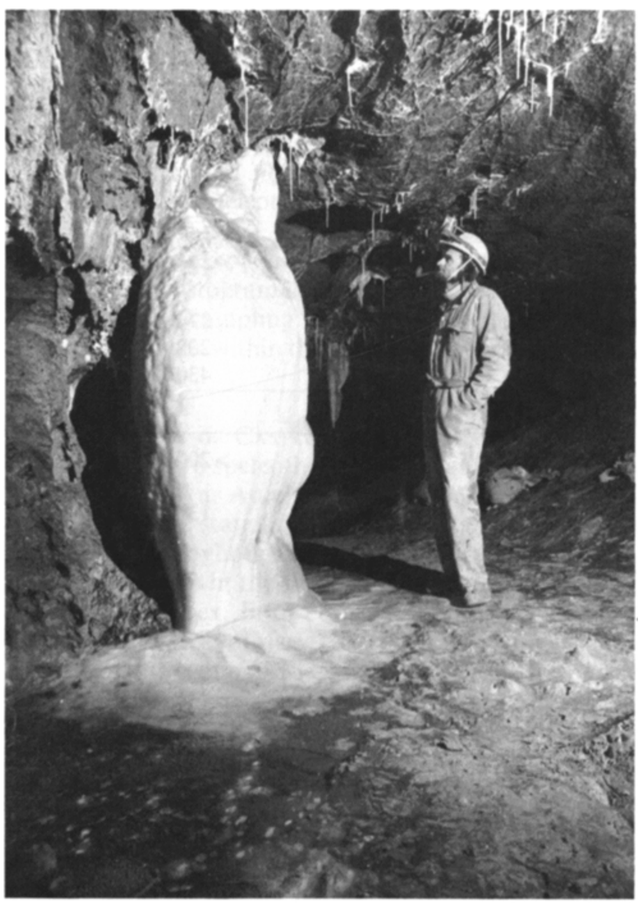

FIGURE 2. A large, columnar stalagmite that is actively growing in the Grottoes.

FIGURE 3. A detail of the ceiling in the Grottoes. Type 2 re-solution (see text) has eroded an original stalactitic mass nearly flush with the bedrock roof. Calcite growth layers are clearly exposed by the erosional level. Younger overgrowth of stalactites and draperies shows no solution damage. The thick stalactite at top center is ca. 20 cm in length.

In expeditions between 1973 and 1980, 22 calcite samples were taken from 16 different speleothems in Castleguard Cave. Twenty-seven U-series dates have been obtained from them. This collection may be considered to be a fair areal sampling of the cave except for parts of the Headward Complex (Figure 1). The sampling, however, has tended to concentrate on the older-appearing speleothems with the object of establishing the

TABLE 1
Site and analytical data for speleothem samples

Speleothem	Location and Description		Analysis	U conc.	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$	Age ± 1σ (ka)
	A. Samples >350 ka in whole or part							
77033	Corridor Stalagmite Grottoes, near Base		B-1	1.96	1.065	0.982	105	>350
79014	Second collection near 77033		B-1	2.3	1.067	1.019	61	>350
80701	Subspecimen of 79014 (reversely magnetized)			1.06	1.095	1.213	18	>720
73010	Corridor Stalagmite overgrowth	Top	-7	2.5	1.09	0.58	26	92 ± 3
		Base	-6	2.5	1.08	0.75	159	147 ± 12
77034	Eroded Boss in First Fissure	Top	A-1	1.07	1.117	1.007	33	>350
		Base	F-1	1.66	1.057	1.066	35	>350
80702	Subspecimen of 77034 F-1			probably reversely magnetized				>720
73008	Eroded Boss, Portion of fin		-3	2.6	1.08	0.405	42	57 ± 2
80025	Eroded Boss near the Crutch	Top	A-1	2.0	1.090	0.987	161	>350
77031	Flowstone near Big Room		-1	4.2	1.036	0.964	330	$332^{+>35}_{-44}$
77035	Eroded Boss in Second Fissure		-1	2.2	1.087	1.053	58	>350
77037	Flowstone in Helictite Passage		-1	1.9	1.172	1.017	>1000	>350
79012	Flowstone in Helictite Passage	Top	-1	1.3	1.102	0.916	635	243^{+22}_{-18}
		Base	-2	1.5	1.075	1.027	116	>350
77032	Fallen Stalagmite at Base at P24	Top	-2	2.5	1.362	0.995	274	278^{+26}_{-22}
		Base	-1	2.6	1.401	1.080	202	>350
	Duplicate of -2		-3	—	1.334	—	430	>350[a]
	B. Younger samples							
80502	Stalactite near Ice Blockage		-1	15.4	0.82	0.11	>200	13 ± 1
80024	Flowstone on silt near Big Room		-1	3.1	1.113	0.683	134	121 ± 6
80501	Bulk stalactite, West End of Holes-in-the-Floor		-1	3.3	1.54	0.05	17	6 ± 0.7
77036	Flowstone on silt, near Holes-in-the-Floor		-1	4.1	1.368	0.300	61	38 ± 1.5
73009	Stalagmite in Grottoes	Top	-3	5.9	1.33	0.012	>1000	1 ± 0.5
		Base	-4	19.1	1.34	0.024	35	3 ± 0.2
79016	Flowstone on silt in Grottoes		-1	1.0	1.221	0.759	19	144 ± 7
79011	Flowstone on silt First Fissure		-1	1.0	1.270	0.654	11	100 ± 4[b]
73011	Fallen stalagmite at base of P24		-2	8.7	1.34	0.69	68	120 ± 6
80503	Bulk stalactite near Pools Entrance Complex		-1	2.4	1.65	0.06	>200	7 ± 0.6

