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PETER W. MARSHALL*
Winnipeg

THE FORMATION AND AGE OF ICE IN CAVES

Abstract

Controversy regarding the age and origin of deposits of massive ice in high altitude caves has existed for almost a century. Some writers believe that the ice has formed during postglacial time, while others suggest glacial origins for the ice. Caves falling into the latter category are commonly at high altitudes in recently glaciated or periglacial regions.

Two cases illustrating crystallographic and isotopic techniques used in the study of cave ice are described from western Canada. In one case a vertical wall of ice completely blocks passages in a high altitude cave. In the other case two caves situated in a low altitude lava flow, which has been dated by radiocarbon analysis, are blocked by horizontal ice. The summary discusses the similarities in the ice crystallography of the caves and points out that the terms fossil and glacial ice must be severely restricted when describing cave ice deposits.

INTRODUCTION

For almost a century the lack of basic data has led to controversy over the origin and age of massive ice formations in some caves. The controversy centers on those deposits of ice in caves whose temperature remains below freezing throughout the year. In some cases vertical walls of ice completely block passages. Such ice formations are substantially different from minor formations for two reasons: (1) the principle of uniformitarianism: i.e., that the "present is the key to the past", cannot be rigidly applied; (2) the deposits are often found in recently deglaciated or in periglacial environments.

Recently some authors have revived the theory of fossil glacial ice to explain deposits in some high altitude or high latitude regions (CASTERET, 1954; HALLIDAY, 1954, p. 17; 1970, p. xvi; MERRIAM, 1950, p. 1). Supporting the glacial ice theory are cave temperatures low enough that ice could have survived any postglacial warm periods. The literature, on the other hand almost consistently favors the freezing of meteoric water.

BALCH was one of the pioneers in the study of ice caves (1900). In a detailed set of deductions based on numerous analytical observations, he considered the origin of cave ice to be a function of temperature, availability of water, cavern shape, and topographic location. Most important, BALCH noted that in many ice caves the ice was associated with ponded water (1900, p. 7, 12), or occurred at horizontal surfaces comprised of prismatic crystals similar to the ice cover on a frozen lake (1900, p. 2, 129—130). At this early date, the theory of a glacial origin for cave ice was discounted (1900, p. 55).

Over the next half century the number and detail of observations increased both in Europe and North America. Many American ice caves were discovered in lava

* The University of Manitoba, Winnipeg, Manitoba. Present address: 2074 Lorne Ter., Victoria, British Columbia, Canada.

flows at high altitudes (HARRINGTON, 1934; LEE, 1926; MACCLARY, 1936; SWARTZLOW, 1935). LEE noted horizontal layers separated by thin seams of impure ice which he thought might represent annual accumulations or climatic cycles of several years. In either case he felt that a depositional chronology might be determined (1926, p. 56, 59). HARRINGTON noted that despite a mean annual temperature of 6.1 °C the cold air of winter was sufficient to maintain ice at depth. SWARTZLOW expanded on HARRINGTON by suggesting that ice is often located at the lower end of a downward sloping passage in which dense cold air maintains depressed temperatures. Also, he noted that the dead air spaces in the basalt act as an insulator for the ice (1935, p. 441—442). Even in the glaciated Rocky Mountains of Canada, there is no suggestion that cave ice is actually fossil glacial ice, but, rather that the formation of ice depends on the availability of water and temperatures below freezing (Canada, Department of the Interior, 1907).

In Europe ice cave studies were more advanced at this period. FUGGER in 1886, proposed a winter ice theory based on measured variations of growth and decay of ice in Austrian caves (ABEL, 1953, p. 322). In some caves, records of the position of ice deposits have been maintained from 1879. Numerous observations of relative ice positions and cave temperatures were undertaken in the first three decades of this century (ABEL, 1934; KYRLE, 1929; OEDL, 1923; PIRKER, 1929; RACOVITZA, 1927; SAAR, 1921). However, the methodology of ice crystal analysis was only beginning to be understood. Thus the assigning of an age to cave ice was not possible.

