AN ICE CALDERA IN NORTH-EAST GRAHAM LAND

By N. AITKENHEAD

AN ice caldera, which was first noticed on a vertical air photograph, was visited on three occasions by the writer in 1961 whilst carrying out geological field work in north-east Graham Land. Steep-sided depressions and crater-like features on glaciers and ice shelves have been reported from Antarctica by several observers, especially Fleming and others (1938, p. 512), Stephenson and Fleming (1940, p. 160) and Mellor and McKinnon (1960). Of the various names—ice doline (Mellor, 1960), ice cauldron and ice caldera—which have been given to these features, the last term is used here because it implies the mode of circular collapse which is thought to have taken place initially in this case. A comparison is also made between this ice caldera and other similar features.

GENERAL CLIMATIC AND GLACIAL CONDITIONS

The position of the ice caldera is lat. 64°12′S., long. 58°58′W. (Fig. 1). It is situated near Mount Wild, 1·75 miles (2·8 km.) north-north-east of the northern lateral moraine of the Sjögren Glacier on a relatively inactive tributary glacier. Many of the climatic and

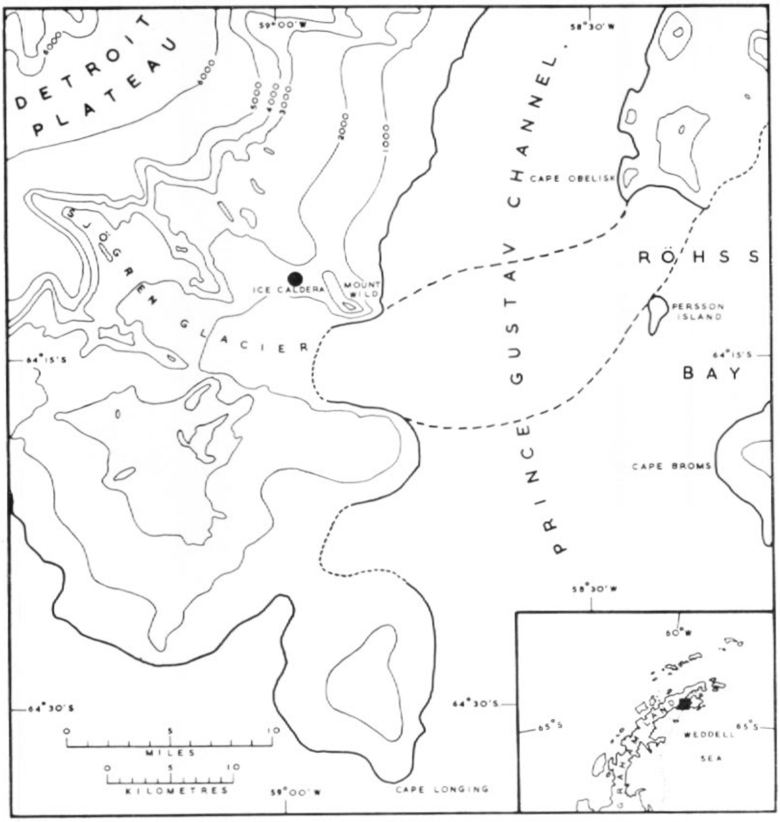

Fig. 1. Sketch map of southern Trinity Peninsula and Prince Gustav Channel showing the location of the ice caldera. The inset shows the area's position in Graham Land. Contours at 1,000 ft. intervals.