[a] $^{231}Pa/^{230}Th$ date.

[b] Age corrected for detrital thorium; uncorrected age is 109 ± 4 ka.

antiquity of parts of the cave. Not all periods of speleothem deposition may be represented. A summary of the descriptions and the analytical data are presented in Table 1.

In U-series dating of calcite speleothems the two analytical problems most commonly encountered are lack of coprecipitated uranium and contamination by detrital thorium (Harmon et al., 1975). Speleothems that have as little as 0.05 ppm U may be dated but greater abundance is preferred. At Castleguard Cave, the U concentrations are all greater than 1 ppm, easily high enough for routine analysis.

In addition to the radiogenic ^{230}Th, some speleothems may contain ^{232}Th, and the ratio $^{230}Th/^{232}Th$ may therefore be used as an index of contamination. Where the ratio is <20, an age correction is made to the dates assuming an initial, time-zero, $^{230}Th/^{232}Th$ ratio of 1.5 (see, e.g., Gascoyne, 1980); otherwise, no correction is required. Table 1 shows that $^{230}Th/^{232}Th$ ratios were mostly greater than 20 and an age correction was made only to sample 79011.

Paleomagnetic Analysis

Latham (1981) has shown that some speleothems contain fine particles of magnetite within the calcite matrix, and that these may record the inclination and declination of the earth's field at the time of deposition. Full chemical, physical, and analytical details are given in Latham (1981), and summaries are presented in Latham et al. (1979, 1982). Speleothems recording a reversed natural remanent magnetization are considered to have been deposited during one of the reversed chrons or subchrons. During the 1980 expedition samples 80701 and 80702 were taken from eroded speleothem deposits known to be older than 350 ka, the normal limit of the $^{230}Th/^{234}U$ method (Table 1). The orientation of the samples, in situ, was made with respect to the vertical, and approximately to geographic north, by reference to the surveyed passage direction. Magnetic measurements were made using a SQUID magnetometer and the facilities at the University of Toronto (courtesy of Drs. G. W. Pearce and D. W. Strangway). The results are included in Table 1 and discussed below.

RESULTS AND DISCUSSION

Age Frequency Distribution

The frequency of dated growth periods in the collection is shown as a histogram in Figure 4. This is broadly similar to other speleothem frequency histograms published for glaciated regions (Gascoyne et al., 1983). The Holocene is strongly represented, and there is some evidence of the 60 to 30 ka mid-Wisconsinan interstadial demonstrated by speleothem studies on Vancouver Island (Gascoyne et al., 1981). The last interglacial is represented with a weak peak of growth between 120 and 130 ka. However, the histogram cannot be considered significant in view of the sampling biases. It may be that some periods of growth within the period 350 to 0 ka have been missed.

The Antiquity of Castleguard Cave

Seven of the 16 speleothems investigated proved to be older than 350 ka. An eighth example, 77031, overlaps this limit at one standard deviation. These samples are distributed throughout the central cave and extend into Helictite Passage in the flood-free upstream part of the Entrance Complex. Ford et al. (1983, this symposium) have shown that all of these passages appear to have been created during one major erosional phase, at the end of which the phreatic parts were drained with little modification, suggesting that dewatering was comparatively rapid.

