A MAGNETIC SURVEY OF THE LAKE BOECKELLA AREA, HOPE BAY, GRAHAM LAND

By M. J. G. Cox

Abstract. A detailed magnetic survey of the total component of the Earth's magnetic field was carried out during the latter half of 1962 in the vicinity of Lake Boeckella, close to the British Antarctic Survey station at Hope Bay. The object of the survey was to delineate in more detail part of the Andean intrusion, indicated by an earlier magnetic survey to underlie the area. Several configurations of the intrusion, all of which have their upper surfaces at approximately sea-level, are shown to fit the observed magnetic anomaly. It was not found possible to establish the type of Andean intrusive rock producing the anomaly. The presence of dykes beneath the superficial deposits over the area surveyed is also postulated from the magnetic data, and the depth to their upper surfaces is suggested as being a close approximation to the thickness of these deposits.

The magnetic survey was carried out on the predominantly ice-free lowland to the south-east of Hope Bay in the immediate vicinity of Lake Boeckella (Fig. 1). This lowland area has an elevation of less than 200 ft. (61 m.) and is formed of the typical rounded hills and hollows associated with the passage of ice. At several localities at the edge of the area, outcrops of the Trinity Peninsula Series greywacke-shales, dipping at 20–30° to the west or south-west, have been recorded (Croft, 1946). The whole of the centre of the area is covered by morainic detritus. The majority of these superficial deposits are composed of fragments of the greywackes, together with erratics from the Jurassic rocks of Mount Flora (Fig. 1) and from the Andean Intrusive Suite. No evidence is available for the thickness of these superficial deposits. Basic sills and dykes are known to occur in the vicinity of the area of survey (Croft, 1946), but they cannot be observed directly where there is a cover of superficial deposits. After an earlier magnetic survey, Ashley (1962) postulated the existence of an Andean intrusion which, on the assumption that it is wholly composed of diorite, underlies this area at a depth of 1,500–4,000 ft. (460–1,220 m.). Recent laboratory work on specimens from Andersson Nunatak (Fig. 1) has emphasized its petrographic similarity to the gabbro from Nobby Nunatak (Fig. 1), and has led to a suggestion that the diorite intrusion may have a marginal gabbroic phase (personal communication from A. Allen). If this is so, the part of the intrusion underlying this area would be of gabbro, but there would be diorite to the west.

Magnetic Survey Procedure

An ELSEC total field proton magnetometer was used to carry out a survey over an area of 0·2 sq. miles (0·5 km.^{2}) during the period 27 August to 8 December 1962. The detector head of the magnetometer was slung in a wooden framework inside a non-magnetic tripod so that it was held approximately 2 ft. (0·6 m.) above ground level. This was found to be more stable and more convenient to use than the single pole support supplied by the manufacturers.

The survey was conducted using a station spacing of nominal length 5 yd. (4·6 m.) based on a square grid of intersecting profiles. This procedure was used to provide detailed coverage of geological features; at the same time the anomalies due to surface and near-surface bodies, such as erratic boulders of igneous rocks, could be distinguished from those due to deeper-seated features. The main profile was located between two trigonometrical stations of the detailed survey of Hope Bay—the new meteorological tower and "Scar Hills north" (Fig. 1). Base stations were positioned on a square grid of nominal side 120 yd. (110 m.). The positions of the base stations along the main profile were measured relative to the new meteorological tower with a tape. They were then plotted on to a plane-table sheet and used to fix the positions of the other base stations with a telescopic alidade. The plane-table sheet was drawn to a scale of 1 : 2,500. The error in the plotted base-station positions was estimated as ±3 ft. (0·9 m.).

