GRAVITY SURVEY ON SHOESMITH GLACIER, HORSESHOE ISLAND, GRAHAM LAND

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ABSTRACT. The survey procedure, the reduction of the data and the results of a gravity survey on a small cirque glacier, Shoesmith Glacier, Horseshoe Island, are described. The results are discussed with reference to the possible bisection of the island by the sea.

A DETAILED gravity survey was carried out on Shoesmith Glacier, Horseshoe Island, when a geophysical field party was isolated there during the austral winter of 1969.

The glacier occupies a cirque about 4 km. by 2 km. on the mountainous southern part of the island, and abuts at its snout on to a narrow isthmus on the lower northern part, falling from about 300 m. to sea-level (Fig. 1).

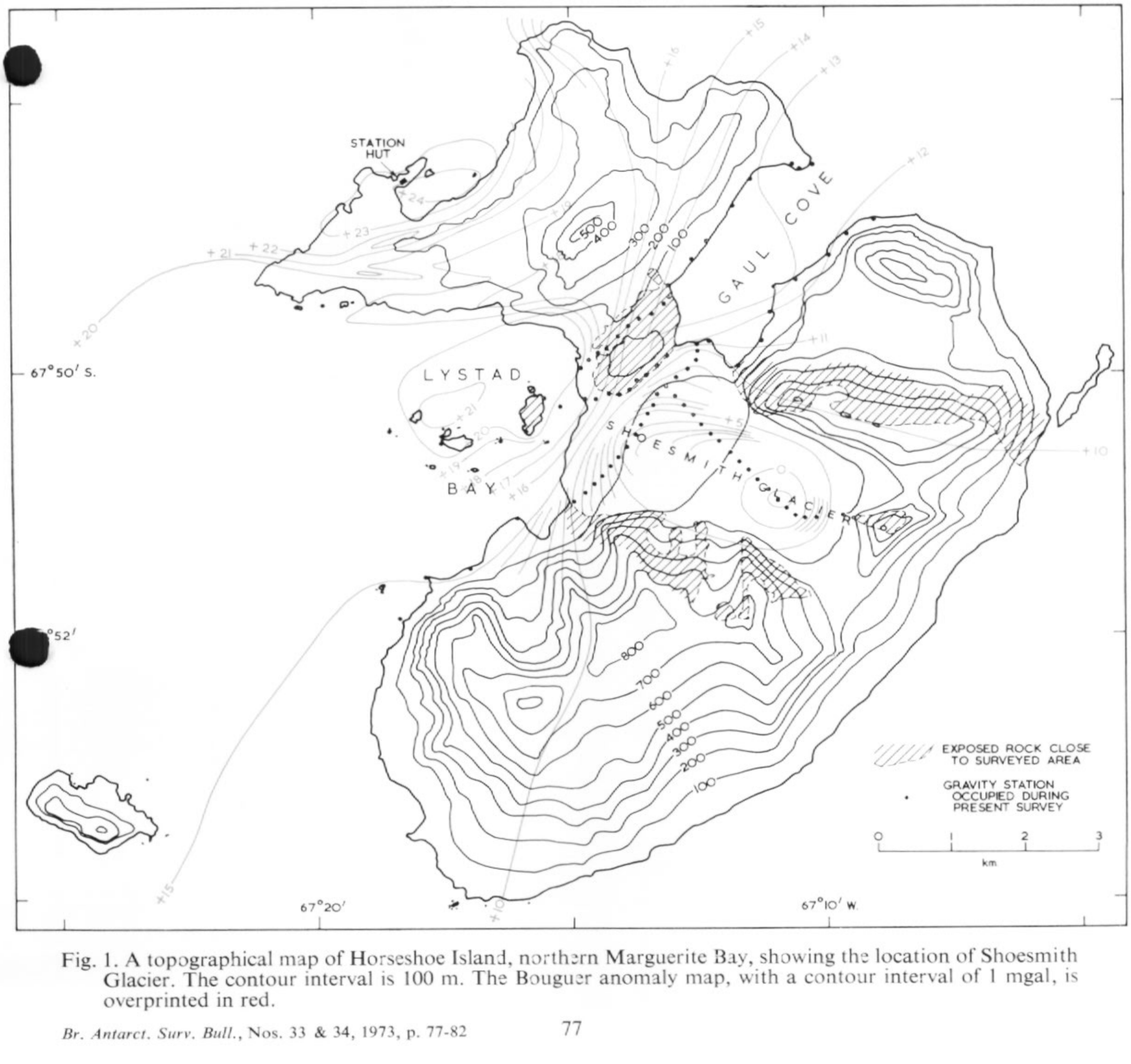

Fig. 1. A topographical map of Horseshoe Island, northern Marguerite Bay, showing the location of Shoesmith Glacier. The contour interval is 100 m. The Bouguer anomaly map, with a contour interval of 1 mgal, is overprinted in red.

Br. Antarct. Surv. Bull., Nos. 33 & 34, 1973, p. 77-82

The intention of the gravity survey was to determine the thickness of the glacier ice and to suggest the form of the rock–ice interface, thereby deciding whether the island is divided into two parts at sea-level, as is suggested by its topography.

GEOLOGY OF HORSESHOE ISLAND

A brief review of the geology of the island is necessary to justify the choice of density used in the data reduction and interpretation of the gravity results.

