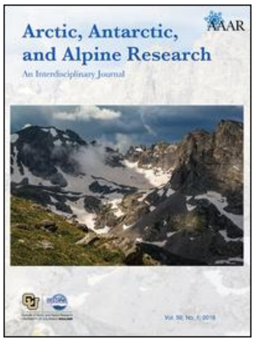

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Concluding Discussion

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CONCLUDING DISCUSSION

This symposium has been tightly focused on specific karst studies in a small geographical area. The purpose of the Concluding Discussion is to briefly indicate some points arising from some of the papers that may be of broad interest to alpine and Quaternary specialists.

The Persistence of the Columbia Icefield

The depletion of biogenic carbon in young speleothems from beneath the Icefield and the Castleguard glaciers (Gascoyne and Nelson, 1983, this symposium) suggests that, throughout the Holocene, the glacier ice has not been very much smaller than it is at present in the area. From similar carbon isotopic data for older speleothems, Harmon et al. (1983, this symposium) propose that the icefield persisted over much of Castleguard Cave throughout the period, 145,000 to 90,000 yr BP. This period was the last interglacial in other regions.

We do not have stable isotopic evidence for persistence during any earlier interglacials. However, it may be noted that the age frequency and comparative ornamentation of dated speleothems from other sites in the Rock and Mackenzie Mountains of Canada (Harmon et al., 1977) suggest a stronger, more protracted, interglacial phase extending back from ca. 280,000 yr towards the U-series dating limit at 350,000 yr. Because it is close to that limit, it is difficult to be more specific about that apparent phase.

Our impression is that the Columbia Icefield is likely to have persisted since, at least, the start of a colder phase about 280,000 yr ago. It is a highland ice cap built upon a stepped plateau at 2300 to 3000 m a.s.l. It is the most extensive surviving example of a source glacier ice mass in the modern Rocky Mountains.

Older Evidences of Glacial Action

Gascoyne et al. (1983, this symposium) have shown from the speleothem evidence that the principal passages of Castleguard Cave were already drained and relict at least 750,000 yr BP. It is quite possible that their drainage occurred before 1,250,000 yr BP. They were drained by development of an underlying passage system, Castleguard II, that continues in action today.

Central arguments of the speleogenetic paper (Ford et al., 1983, this symposium) were that (1) Castleguard Cave itself was developed as an offshoot or diversion drain from older caves, and (2) this diversion was of a very unusual kind in speleogenesis. It led to the creation of a long, unbranched passage passing beneath a mountain. The best explanation for this unusual behavior is that glacial infillings obstructed the older caves, compelling the diversion.

This may be taken as circumstantial, but strong, evidence that there has been powerful glacial action at the Columbia Icefields for at least the past 1,000,000 yr. Ford et al. (1981: 8) have contended from more general evidences that glaciers are likely to have been present (sporadically at least) for 4,000,000 yr or more.

The Interaction of the Glacial and Karst Erosion Systems

Castleguard Cave and the modern, inaccessible karst drainage systems, Castleguard II and III, all appear to have developed at unknown times after the first effective glacial erosion of the region. Possibly, the important new developments in the karstic systems occurred at stages during remote interglacials when all glacier ice was removed, i.e., when the more "normal" karst environmental conditions of continuous soil and vegetation cover may have prevailed. This cannot be shown. What we may assert is that no significant components of the modern Castleguard karst are truly "preglacial." The glacial and karstic erosion of the landscape have proceeded broadly together.

This resolves a major uncertainty in much earlier alpine karst study: whether it is possible to generate large karst systems during the period of the Quaternary glaciations, or whether their very existence is sure evidence of the survival of preglacial erosion phases in the landscape. The earlier work was centered in mountain regions of notably less severe alpine glaciation, i.e., the Alps, the Pyrenees, the Caucasus, the Atlas, etc. The amount and geographical extent of erosion by glaciers in them is locally less than is general in the Rocky Mountains of Canada. The question of a preglacial origin for karst elements may be a genuine perplexity at such sites. Here, it has been shown that it is not necessary to postulate preglacial origin where a large and well-integrated karst is known to exist.