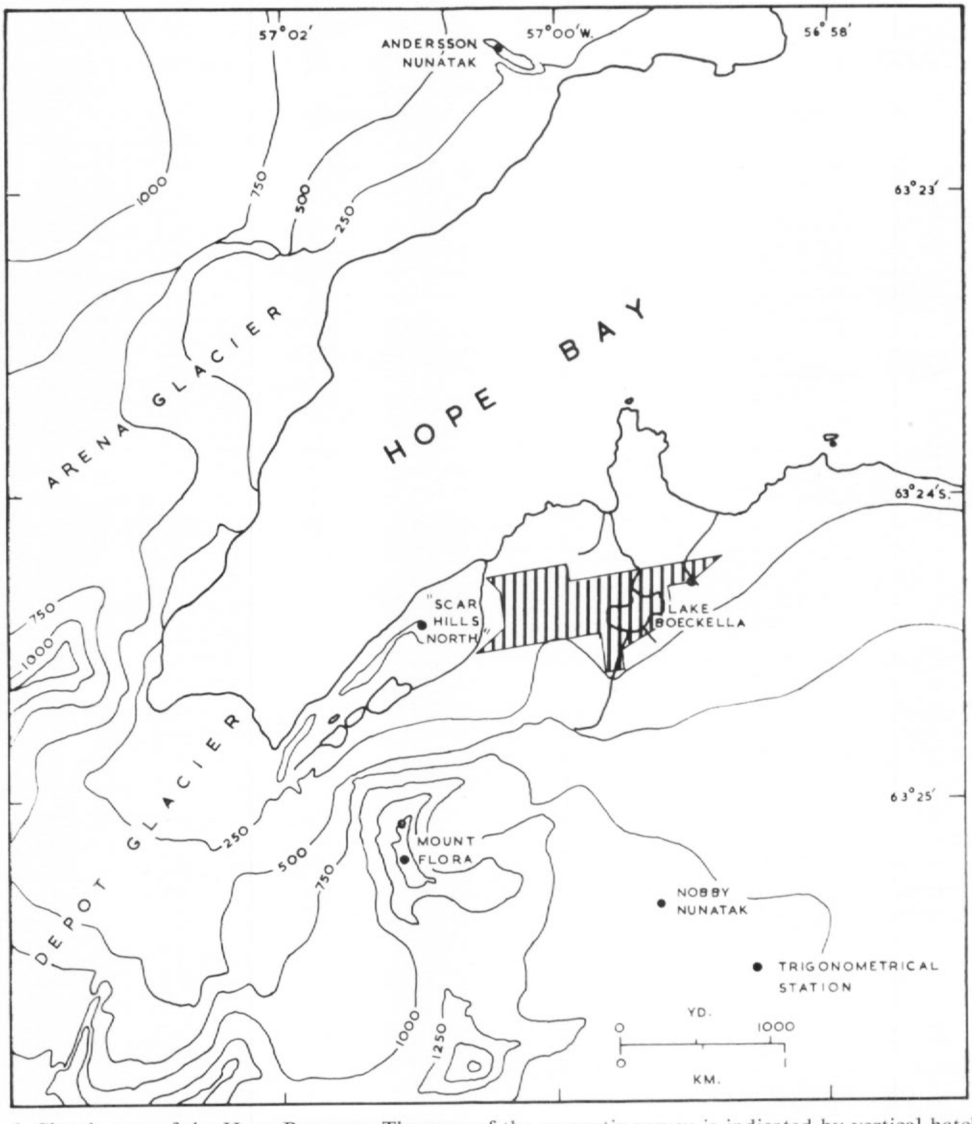

Fig. 1. Sketch map of the Hope Bay area. The area of the magnetic survey is indicated by vertical hatching. The contour interval is 250 ft. (76 m.).

More than 2,000 stations, including 53 base stations, were occupied during the course of the survey. A set of five readings at approximately 7 sec. intervals was observed at each station. The base stations occupied during the course of each day were re-occupied at frequent intervals (generally less than 20 min.) in order to obtain an indication of the nature of the diurnal variation in the direction of the Earth's total magnetic field.

Correction for diurnal variation

During the course of the survey the diurnal variation of the vertical component of the Earth's magnetic field was recorded with an Askania Gf6 magnetometer in conjunction with a Hartmann and Braun clockwork recorder in the magnetic hut at Hope Bay (Ashley, 1962).