The five ancient speleothems from First Fissure, the Grottoes, and Second Fissure show evidence of re-solution. In four cases this is "Type 2," or inundation re-solution, as defined above. The fifth case is the Eroded Boss in First Fissure; this suffers severe Type 1 re-solution today, but also shows evidence of earlier Type 2 re-solution. Sample 77032 was a stalagmite that had fallen from the lip of P24, the very head of Helictite Passage; evidence of re-solution is uncertain as it was exposed to a modern drip source where it had come to rest. Two samples from Helictite Passage itself (77037 and 79012) are also eroded, but the re-solution is probably caused by periodic local stream action that is indicated by potholing in the adjacent passage floor.

The most important speleothem is the "Corridor Stalagmite" in the central Grottoes, illustrated in Figure 5. This fossil deposit has suffered considerable re-solution and partial burial. It is over 2 m in height, the true base being masked by clastic debris. It is partly buried by an indurated clayey silt. The "Third Silt" (Schroeder and Ford, 1983, this symposium) is present at both ends of the Grottoes, so it is inferred that final burial was by that silt or reworked deposits of it. Immediately about the stalagmite the silt settled as a consequence of sapping, and a younger flowstone layer was deposited upon the settled surface. Silts were later removed from beneath this layer to leave it suspended as a "false floor"; it is represented by sample 79016 (Table 1). Sixty centimeters above the false floor a "collar" on the stalagmite appears to correspond to the undisturbed surface of the silts seen in the background.

The stalagmite reveals very complex growth layering that is truncated by re-solution facets. The top is eroded away. The upper part was probably of greater diameter than it is today. Much of the complexity of the layering can be explained if it is supposed that the deposit has suffered several periods of Type 2 re-solution, interspersed with renewed growth onto unconformable surfaces.

Sample 73010 was a calcite projection on the stalagmite, taken from just below the false floor. It proved to have been deposited from ca. 150 to 90 ka (Table 1), and yielded the oxygen isotope paleoclimate profile published by Ford et al. (1976). It is now appreciated that sample 73010 was an overgrowth onto the Corridor Stalagmite. Its isotopic records are valid in their own right, but the conclusion that at least one major phase of re-solution occurred after ca. 90 ka (Ford et al., 1976: 228) was in error. Sample 77033, taken from closer to the exposed base (Figure 5), yielded a U series age >350 ka, and this was confirmed by analysis of sample 79014, taken from nearby.

An oriented sample, 80701, was taken from near the base of the Corridor Stalagmite. The natural remanent magnetization was measured and its stability was tested by leaving it in the laboratory field for 1 wk before repeating the measurement. It was found to be stable and reversely magnetized. U-Th isotope activity ratios for this sample show it to be older than 350 ka, like samples 77033 and 79014. Its $^{234}U/^{238}U$ ratio of 1.095 indicates that equilibrium has not yet been attained. The time for equilibration of ^{234}U with ^{238}U from some initial disequilibrium is approximately 1 to 1.5 ma. The Earth's magnetic field was reversed between 900 and 720 ka, normal between 970 and 900 ka (the Jaramillo subchron), and reversed before that (see, e.g., Mankinen and Dalrymple, 1979). It is therefore inferred that this specimen probably grew within the period 900 to 720 ka, though a period of growth before 970 ka is not ruled out. From the $^{234}U/^{138}U$ ratio, however, the sample is unlikely to be older than 1.25 ma. The true base of the stalagmite must be older than these measured samples by some unknown span of time.

The Corridor Stalagmite stands in the center of a passage in the Grottoes which was phreatic during the main expansion phase of the cave. Water flowed through it under hydrostatic pressure to spill over into the head of First Fissure, a drawdown vadose canyon (Ford et al., 1983, this symposium). The Grottoes were dewatered and the main expansion phase terminated some unknown period of time before the stalagmite began to grow. It is most unlikely that this dewatering can be younger than 720 ka. From the data presented here it could be older than 970 ka.