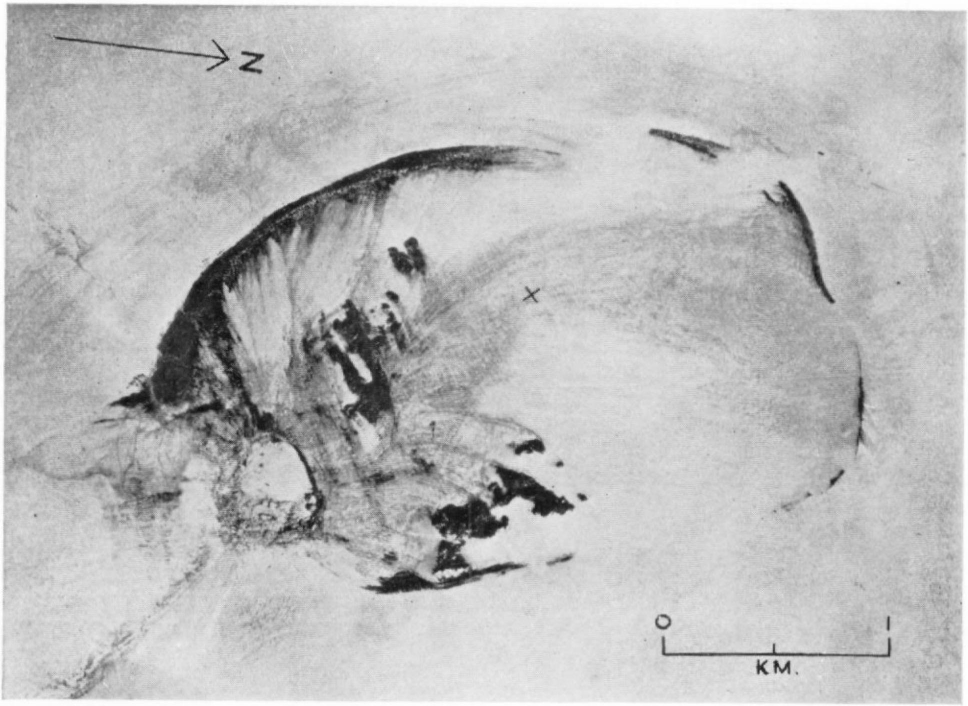

Fig. 2. An air photograph taken in February 1957 showing the ice caldera in its drained state and the moraine encircling the bedrock knolls.