An approximate diurnal variation for the total field was obtained by using the linear relationship of the field values obtained by repeated observations at base stations. This linear relationship was then modified by using data from the magnetic observatory at the Argentine Islands, 260 miles (420 km.) away. The modification was carried out by comparing the diurnal variations for the vertical component and the total magnetic field at the two localities. Even though the Hope Bay diurnal variations were always more disturbed than those at the Argentine Islands, the main peaks and troughs observed at these two stations occurred at approximately the same time (to within 12 min.); the ratio of the amplitudes varied from 1·5 : 1 to 3·0 : 1. The diurnal variation of the total field, used for the correction of all field data, consisted of major peaks and troughs from the Argentine Islands data superimposed on the original linear relationship. The difference between these two—the approximate and the modified diurnal variations—was usually less than 5 gamma but never more than 11 gamma. It was estimated that the diurnal correction used had an accuracy of ±3 gamma. This, combined with an instrumental error of about ±1 gamma, gives a total accuracy for the corrected field readings of ±3 gamma. The eastern and western extremities of one of the corrected profiles, from the new meteorological tower towards "Scar Hills north", are shown in Figs. 2A and B. A larger positive value of the field indicates an increase in the magnitude of the Earth's magnetic field.

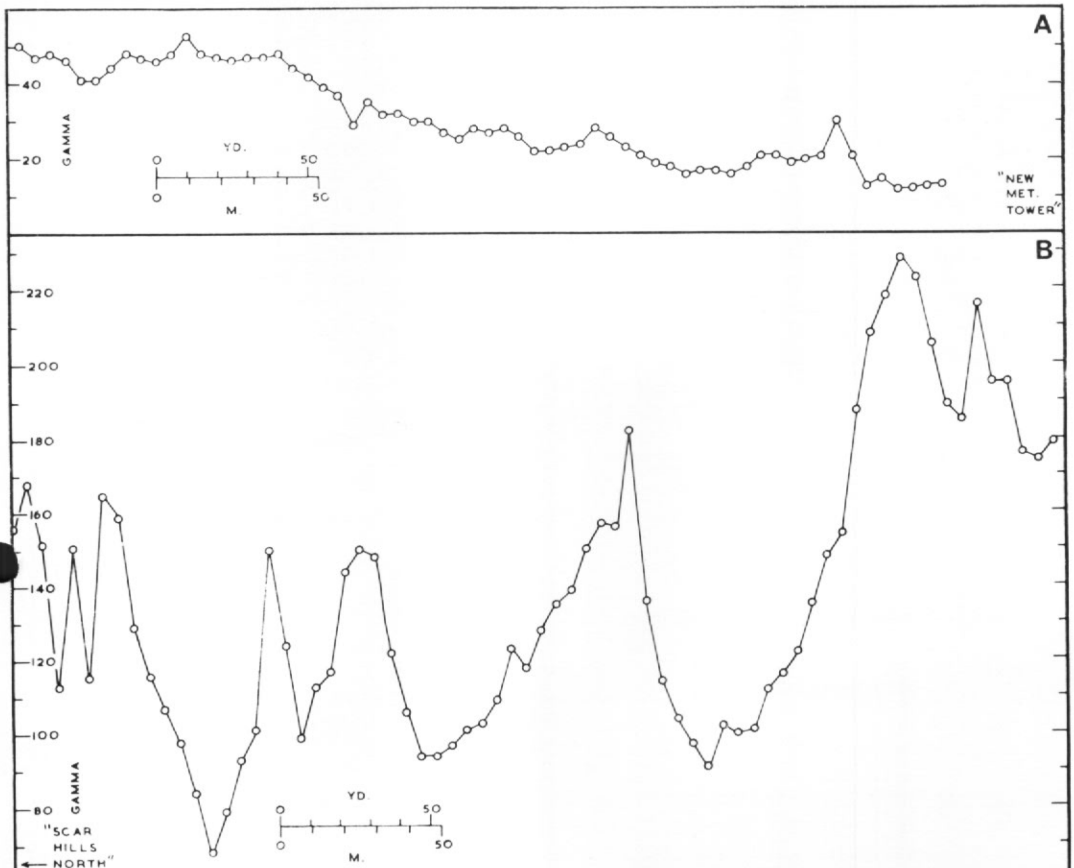

Fig. 2. Parts of the east–west magnetic profile from the new meteorological tower towards "Scar Hills north" after correction for the diurnal variation of the Earth's magnetic field.