A second important deposit is the "Eroded Boss" in the First Fissure (Figure 6). This was a great beehive-shaped stalagmite that grew upon fallen blocks resting on a ledge 7 m above the canyon floor. Its maximum diameter was 6 m. It was deposited by water dripping from a local fault. These waters, now acidic, have carved a shaft overhead and drilled a pothole through the center of the stalagmite (Type 1 re-solution). Remnants of it also display Type 2 re-solution features. Sample 77034 F-1, taken close to the apparent base of the Boss, gave an age >350 ka. A sample at the top of the Boss, 77034 A-1, was also >350 ka. Sample 80702, taken close to the base, is probably reversely magnetized, although imprecise orientation due to steep dip of the flowstone introduces some uncertainty. Sample 73008, taken from the tip of an eroded fin approximately 1 m above the base is 57 ka. The stalagmite was growing, probably intermittently, down to this later time. There is no growth today.

The other ancient samples reported in Table 1 confirm that the cave was dewatered and main phase vadose entrenchment completed in the First and Second Fissures and Helictite Passage before 350 ka. Although there are no paleomagnetic data for these passages, the U-Th results may be taken as general confirmation of the history suggested by the Corridor Stalagmite.

The Age of the Varved Silt Deposits

Schroeder and Ford (1983, this symposium) have shown that at least three deposits of varved silts extend

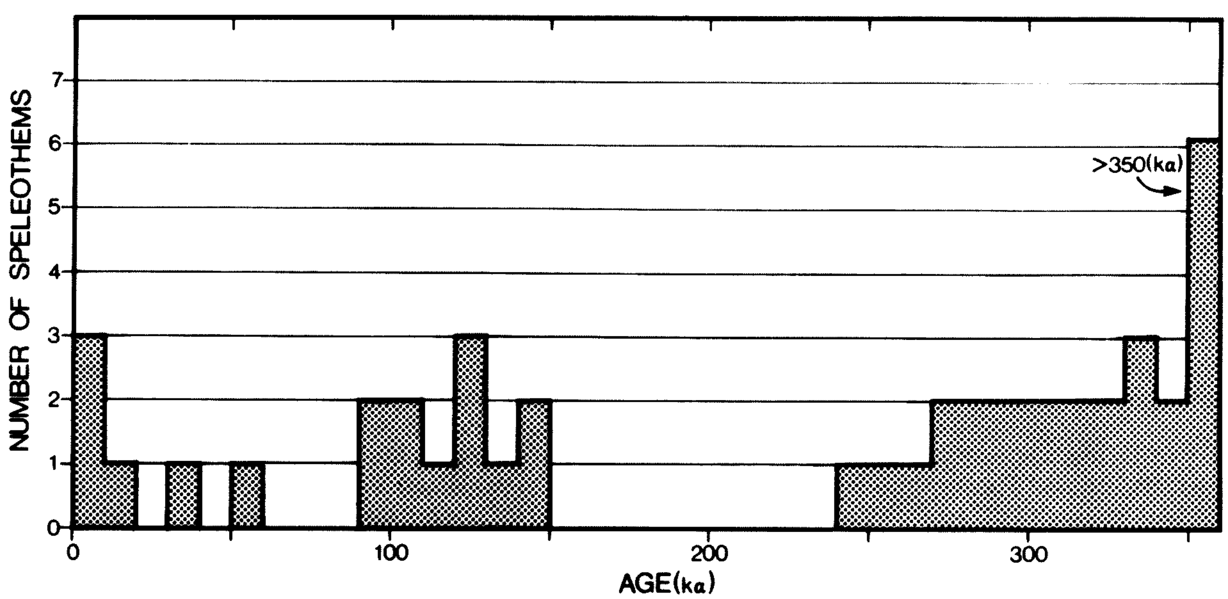

FIGURE 4. Age frequency histogram of the speleothem samples.

through parts of the central cave. Silt deposition was succeeded by phases of induration and local flowstone deposition. The deposits are much eroded by invasion waters today. These authors suggest that the silts were deposited by waters which, at times, inundated all of the cave between P24 and the head of Second Fissure. Inundation must have brought all contemporary stalagmite deposition to a halt.

Samples 80024, 77036, 79016, and 79011 are of thin flowstones overlying uppermost silts in Second Fissure, Holes-in-the-Floor, the Grottoes, and First Fissure, respectively. All four are fresh, without re-solution damage, and are not overlain by any later clastic detritus. Three of them give basal ages of 144, 121, and 100 ka that fall broadly within the last interglacial. The fourth sample was younger (38 ka). These dates strongly suggest that the final Third Silt inundation occurred before about 144 ka.