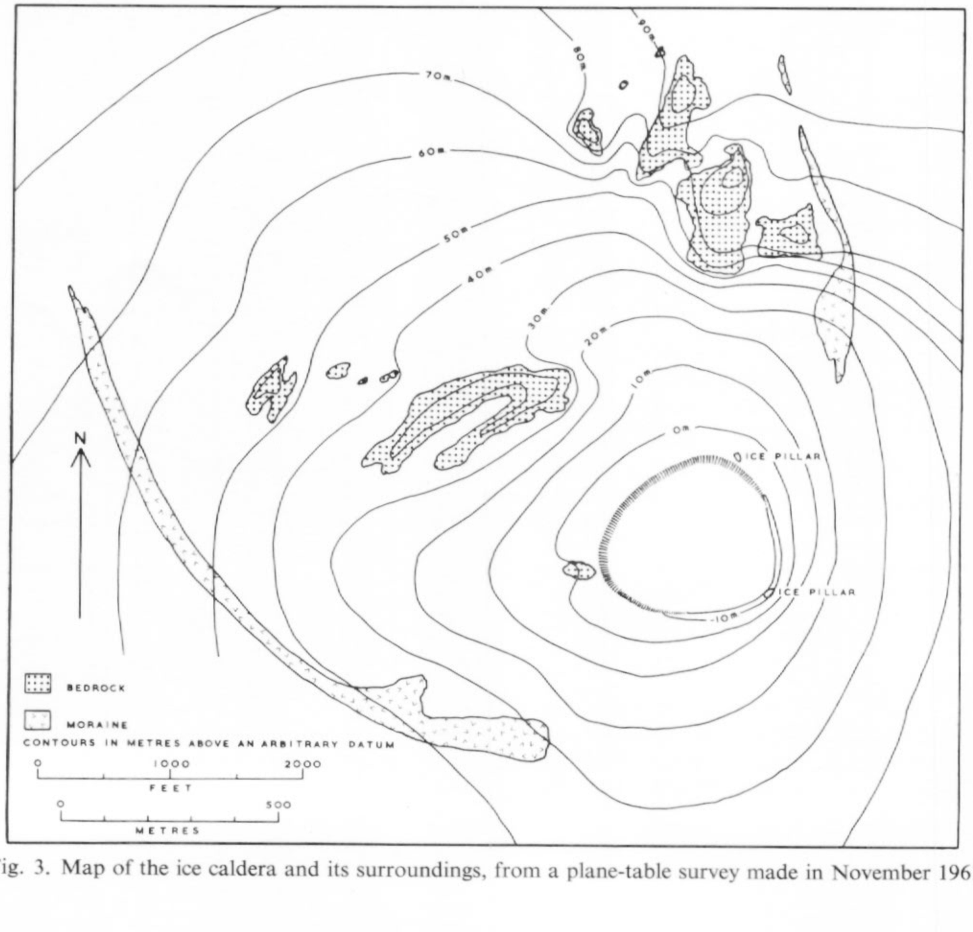

Fig. 3. Map of the ice caldera and its surroundings, from a plane-table survey made in November 1961.

glaciological features described by Koerner (1961*b*) in the more northern parts of Trinity Peninsula are also found in this area.

Observations made by the writer on the Sjögren Glacier suggest that below about 1,200 ft. (366 m.) snow accumulation is virtually nil. Even in August there were large areas of bare glacier ice and fresh moraine commonly occurred on the ice surface, especially near the edge of the glacier. This moraine consists of an unsorted conglomeration of boulders, pebbles and rock flour. Some of the larger boulders are supported by a column of ice forming glacier tables. Low precipitation and frequent strong dry winds which are often of the föhn type are probably the two most important factors preventing snow accumulation and aiding ablation. Deep channels in the ice suggest that at times there is an abundance of melt water which either gathers in surface pools or finds its way into the subglacial drainage system. Many of the features associated with the glaciers in this area are more characteristic of alpine glaciers than of Antarctic glaciation.

The Ice Caldera

1. *General description*

Despite considerable gradients in the glacier surface near the ice caldera only a few small crevasses are present, giving the impression that the ice is very slow-moving or is quite stagnant in places. A group of bedrock knolls crops out immediately up-stream of the ice caldera (Figs. 2 and 3). These knolls are ice smoothed, striated and unweathered greywackes and phyllites, and most of them show a typical roche moutonnée form. The highest of the knolls is about 345 ft. (105 m.) above the rim of the ice caldera, while the lowest is only 16·4 ft. (5 m.) from the rim. A moraine, which has a very striking oval shape in plan, partially encircles the ice caldera and the bedrock knolls (Figs. 2 and 3). This moraine probably marks the boundary between the stagnant ice surrounding the knolls and the moving ice of the glacier.

The ice caldera itself lies at the bottom of a large roughly circular depression (Fig. 4). In October 1961 it was oval shaped, being 396 yd. (363 m.) wide in a north–south direction and 417 yd. (383 m.) wide in an east–west direction. On the immediate down-glacier side the lowest part of the glacier surface is about 115 ft. (35 m.) above the rim of the ice caldera.

Fig. 4. The ice caldera from the south-west with Mount Wild in the background, showing the fallen lake surface and the general topography of the surrounding area. 18 October 1961.

The caldera contains a lake whose level has shown spectacular changes. It is suggested that the behaviour of this lake is directly related to the formation of the ice caldera.

2. *The ice caldera before drainage*

The ice caldera was first visited during the mid-winter period in June 1961. The whole area was under a fresh snow cover which had an average depth of about 3·2 in. (8 cm.) and visibility was very poor. The presence of the ice caldera was barely discernible as the frozen surface of the lake had risen and stabilized at a level just submerging the rim. A few large pieces of rounded and weathered ice were scattered about the lower slopes of the depression. These included one large ice pillar about 20 ft. (6 m.) high which was situated right on the edge of the flat lake ice. Photographs taken from one of the Survey's "Otter" aircraft in April 1961 show the ice caldera in a similar state to that observed in June.

3. *The ice caldera after drainage*

The presence of the ice caldera was first noticed on air photographs taken by the Falkland Islands and Dependencies Air Survey Expedition in February 1957 (Fig. 2). A close examination of these photographs shows that the lake was in its post-drainage state with the lake ice level at least 66 ft. (20 m.) below the rim. Fallen ice debris was banked up against the ice caldera walls and some of this was probably resting on the lake floor. February 1957 was an exceptionally warm month with a mean daily temperature at Hope Bay of +1·7° C. The effects of these conditions are well demonstrated on the air photographs, which show large areas of bare glacier ice, numerous melt streams and surface melt-water ponds.