A. Eastern extremity of the profile.
B. Western extremity of the profile.

Interpretation

Before the magnetic survey interpretation could be carried out, some modification of the corrected data was necessary. First, the effect of the surface bodies was removed from the observed profiles by neglecting all single-point anomalies, i.e. an anomaly was only considered geologically significant if it was spread over three or more stations. The broad anomalies were then separated from the narrower ones by a method in which the field values of all stations within 60 yd. (55 m.) of each base station (12 stations along each profile) were averaged to give a mean value for that base station. These values were then plotted to give smoothed profiles and the resulting contour map, based on these smoothed profiles, is shown in Fig. 3. Because the area covered by the survey was small, no correction was made for the gradient of the Earth's normal magnetic field. The difference between the observed and the smoothed profiles, or residual profiles, will be discussed elsewhere.

1. *Main anomalies*

The more northerly of the two anomalies shown in Fig. 3 has an east–west trend with a somewhat steeper gradient to the north than to the south. As a first approximation this was interpreted as a two-dimensional feature (infinite in the third dimension) by three different methods. In the first method the assumed model was a horizontal line of magnetic dipoles. The best fit to the observed anomaly was given when the dipoles dipped at 30° to the south at a depth of 300 ft. (91 m.). By using the "short-cut" method of Peters (1949), which is based on a model of a vertically sided prism, a depth of 250 ft. (76 m.) to the upper surface of the body was obtained. Finally, by using the method of Gay (1963), which involves the matching of the observed profile with a set of standard curves for inclined tabular bodies, a body at a depth of 200 ft. (61 m.) dipping at 25° to the south was obtained.

An attempt was made to obtain more information on the nature of the body producing the anomaly by calculating several second vertical derivative, or curvature, maps for the area. A curvature map may isolate anomalies which were obscured on the intensity map, and it may also help to delineate the geological features producing the anomaly. Variation of the grid spacing used in calculating the curvature at any one point alters the filter factor of the method, thereby retaining features above different depths. Curvature maps were calculated from the data of Fig. 3 and contoured for grid spacings of 150 ft. (46 m.), 225 ft. (69 m.), and 300 ft. (91 m.). The general form of these is shown in Fig. 4, where it can be seen that this operation accentuates the shape of the two anomalies noted before, and suggests the presence of a third anomaly near the eastern 50 gamma contour of Fig. 3.

On the basis of the results of these preliminary investigations, a more rigorous analysis was carried out using the total magnetic field chart described by Henderson and Zietz (1957) for three-dimensional bodies. This is a chart method for the calculation of the anomaly produced by a body having a certain magnetic susceptibility in a certain field strength and inclination of the Earth's magnetic field. Such a chart was constructed for a volume susceptibility contrast initially assumed to be 6×10^{-3} c.g.s. units, in a total field of 41,000 gamma at an inclination of 60° upward to the horizontal; this is approximately the magnitude and direction of the Earth's normal magnetic field in the area of survey (Vestine and others, 1947). After calculation at several points, the resulting profile was adjusted, using an arbitrary zero and different values of the susceptibility contrast to obtain the closest fit with the observed profile. The best fit for each configuration used and the observed east–west and north–south profiles are shown in Fig. 3. If the northern slope of the body is at 60° to the horizontal, too large a half-width results on the north–south profile. Also, if the depth to the base of the body is too small, as in the two configurations having a base at 1,000 ft. (305 m.), the anomaly flattens out too soon on the east–west profile. The best fit was obtained for a body at a depth of 150–200 ft. (46–61 m.) (or at approximately sea-level) with a vertical northern face, east, south and west slopes of 30°, a depth to the base at approximately 1,500 ft. (460 m.), and a susceptibility contrast of $1 \cdot 25 \times 10^{-3}$ c.g.s. units. In the model the upper surface was represented by a rectangle of length 425 ft. (130 m.) and breadth of 80 ft. (24 m.).