The abundance of Type 2 re-solution of massive, ancient speleothem deposits in the central cave has been stressed. Most of these speleothems are discolored by fine clastic particles impregnating the eroded surfaces. There seems little doubt that the speleothem erosion was effected by the inundations that also deposited the silts. If the correlation of calcite re-solution with silt deposition is correct, then the Third Silt is certainly older than 144 ka, and the concordance of last interglacial ages for undamaged flowstones resting upon it suggest that it was deposited during the penultimate glaciation.

Schroeder and Ford (1983, this symposium) propose that silt deposition occurred under some parts of "full glacial" conditions. Full interglacial conditions were not attained until some time after 144 ka, as many quite independent records attest (e.g., Shackleton and Opdyke, 1973). This tends to support the "full glacial" proposition for the emplacement of the Third Silt. It may be confirmed by making U-series age determinations across erosional unconformities in the ancient speleothems; such a program might also determine the ages of the First and Second Silts.

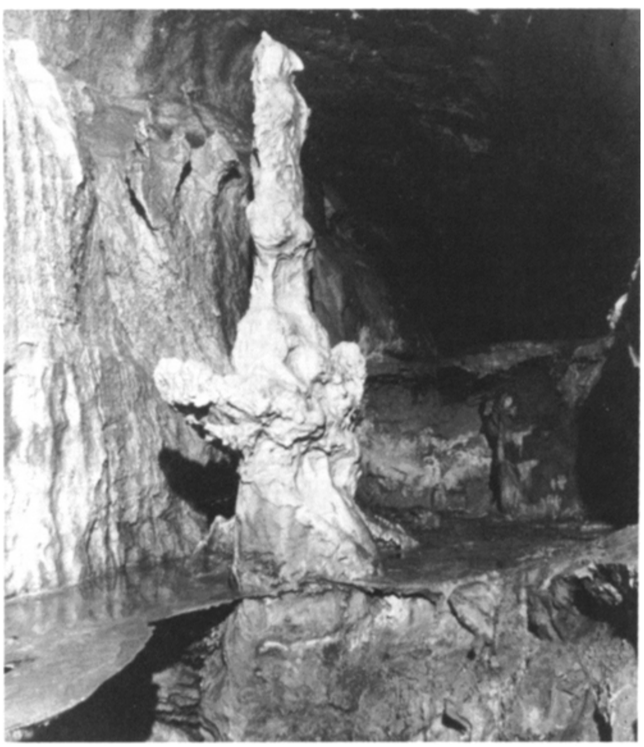

FIGURE 5. The Corridor Stalagmite, central Grottoes of Castleguard Cave. The stalagmite is at least 2 m in height (true base unseen). It has been highly eroded by one or more floods that filled the passage; floodwater velocities were too low to topple it. Deposits of the Third Silt (or later reworkings) form the flat floor seen in the background; this is overlain by undamaged flowstones. Silts settled at the stalagmite and then were sapped away, leaving the flowstone "false floor" seen at the left; speleothem samples 73010, 77033, 79014, and 80701 were taken from projecting facets of the stalagmite exposed below the false floor. Sample 79016 was taken from the false floor at the center of the picture. See text for discussion.