The main rock types are a coarse-grained pink granite (cf. Adie, 1955) and basic coarse-grained intrusive rocks which occur all over the island in complex relation to one another. Smaller bodies of volcanic and metasomatized sedimentary rocks are found locally. The whole area is cut by small dykes of various compositions, which are generally associated with the more recent plutonic intrusions.

The geology of the island is too complex to allow a fair assessment of the average density to be made, but the southern part occupied by Shoesmith Glacier is rather simpler. This consists largely of pink granite with local rafts and lenses of diorite which intrude the granite.

To the west of the snout of the glacier are outcrops of diorite which are not thought to penetrate the granite to any depth, but thicken to the north, where they crop out on small islands. A complex of metasomatized sedimentary rocks and dykes forms the isthmus adjacent to the glacier.

GRAVITY SURVEY

The instrument used for the gravity survey was a Worden Master No. 556, which has a calibration factor of 0·22976 mgal/scale division at 78° F [25·5° C].

Profiles were measured on ice along the length (profile C–D) and across the breadth of Shoesmith Glacier (profile A–B), on rock across the isthmus at the snout of the glacier and about 0·5 km. to the north of it (Fig. 2). About 60 stations were occupied at a spacing of 200 m. Stations were read on rock outcrops in the surrounding area to obtain regional gravity information.