Some Surficial Mean Erosion Rates

From C. C. Smart's hydrological analysis (1983a, this symposium), the modern solution rate for carbonate rocks at the base of the glaciers and the Icefield is 6 to 15 mm 1000 yr^{-1}, or 6 to 15 m^3 km^{-2} yr^{-1}. This is a low erosion rate for a mountain environment; it may be contrasted with values of 80 to >1000 mm 1000 yr^{-1} cited by Embleton and King (1975), for example. The Castleguard rate refers only to bedrock solution, not to the aggregate for all erosion processes. Nevertheless, it is an unusually low solution rate, reflecting the fact that the waters are depleted in CO_2 with respect to global norms.

The paleomagnetic age result for the Corridor Stalagmite (Gascoyne et al., 1983, this symposium) gives us a minimum age for the lowering of springs in Castleguard Valley below levels that maintained inundation in the central relict cave. Lowering of spring elevations implies entrenchment of valley floors. Ford et al. (1981) used these relationships at Castleguard and at Crowsnest Pass to the south to obtain estimates of mean valley deepening rates in these areas. The rate at Castleguard may now be refined from our more recent work. Deepening of the Castleguard Valley downstream of the present snout of the South Glacier has proceeded at a mean *maximum* rate of 13.7 cm 1000 yr^{-1} if the absolute minimum timespan that has been demonstrated (730,000 yr BP) is taken. This rate falls to ca. 10.0 cm if a more likely span of 1,000,000 yr is assumed. The latter is a rate very close to those that can be more narrowly defined at the Crowsnest sites (Ford et al., 1981: Table 2).

Cliff recession by quarrying is common in alpine landscapes. It is very prominent in the Castleguard area which is a carbonate benchland. Crevassing in the southern icefield indicates that there are steps and benches beneath the ice. These are in the upper Cathedral Formation plus, perhaps, a moutonnée in the Stephen Formation (Ford et al., 1983, this symposium). The Headward Complex of the cave is in the upper Cathedral beds and evidently first developed when the local Stephen strata were stripped back by cliff recession. Assigning a minimal age of 1,000,000 yr BP to the Headward Complex, a mean scarp recession rate of ca. 3.2 m 1000 yr^{-1} is needed to erode the Stephen scarp to its present approximate position. The true mean recession rate is almost certainly lower, because the Headward Complex of the cave is older. If we guess a likely maximum age of 3,000,000 yr BP for the latter, a scarp recession rate of ca. 1.0 m 1000 yr^{-1} is obtained.

There is much uncertainty in these recession estimates. Nevertheless, it is probably valid to conclude from them that scarp recession (by quarrying and other processes aggregated) has been proceeding faster by an order of magnitude than valley deepening by entrenchment in the same rocks at the same sites. Stripping of regularly bedded strata proceeds more rapidly in a temperate glacier environment. This will be particularly true where strata are soluble, permitting subglacial groundwaters to penetrate them and commence their detachment.

Water at the Base of Glacier Ice Passing into Karst Rocks

C. C. Smart (1983a, this symposium) has shown that the upper half of the Saskatchewan Glacier, a substantial part of the central Columbia Icefield, and the small cirque glaciers surrounding Castleguard Mountain are drained karstically to a system of springs in the Castleguard Valley. For the upper Saskatchewan and the Icefield, this condition has prevailed for at least the past 750,000 yr, although there have probably been significant extensions of the plumbing beneath the icefield during that time. The modern plumbing system is very efficient: water is cleared rapidly from the base of the ice through the rock to springs. Mean underground velocities established by dye tracing experiments are generally in excess of 100 m h^{-1}.

The sinking waters include supraglacial melt streams, subglacial pressure melt waters and (presumably) mixtures of the two. Within the space of a few hours the supraglacial waters are descending through 300 m of glacier ice and more than 500 m of bedrock strata; strong diurnal melt pulses are received at the karst springs. At the base of the ice these waters are directed by Nye (bedrock) subglacial channels which deliver them to karst sinkpoints which are usually vertical shafts descending major joints. These waters are dissolving limestone and transporting erratic material of cobble size and smaller into the caves.