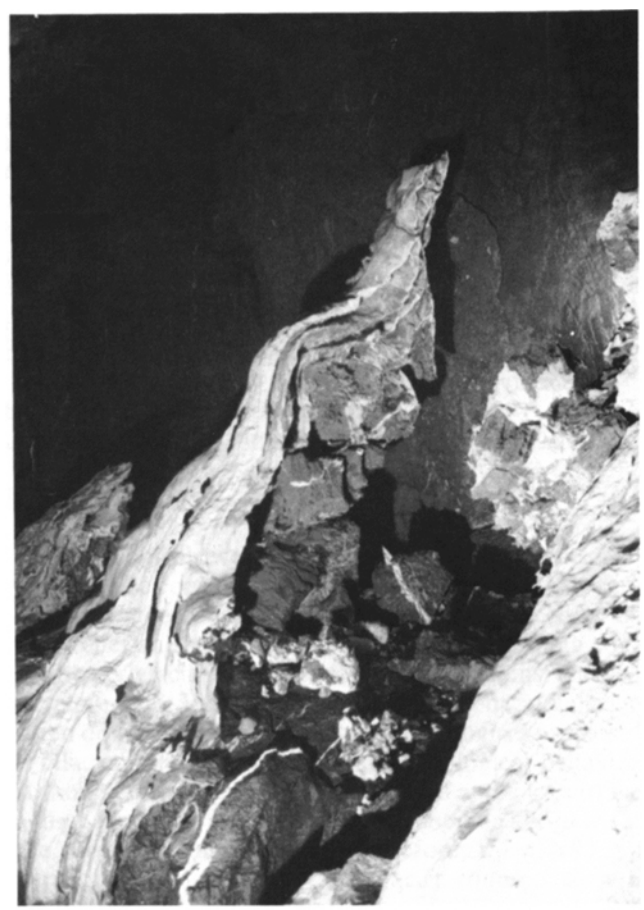

FIGURE 6. The Eroded Boss in First Fissure, Castleguard Cave. Flowstone sheets in center of the scene are ca. 5 m in length. Samples 73008, 77034A, 77034F, and 80702 were taken from this deposit. See text for discussion.

CONCLUSIONS

Calcite speleothems are abundant in parts of the central part of Castleguard Cave, many of them being unusually massive for an alpine environment. The massive deposits divide into two groups: ancient ones that have suffered much re-solution damage, and younger, pristine ones. The latter may include ancient cores fully masked by younger overgrowth.

Samples of these deposits have high uranium concentrations and little detrital thorium, making them well suited for U-series age determinations. Two oriented samples also yielded measured paleomagnetic signals. Speleothem U-series ages >350 ka and one reversely magnetized sample have established that the principal phase of cave development was completed before 720 ka. It may have been complete as early as 1.25 million years ago. Widespread re-solution by inundating waters is tentatively correlated with the three known phases of varved silt deposition and possible earlier phases. The youngest silt, Third Silt, is older than 144 ±6 ka.

REFERENCES CITED

Ford, D. C., Harmon, R. S., Schwarcz, H. P., Wigley, T. M. L., and Thompson, P., 1976: Geo-hydrologic and thermometric observations in the vicinity of the Columbia Icefield, Alberta and British Columbia, Canada. *Journal of Glaciology,* 16(74): 219–230.

Ford, D. C., Smart, P. L., and Ewers, R. O., 1983: The physiography and speleogenesis of Castleguard Cave, Columbia Icefields, Alberta, Canada. *Arctic and Alpine Research,* 15: 437–450.

Gascoyne, M., 1980: Pleistocene climates determined from stable isotope and geochronologic studies of speleothem. Ph.D. dissertation, McMaster University. 467 pp.

Gascoyne, M., Ford, D. C., and Schwarcz, H. P., 1981: Late Pleistocene chronology and paleoclimate of Vancouver Island determined from cave deposits. *Canadian Journal of Earth Sciences,* 18: 1643–1652.

Gascoyne, M., Schwarcz, H. P., and Ford, D. C., 1983: Uranium-series of speleothem from N. W. England; correlation with Quaternary climate. *Philosophical Transactions of the Royal Society,* Series B, 301: 143–164.

Harmon, R. S., Schwarcz, H. P., and Ford, D. C., 1975: Uranium-series dating of speleothems. *National Speleological Society of America Bulletin,* 37(2): 21–33.

Latham, A. G., 1981: Paleomagnetism, rock magnetism and U-Th dating of speleothem deposits. Ph.D. dissertation, McMaster University. 507 pp.

Latham, A. G., Schwarcz, H. P., Ford, D. C., and Pearce, G. W., 1979: Paleomagnetism of stalagmite deposits. *Nature,* 280: 383–385.

———, 1982: The paleomagnetism and U-Th dating of three Canadian speleothems: Evidence for the Westward Drift 5.4 to 2.1 Ka B.P. *Canadian Journal of Earth Sciences,* 19: 1985–1995.

Mankinen, E. A. and Dalrymple, G. B., 1979: Revised geomagnetic polarity time scale for the interval 0-5 my B.P. *Journal of Geophysical Research,* 84(B2): 615–626.

Schwarcz, H. P. and Gascoyne, M., 1983: Uranium-series dating of Quaternary deposits. *In* Mahaney, W. C. (ed.), *Quaternary Dating Methods.* Downsview: York University (in press).

Shackleton, N. J. and Opdyke, N. D., 1973: Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 10^5 year and 10^6 year scale. *Quaternary Research,* 3: 39–55.

Schroeder, J. and Ford, D. C., 1983: Clastic sediments in Castleguard Cave, Columbia Icefields, Alberta, Canada. *Arctic and Alpine Research,* 15: 451–461.

White, W. B., 1976: Cave minerals and speleothems. *In* Ford, T. D. and Cullingford, C. H. D. (eds.), *The Science of Speleology.* London: Academic Press, 267–328.