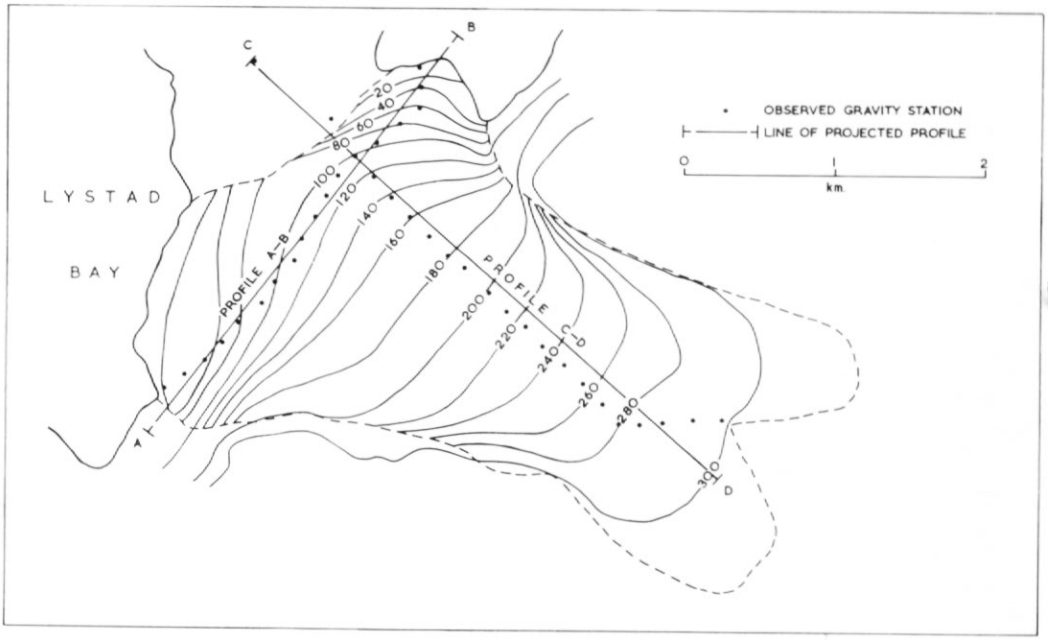

Fig. 2. Surface topography of Shoesmith Glacier. The contour interval is 20 m.

A base station below the snout of the glacier was occupied before and after each day's work, a time interval of about 7 hr., so that an estimate of instrumental drift could be made.

The station positions and heights were determined by theodolite traverse, checked with compass resection at key points. The heights were tied to sea-level at Mean High Water, and azimuths were taken on to points with heights on the published 1:25,000 map.

DATA REDUCTION AND ERRORS INVOLVED

Normal instrumental drift and latitude corrections were carried out. The elevation corrections were made to a sea-level datum using the average crustal density of 2·67 g. cm.$^{-3}$; terrain corrections using Bible's (1962) modification of the Hammer tables and graticules were also applied.

Errors in the drift correction were estimated from seven re-occupied stations on a survey undertaken prior to the present work; the mean error was computed as ±0·3 mgal.

Positions of stations were determined by tachymetry to within 1 m., and the latitude can be estimated from the map to within 0·005′. Together these are equivalent to an error in latitude correction of less than ±0·01 mgal at that latitude.

Heighting was a main source of error in the survey because of difficulty in levelling and reading the theodolite in poor light, settling of the tripod legs into the snow surface, and refraction errors. Closures were to within 4 m. whenever checks were made; this is equivalent to an error of ±0·43 mgal.

The choice of density for the Bouguer correction was subject to considerable error. Determination of the density of pink granite from four specimens gave a value of 2·57 g. cm.$^{-3}$, which falls within the range of granite densities, but is lower than average (Berman and others, 1942, p. 14) possibly due to weathering. Since it was difficult to estimate the ratio of granite to basic rocks over Horseshoe Island, it was decided that the average crustal density of 2·67 g. cm.$^{-3}$ should be used for the Bouguer correction, thus leading to a possible error of 0·1 g. cm.$^{-3}$, which is equivalent to an error of +1·32 mgal in the Bouguer correction for the highest station.

Thus the r.m.s. standard deviation was ±0·52 mgal at the lowest stations, increasing to ±1·38–0·52 mgal at the highest.

INTERPRETATION OF THE GRAVITY DATA

The reduced data were plotted on the published map which was modified by additional survey data obtained during the work. Having contoured this, straight-line profiles approximating to the observed profiles were drawn.

Regional gravity trends for the profiles were estimated from the widely spaced data off the ends of the profiles, which were considered to be unaffected by the glacier. These regionals were removed from the data leaving a residual anomaly for each profile (Figs. 3 and 4).

An initial approximation to the bedrock profile was obtained by using the iterative computer method described by Bott (1960), in which the gravity values of the anomaly are ascribed to a series of two-dimensional prisms forming a model approximating to the anomalous body. Profiles A–B and C–D were interpreted in this way.