By mid-century temperature and ice growth observations were sufficiently numerous that theories based on data were being presented. ABEL categorically rejected suggestions that ice in Austrian caves was of glacial origin by illustrating that only slight differences in temperature were required in order to considerably influence underground ice, and even to cause its complete disappearance (1953, p. 324). He noted that from the last glaciation to the Middle Ages there has been a noticeable increase in temperature — an increase sufficient to cause the melting of ice in Austrian caves. Recent, cooler temperatures provided suitable conditions for the accumulation of ice.

KUNSKÝ used archaeological evidence to give a maximum age of 2,000 years before present to the ice in Silica Cave (1954, p. 176). Very few cases exist, however, where dates have been assigned to either minor or major ice deposits.

The problem of assigning an age to major cave ice deposits is a lack of critical data in two subject areas: (1) detailed study of ice crystals and bands or layers in the ice to determine the mode of origin, and (2) dates obtained by archaeological, pollen, or isotopic methods. The first type of study would be able to determine whether or not ice moved into the caves by plastic flow, or if it derived from the freezing of cave water. Crystallographic studies would not, however, be able to differentiate between glacial melt water or meteoric water accumulations. Dating by one or several of the above methods would determine the age and possibly the origin. Together, the crystallographic and dating techniques should be able to clearly indicate the origin of a given ice deposit.

The two cases which follow illustrate the above mentioned techniques.

CASE 1: COULTHARD CAVE

Coulthard Cave is located in the Crowsnest Pass area of southwestern Alberta, at an elevation of 2,650 m above mean sea level. The entrance of the cave faces north, and all but one of the passages in the cave end in ice blockages. Some of these passages are greater than 6 m in diameter and the ice surfaces are clear enough that the passage walls may be seen extending 3 m beyond the ice wall.

The ice deposits in Coulthard Cave are unlike many of those cited in the literature. The ice does not persist as extensive, almost horizontal floors, but rather as steeply sloping or vertical faces which completely block the passages. Many caves that contain seasonal ice also contain ample evidence of melt water movement; Coulthard Cave is dry, notably in downward sloping passages blocked by ice. Ice stalagmites commonly found associated with the margins of ice floors in other caves are not found in the proximity of the ice blockages. Rather, in Coulthard Cave, they are located only near the cave entrance where the temperature of the rock walls is considerably warmer than the —2.6° C recorded at the end of the ice blocked passages.

In order to determine the structure of the ice and, thereby, the likely method of freezing, laboratory petrofabric analysis was carried out on samples removed from the cave (Marshall and Brown, 1974). Since crystal orientation is the most important parameter for predicting the properties of a given block of ice, it receives the major attention in ice studies (Knight, 1963, p. 319). While the literature on ice orientations is quite extensive, the few crystallographic studies, undertaken on cave ice, have been limited to ice speleothems (Pulinowa and Pulina, 1972; Racovitza, 1927).

Distinctive crystal patterns identify each of the following possible variants of massive ice: (a) forceable entry of glacial ice, in which case the crystal long axes would be parallel and the c-axes would be perpendicular to the direction of the cave passage; (b) sheet flow of water seepage through the walls or roof would deposit thin layers of crystals orientated perpendicular to the air-ice interface; (c) freezing of a cave stream would present a radial crystal pattern, possibly with semicircular layers when viewed in cross section; and (d) ponded water crystals may have either vertical or horizontal orientation, but the strata would be considerably thicker than those of variant "b" and the upper surface of the strata would be horizontal.

The studies ascertained that the ice in Coulthard Cave is variant "d". Ice froze downward from the surfaces of successive ponds, each stratigraphically higher than the last. Vertical crystals of large dimensions (greater than 7 cm in diameter and greater than 10 cm in length) containing columns of bubbles are located at the top of each stratum. Initially, supercooling decreased away from the freezing surface and the c-axes orientation paralleled the direction of heat flow (perpendicular to the ice-water interface). The c-axes of ice 15 cm or more below the former pond surfaces are horizontally or randomly oriented. A similar transition from vertical to horizontal orientation has been found in lake ice (Perey and Pounder, 1958; Lyons and Stoiber, 1959).