For the less well-defined southern anomaly, the methods of Gay (1963) and Peters (1949) indicate a depth of burial of 300 ft. (91 m.) associated with a dip of 20–30° to the south.

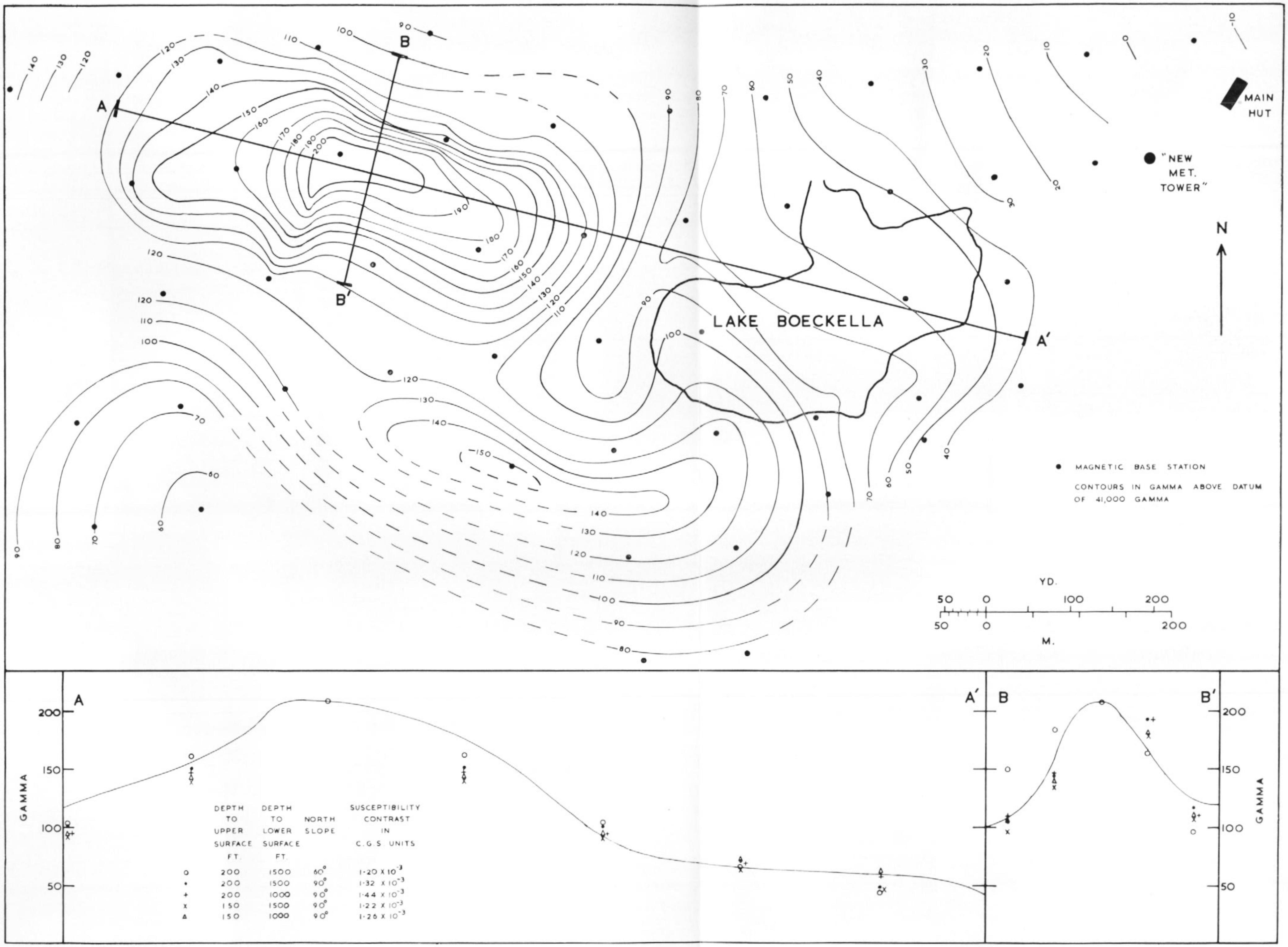

Fig. 3. Contour map of variations in the total component of the Earth's magnetic field. Superimposed on profiles A–A′ and B–B′ are calculated values for theoretical models.