This two-dimensional interpretation was strictly inappropriate because of the closely confined shape of the glacier, and its relatively deep bedrock. Therefore, a three-dimensional method was indicated. Talwani and Ewing (1960) designed a computer method in which a model of the anomalous body can be constructed from a series of thin vertical-sided horizontal polygons. The gravity effect of each polygon is computed and they are summed at any specified point to give a theoretical value of the anomalous field due to the body at that point. Thus a profile across the model can be compared with the observed profile. To produce a good approximation to the true shape, the method relies on a reasonable cover of stations combined with a knowledge of the outline of the anomalous body. It was felt that the control given by the topography was sufficient to enable a reliable interpretation to be made.

A contour map of the bedrock surface was drawn using the results obtained by the Bott method, and by assuming the characteristic U-shaped glacial valley for the upper part of the glacier where it runs between more-or-less regular sub-parallel mountain sides, and where no gravity data were available.

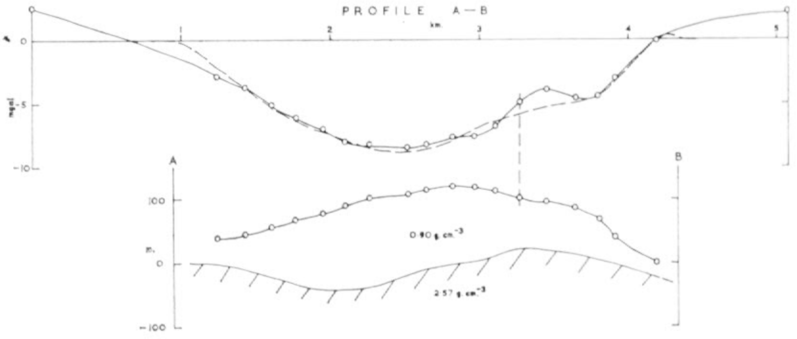

Fig. 3

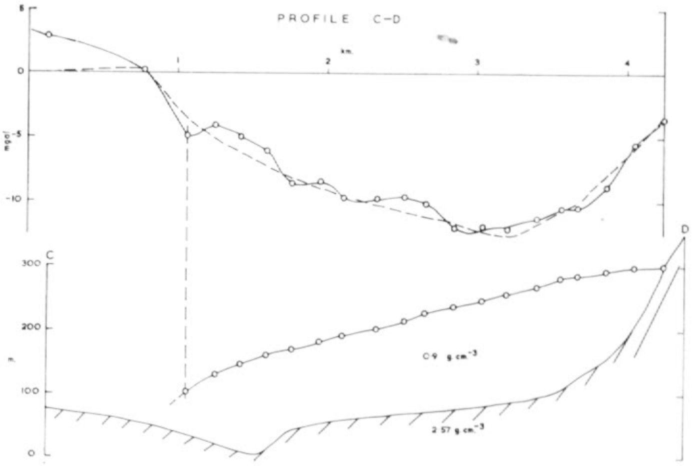

Fig. 4

Figs. 3 and 4. Sections showing the residual Bouguer anomaly (solid line), the calculated Bouguer anomaly (dashed line) and the observed height of the ice (solid line), with the calculated ice–rock interface (the rock is hatched).

Polygons were drawn by squaring off the contours to approximate to the body shape. The anomaly due to the model was computed at each station along the profiles, and then adjustments were made to the model as indicated by the deviations of the calculated anomaly from the observed.

Results and Discussion

For the interpretation, a density contrast of $-1 \cdot 67$ g. cm.$^{-3}$ was used; this is the difference between the densities of the ice and the pink granite. Field observations suggested that the amount of basic material included in the granite was not large enough to invalidate this choice of density.

Selection of a suitable regional was difficult because variations in the geology in the vicinity of the glacier caused anomalous changes in the gravity field which interfered with the anomaly due to the glacier. To separate one from the other, a regional was chosen which gave zero residuals at the rock stations near the glacier. It was found during the interpretation that none of the models tried had any great effect on the gravity values at that short distance from the ice–rock contact thus justifying this choice of regional. The south-west end of profile A–B was known to be very close to rock and an estimate of ice thickness at that point enabled an approximation to the regional value to be made. Thus a set of residual values was obtained.