Nye channel water flow completely ceases during the winter. The channels may be temporarily sealed by plastic deformation of the basal ice in that season, but all that are draining to known shafts appear to be open and active every summer. In addition, Atkinson et al. (1983, this symposium) have shown that air may flow from branch passages of the Headward cave into the base of the icefield at mean rates of 2 m^3 s^{-1} or greater, throughout the winter. Evidently, some ice base cavities remain open and efficiently connected to the Icefield surface where the air is discharged.

Atkinson et al. (1983, this symposium) also expand upon a point suggested earlier by Ford et al. (1976). The flow of meltwater down into the karst rock may reduce the upward flux of geothermal heat reaching the ice base. Their suggested reduction is about 66%.

The subglacial pressure meltwaters have deposited outstandingly good displays of calcite precipitate at lee positions on the glacierized carbonate bedrocks in this region. C. C. Smart (1983a, this symposium) shows that the water often makes short passes through the bedrock to gain these positions, rather than following the ice-rock interface. In so doing they are creating microcave systems. Smart further suggests that penetration by pressure meltwaters may be the explanation of the genesis of macrocave systems beneath the ice.

It is most probable that the pressure meltwaters are the sources of drip water observed to be vigorously depositing stalactites in cave passages that (in some instances) may be no more than 5 m beneath the ice. Atkinson (1983, this symposium) has investigated the very complex chemical evolution that may occur along the path between ice base and stalactite tip. It appears that most water flow and calcite deposition occurs during the summer, but some waters are still flowing at the stalactite tips at the close of the winter season.

Many other points concerning ice base hydrology and the karst interaction in the Castleguard area may be found in C. C. Smart's newly completed Ph.D. thesis (September 1983) (Smart, 1983b).

Subglacial Hydrological Conditions Producing Periodic Inundation with Varved Silt and Clay Deposition in Castleguard Cave

Since the relict cave was first fully drained there have been at least three phases of substantial and prolonged inundation. During each, some calcite speleothem and wall rock was dissolved by acidic waters, and sequences of varve couplets of silt and clay were deposited. Depth of inundation exceeded 300 m in at least one of the phases. Aggregate depth of varved material that accumulated during a phase may exceed 5 m. Within each phase, waters drained away slowly but entirely on one or more occasions, and then returned. Each phase was succeeded by periods of erosion, dessication, or calcite deposition onto the silts. The last depositional phase terminated before 145,000 yr BP, i.e., varve deposition did not occur in the cave during any part of the last glacial cycle (Schroeder and Ford, 1983, this symposium).

It is difficult to understand the nature of the karst-plus-alpine-glacier system creating such phenomena. Three possible models may be suggested: (1) The inundating waters poured in through the head (upstream end) of the relict system. This requires generation of a great deal of meltwater and of turbid load at the central Columbia Icefield, implying fini-glacial conditions. In such conditions the springs in the valley would be ice-free, and one cannot imagine a mechanism to block them all simultaneously (and unblock them gently from time to time); such a mechanism is required to effect the inundation. (2) The inundating waters entered the system (and withdrew from it) laterally from a major glacier occupying the Castleguard Valley, i.e., the cave was adjunct and hydrologically subsidiary to a glacier with a raised water table. As an example, such a water table would need to be raised 200 m above the bedrock floor where the snout of South Glacier now stands. A reasonable hydraulic gradient in the downstream direction then demands that the valley glacier be no less than ca. 32 km in length. This is a model of inundation and varve deposition during some part of full glacial conditions. It explains the ebbing and flowing characteristics and furnishes sources of turbid load. It hints that perhaps a lesser magnitude of Wisconsinan glaciers explains the absence of Wisconsinan inundations. However, calculations suggest that it requires unreasonably high melt rates in upstream glacial areas to sustain the 200-m water table. (3) The inundating waters rose out of the Castleguard II system underlying the relict cave. In this model, the relict system is functioning as a muddy manometer. There is a modern example of such behavior, the summer flooding of the downstream (entrance) zone of the relict cave by waters rising up and overspilling the Boon's Blunder well (Ford et al., 1983, this symposium). The model requires some steep hydraulic gradients within the bedrock karst system but obviates the need to flood adjunct glaciers. The sources (and causes) of the high turbidity flooding are not known, however, and a fully analytical application of the model probably requires that the springs be obstructed in some nonrandom fashion.