The first visit to the ice caldera in its drained state was made on 2 August 1961. The six days preceding this date were unusually warm with the temperature at sea-level in the nearby Prince Gustav Channel area remaining above freezing point for all but about 12 hours, and for about one-tenth of the time the temperature was above +4·4° C. The high temperatures were accompanied by periods of gale force wind of the föhn type and on 1 August heavy rain and sleet showers were experienced near Cape Obelisk. It is probable that, allowing for the normal temperature inversion effects over Prince Gustav Channel, temperatures were even higher in the area near the ice caldera which is about 1,000 ft. (305 m.) above sea-level. On 2 August the weather became colder and finer, and by evening when the writer arrived at the ice caldera the temperature had fallen to −12·2° C.

On seeing the ice caldera it was immediately clear that a spectacular fall in the lake level had taken place during the warm weather of the preceding few days. Broken slabs of lake ice, 5 ft. (1·5 m.) thick, were still falling down the steep sides of the ice caldera and much ice debris lay scattered round the rim. There was no doubt that the lake filling the caldera had partially drained, causing its flat frozen surface to descend like the floor of a gigantic lift (Fig. 5). The total fall in level was calculated from Indian clinometer measurements to be about 66 ft. (20 m.). The ice caldera was again visited on 18 October and on 7 November 1961, but little change in its appearance had taken place since 2 August.

4. *The mechanism of lake drainage*

One of the peculiarities of the climate on the east coast of Graham Land is that föhn winds can occasionally cause air temperatures to remain above freezing point for several days, even during the winter months. Where there is little snow cover, melt water drains easily off the ice surface and rapidly accumulates in hollows and depressions such as this ice caldera. It is clear that the accumulated melt water in the caldera is then suddenly and rapidly drained. A rapid drainage is suggested by the chaotic state of the stranded ice debris. The volume of water which was released by the 1961 drainage was estimated to be at least 506×10^5 gall. (230×10^3 m.^{3}) and this water could only have escaped by a subglacial channel. Large pieces of stranded ice above the present rim of the ice caldera show that the lake level in the past has been at least 23 ft. (7 m.) above the June 1961 level (Fig. 6).

A sounding in the lake shows that the lake floor, which is probably bedrock, is 119 ft. (36 m.) below the glacier surface at the rim. A rise in water to a level equal to or higher than this would exert considerable hydrostatic pressure on the confining glacier ice, which would