A consideration of the geology added some qualitative evidence to support this choice of regional, because the ends of the profiles were close to the localities where diorites and metasomatized sediments, with densities greater than the pink granite, occur and hence positive Bouguer anomalies would be expected in those areas.

Several models were fitted to the residual anomaly and, within the conditions discussed below, the final fit was considered satisfactory. However, it was not possible to obtain a precise fit for several reasons:

i. A simple model to which improvements could not be made with the data available.

ii. Variation in the assumed density contrast used for the polygons. A value of $-1{\cdot}67$ g. cm.$^{-3}$ was used; this related all the anomaly to variations in ice thickness, assuming a constant density of $2{\cdot}57$ g. cm.$^{-3}$ for the rocks in the vicinity of the glacier and $0{\cdot}90$ g. cm.$^{-3}$ for the glacier ice. The first assumption has been discussed above; the second is suspect because of suspended morainic material in the glacier, and crevassing of the ice; these factors would respectively decrease and increase the density contrast. The extent of these is unknown but neither was observed to any extent.

iii. The representation of the glacier surface by the stepped surface of a pile of polygons would lead to errors, since stations on the actual surface of the glacier appear to have a theoretical ice cover varying from zero to the thickness of the polygons. The method computes the effect of this ice, and thus the calculated anomaly has a short wave-length variation superimposed upon it. To reduce this variation to within the experimental error and to give a sufficiently precise model, a polygon thickness of 20 m. was used.

The results are shown in Figs. 3–6. In Figs. 3 and 4, cross-sections of the glacier along the different profiles are shown, and these are compared with the observed and the calculated Bouguer anomaly. Fig. 5 shows the postulated ice–rock interface. The results from Figs. 2 and 5 are combined in Fig. 6, an isopachyte map for the ice.