A Subglacial Refugium

Holsinger et al. (1983, this symposium) have shown that one very rare and one apparently unique species of cave-adapted aquatic animals live in pools in the relict cave today. Their range extends beneath the glacier ice, i.e., all waters reaching them are from supra- or subglacial melt sources.

These small and specialized animals are not great travelers; they migrate and colonize very slowly. Holsinger et al. suggest that this is very strong (though not incontrovertible) evidence that they survived at least the Wisconsinan glaciation in the cave. They were living in a subglacial refugium.

An evident problem is that of food supply beneath an extensive ice cover. Possibly, they ate each other. Alternatively, flowing water supplied organic matter that was either weathered from the subglacial rocks (e.g., the Stephen shales) or deposited onto the contemporary snow surfaces (e.g., windborne algae) and then carried underground, or both. Food from flowing water seems more likely. It implies that throughout the coldest glacial periods (when all of Castleguard karst will have lain well inside of the regional firn line) some water circulated from the base of the ice into the rock and out again. If windborne nutrients were important, then it must be supposed that surficial meltwaters passed downwards through the firn pack and ice to gain caves then 500 m or more below.

REFERENCES CITED

Atkinson, T. C., 1983: Growth mechanisms of speleothems in Castleguard Cave, Columbia Icefields, Alberta, Canada. *Arctic and Alpine Research,* 15: 523–536.

Atkinson, T. C., Smart, P. L., and Wigley, T. M. L., 1983: Climate and natural radon levels in Castleguard Cave, Columbia Icefields, Alberta, Canada. *Arctic and Alpine Research,* 15: 487–502.

Embleton, C. and King, C. A. M., 1975: *Glacial Geomorphology.* London: Arnold. 573 pp.

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., Schwarcz, H. P., Drake, J. J., Gascoyne, M., Harmon, R. S., and Latham, A. G., 1981: Estimates of the age of the existing relief within the southern Rocky Mountains of Canada. *Arctic and Alpine Research,* 13: 1–10.

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., Latham, A. G., Harmon, R. S., and Ford, D. C., 1983: The antiquity of Castleguard Cave, Columbia

Icefields, Alberta, Canada. *Arctic and Alpine Research,* 15: 463–470.

Gascoyne, M. and Nelson, D. E., 1983: Growth mechanisms of recent speleothems from Castleguard Cave, Columbia Icefields, Alberta, Canada, inferred from a comparison of Uranium-series and Carbon-14 age data. *Arctic and Alpine Research,* 15: 537–542.

Harmon, R. S., Ford, D. C., and Schwarcz, H. P., 1977: Interglacial chronology of the Rocky Mountains and Mackenzie Mountains based upon ^{230}Th-^{234}U dating of calcite speleothems. *Canadian Journal of Earth Sciences,* 14: 2543–2552.

Harmon, R. S., Atkinson, T. C., and Atkinson, J. L., 1983: The mineralogy of Castleguard Cave, Columbia Icefields, Alberta, Canada. *Arctic and Alpine Research,* 15: 503–516.

Holsinger, J. R., Mort, J. S., and Recklies, A. D., 1983: The subterranean crustacean fauna of Castleguard Cave, Columbia Icefields, Alberta, Canada, and its zoogeographic significance. *Arctic and Alpine Research,* 15: 543–549.

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

Smart, C. C., 1983a: The hydrology of the Castleguard karst, Columbia Icefields, Alberta, Canada. *Arctic and Alpine Research,* 15: 471–486.

———, 1983b: The hydrology of a glacierised alpine karst: Castleguard Mountain, Alberta. Ph.D. thesis, McMaster University. 343 pp.

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