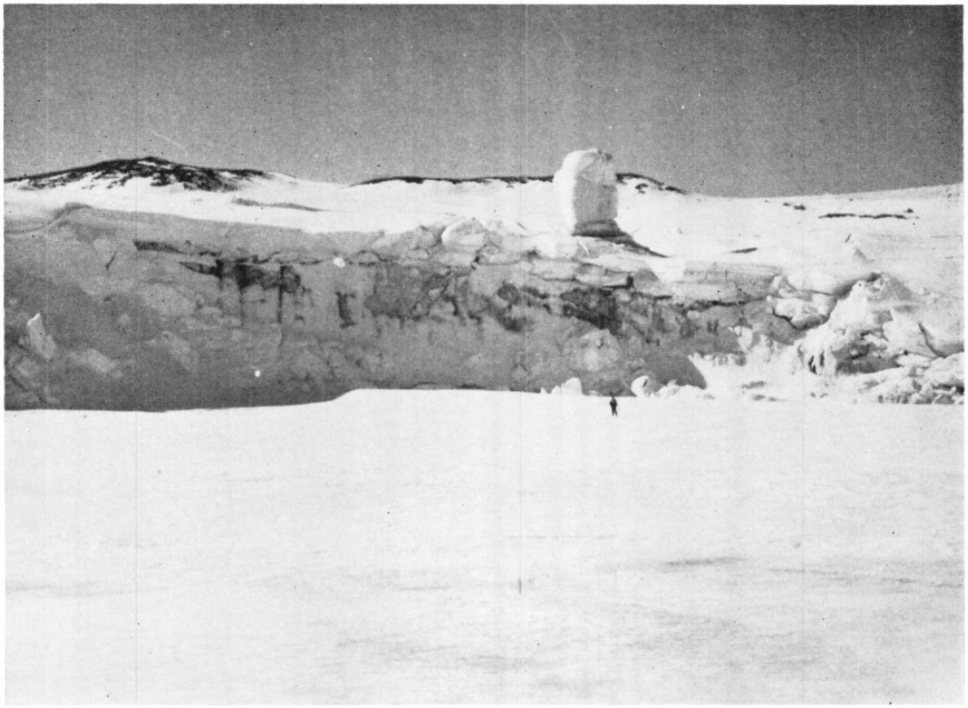

Fig. 5. The frozen surface of the lake in the ice caldera showing the steep ice wall on the north side, a stranded ice pillar and bedrock knolls in the background. 7 November 1961.

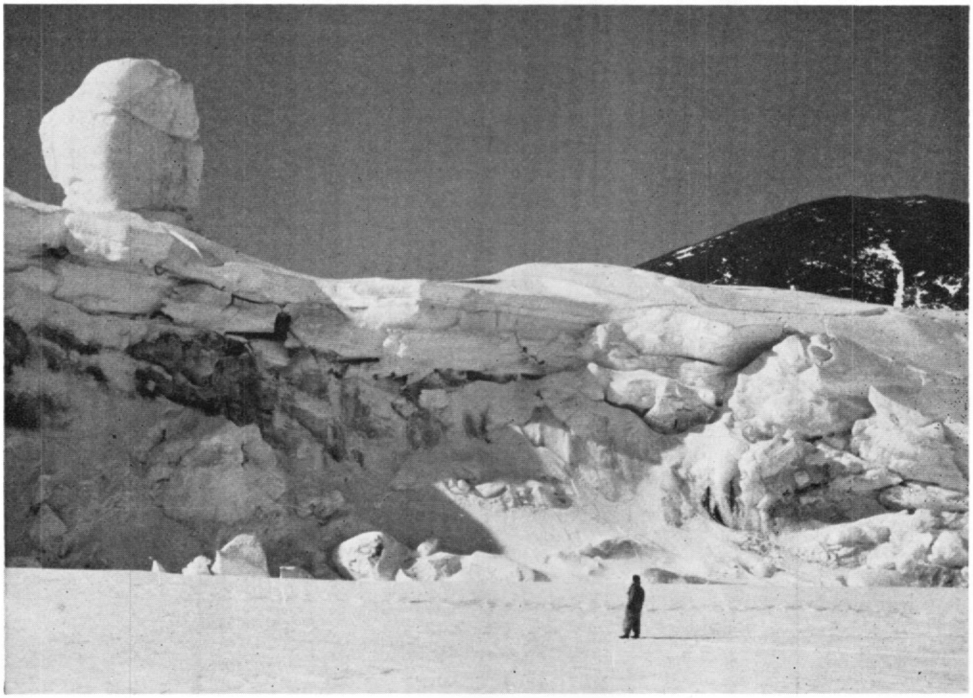

Fig. 6. The steep ice wall and stranded block on the north side of the ice caldera. The ice wall is about 66 ft. (20 m.) high. 7 November 1961.

tend to float. The slightest upward movement of the ice resulting from this would immediately allow the lake water to escape beneath the ice, thus triggering off drainage. A similar drainage mechanism was postulated by Aitkenhead (1960) for an ice-dammed lake in Norway.

Once drainage has occurred and the local temperatures have reverted to their normal sub-freezing levels, the subglacial outlet channel probably refreezes. The next drainage will not take place until successive periods of thaw provide a sufficient head of water to bring about a recurrence of the process already described. It is probable that in the unusually cold summer of 1960–61 the amount of accumulated melt water was not quite enough to cause drainage. Apart from such unusual summers, drainage is probably an annual event. It is, however, conceivable that, following drainage, water remaining in the lake might freeze solid. If this event was followed by a long succession of cold summers the ice caldera might completely fill up with solid ice and no longer be a noticeable feature as in the case of the ice caldera near Nobby Nunatak (Koerner, 1961*a*, p. 44).