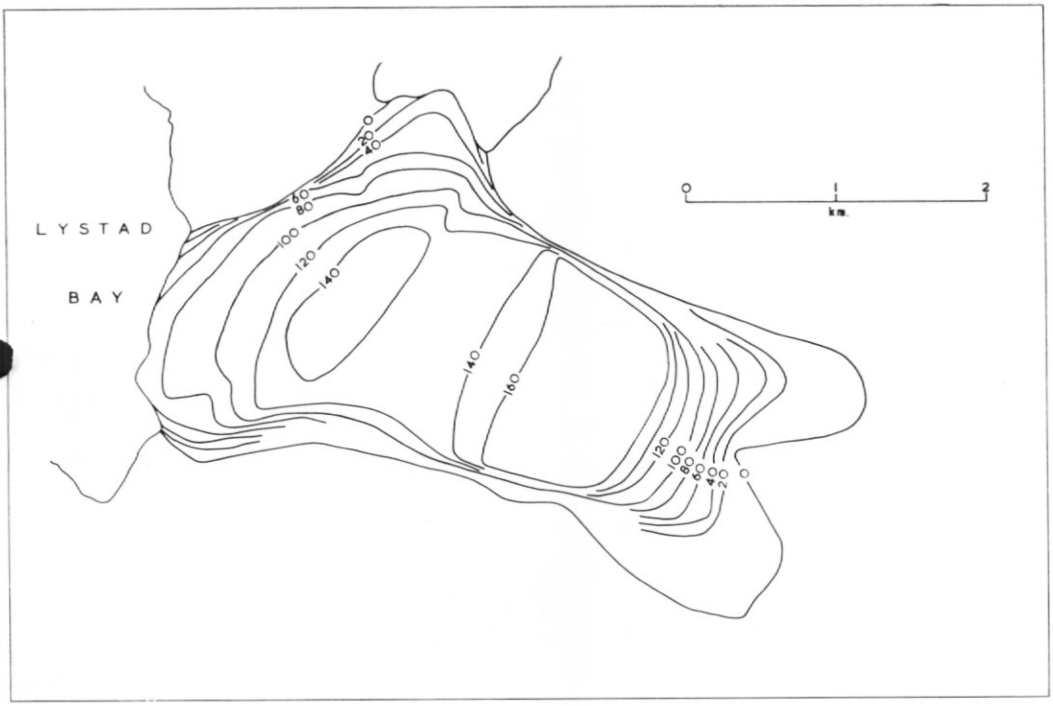

Fig. 5. Postulated subglacial topography of Shoesmith Glacier. The contour interval is 20 m.

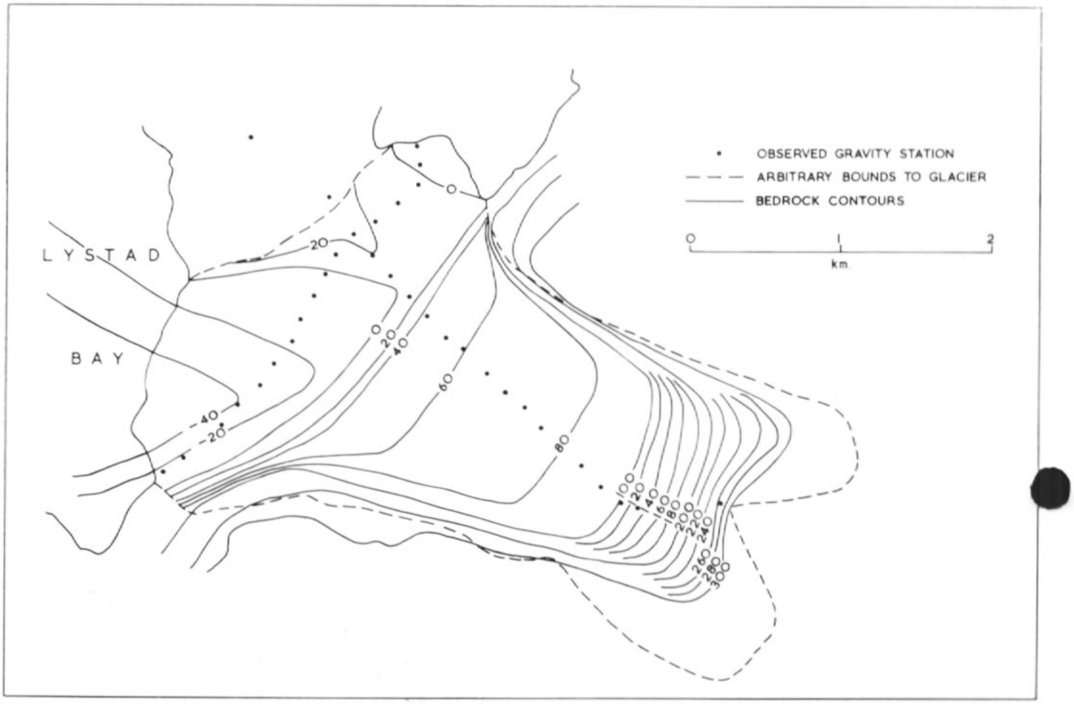

Fig. 6. Postulated isopachyte map of Shoesmith Glacier. The contour interval is 20 m.

The thickness of the ice at any one station is likely to be accurate to within ±10 per cent. Most of the features shown in the profiles are larger than this and are therefore considered to be real. A deepened channel is deduced on the west side of the glacier snout but whether this passes right through and divides the island is uncertain, since it is within 10 per cent of sea-level.

ACKNOWLEDGEMENTS

I wish to thank Professors F. W. Shotton and D. H. Griffiths for the use of laboratory facilities in the Department of Geology, University of Birmingham. I am grateful to Professor Griffiths for his helpful comments, to Dr. R. J. Adie for help in preparing this paper, and to members of the Survey for their advice.

MS. received 23 August 1972

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