The number and volume of gas inclusions increases markedly with depth. In the upper section of each stratum, bubbles occur as vertical chains either within single crystals or at the boundaries of two or more crystals. Within the horizontally oriented crystals the bubbles are distributed throughout the ice and it is thought that the bubbles blocked the growth of vertical crystals while initiating new crystals which grew in a radial pattern from the lower surface of each bubble. These new crystals rapidly blocked the growth of neighbouring ones creating an aggregate of crystals each less than 1 cm in diameter.

It is postulated that the ice in Coulthard Cave formed by the ponding of water after passages had been blocked. Ice froze downward from the pond surfaces, first as larger vertical crystals, then with the accumulation of numerous bubbles, as small horizontally or randomly orientated crystals (Marshall and Brown, 1974).

Presently the ice is dissipating directly from the solid to gaseous state at temperatures below freezing: there is no melt water. The surface of the ice is scalloped by a series of convectional air cells which ablate the ice surface, indicating the formation of larger but slower moving convectional air cells in the upper, distal sections of the ice blockage. Since there is no input of melt water, ablation transforms the originally horizontal ice surface into a sloping and, finally, vertical ice face.

CASE 2: AIYANSH CONE SERIES

An indirect method of determining the age of ice accumulation is to date the age of the cave. This technique is particularly useful in the case of the Aiyansh lava flow, British Columbia (55° 7′N, 128° 54′W) which is one of the youngest volcanic features in western Canada (Sutherland Brown, 1969, p. 1460). A corrected radiocarbon date of samples from involuted trees on the edge of the flow indicates an age of 250 ± 130 years before present (Geological Survey of Canada — 1124).

Two of the four caves in the region of the vent are ice free most of the year. One, Cave A, contains a small braided stream which likely freezes in winter. The other, Cave D, is dry and does not contain stream sediments, indicating that it remains dry. Both caves have exit points for stream flow or precipitation runoff at their lowermost levels. The two other caves, B and C, are not only situated at slightly higher elevations than the two noted above, but they are also completely blocked by floors of horizontal ice. In summer as much as 20 cm of water covers the ice indicating that neither of the ice caves has a low level exit.

Studies in these caves situated at 600 m above mean sea level indicate that the uppermost crystals are long, oriented vertically and, in summer, are truncated by melting. Within some crystals are seen vertical chains of bubbles each approximately 2 to 3 mm in diameter. The bubbles extend downward to a former ice surface, without increasing markedly in number or volume. Although only a limited depth of ice could be studied, it is interesting that the detailed observations are quite similar to those which Balch made in a number of European and North American caves (1900).

The significant feature of the Aiyansh Cone Series is that the caves, two of which are filled by ice, have formed under present climatic conditions in very recent times.

It is one of the few deposits of cave ice that have been dated. That the ponding and freezing of water at a low altitude site having a mean annual temperature of 5 °C occurs at present has a bearing on the studies of other similar ice deposits (MARSHALL, in press).

SUMMARY

The ice caves discussed in this paper are all completely blocked by ice. Crystallographic studies were undertaken in the caves in order to determine the method of ice deposition.

In both high and low altitude caves, it was found that the cave passages had been blocked, water was ponded, then freezing progressed downward from the pond surface. Successive layers may or may not be separated by sediment bands, depending on the origin of the water. Where cave temperatures remain below freezing throughout the year, the ice slowly ablates by sublimation. Where cave temperatures are above freezing for part of the year, melting of the ice surface may occur, truncating crystals and providing water for a new stratum of ice.

High altitude caves which had been thought to contain "fossil" or "glacial" ice, appear to have been ice filled by the same process as some very recent caves at low altitudes. It is thought that the ice in some high altitude caves may have been deposited during the Hypsithermal period when temperatures were warmer than at present. Another possibility is that during deglaciation, the caves may have received inputs of glacial melt water which must be considered distinct from the actual impingement of glacial ice into the cave. Crystallographic studies, alone, are insufficient to distinguish between the two possible sources of ice; however, they do indicate that the term "fossil" or "glacial" must be severely restricted in the context of caves containing ice deposits.

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