5. *The initial formation of the ice caldera*

Before theorizing on the mode of formation of the ice caldera it is useful to summarize the most important factors which have a bearing on the problem.

i. The ice caldera is situated in a depression in the glacier surface on the immediate down-glacier side of a group of bedrock knolls and probably overlies a bedrock basin.

ii. The ice adjacent to the ice caldera and within the bedrock knolls is probably stagnant.

iii. The area is one where ablation now exceeds accumulation, and during thaw conditions surface melt water (and therefore subglacial melt water) is abundant.

Bearing these factors in mind, it is probable that long before the present caldera was formed melt water accumulated in large quantities both in the surface depression below the bedrock knolls and subglacially in the bedrock basin. Despite surface freezing, the ice depression would gradually deepen by melting and at the same time accumulated subglacial melt water would be gradually melting out a system of caves and channels. Eventually the surface water in the depression would find its way by cracks into the subglacial channels and the process of occasional sudden drainage would begin. The repeated build-up and release of hydrostatic pressure would have a disruptive effect on the glacier ice and its sudden release would tend to cause circular collapse into the ice caldera. This process, combined with the general effects of ablation and surface melting, would gradually increase the size of the ice caldera until it reached its present form.

Discussion

D. D. Hawkes (personal communication) has observed and photographed ice collapse features in Spitsbergen, which consist of huge blocks of glacier ice within an oval-shaped area 875 yd. (800 m.) across, in the centre of a depression in the glacier surface. This is thought to be analogous to an early stage in the formation of the ice caldera described above. Koerner (1961*a*, p. 44) has described an ice caldera near Nobby Nunatak, Hope Bay, which reached the stage of collapse and subsequently filled with melt water during 1958. However, this melt water froze and, apart from a shallow depression in the glacier surface, no sign of the feature can now be seen.

The "ice calderas" (Fleming and others, 1938, p. 512) and "ice dolines" (Mellor and McKinnon, 1960), which have been described from Antarctic ice shelves, have several special features suggesting a mode of origin rather different from that of the ice caldera described here. Mellor and McKinnon suggest that an "ice doline" forms by subsidence of the ice covering a lake which occupies a depression in the ice shelf. The subsidence apparently takes place when the lake drains through cracks in the ice beneath it. No collapse of the actual ice shelf is mentioned in their account.

From the various accounts which have been given of ice collapse features it is suggested that a definite distinction can be drawn between those which are primarily due to the collapse of subglacial caverns, as in the present case, and those which are due to the subsidence of ice covering surface melt-water lakes. The terms "ice caldera" and "ice doline" are useful for denoting this distinction and it is therefore suggested that both terms should be retained in ice nomenclature.

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REFERENCES

AITKENHEAD, N. 1960. Observations on the Drainage of a Glacier-dammed Lake in Norway. *J. Glaciol.*, **3**, No. 27, 607–09, 611.

FLEMING, W. L. S., STEPHENSON, A., ROBERTS, B. B. *and* G. C. L. BERTRAM. 1938. Notes on the Scientific Work of the British Graham Land Expedition, 1934–37. *Geogr. J.*, **91**, No. 6, 508–32.

KOERNER, R. M. 1961*a*. Glaciological Observations in Trinity Peninsula and the Islands in Prince Gustav Channel, Graham Land, 1958–59. *Falkland Islands Dependencies Survey Preliminary Glaciological Report*, No. 2, 44 pp.

———. 1961*b*. Glaciological Observations in Trinity Peninsula, Graham Land, Antarctica. *J. Glaciol.*, **3**, No. 30, 1063–74.

MELLOR, M. 1960. Antarctic Ice Terminology: Ice Dolines. *Polar Rec.*, **10**, No. 64, 92.

———. *and* G. MCKINNON. 1960. The Amery Ice Shelf and Its Hinterland. *Polar Rec.*, **10**, No. 64, 30–34.

STEPHENSON, A. *and* W. L. S. FLEMING. 1940. King George the Sixth Sound. *Geogr. J.*, **96**, No. 3, 153–66.