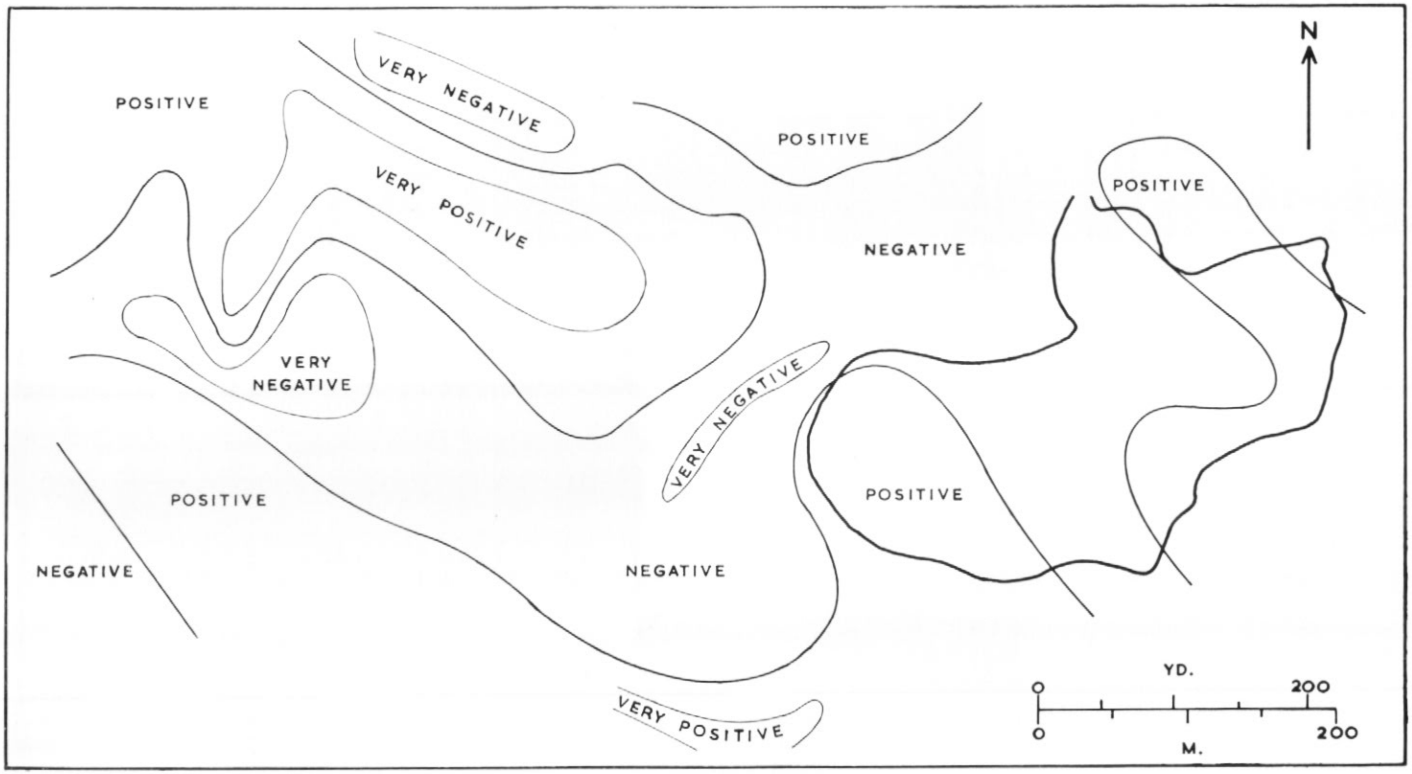

Fig. 4. Sketch map of the general form for the second vertical derivative of the area of survey.

Due to a lack of data in this area, a more rigorous analysis of this anomaly was not attempted. The anomaly in the vicinity of the 50 gamma contour in the east of this area, arising from the curvature map, is thought to be due either to a small change in susceptibility contrast or slope of the main body.

2. *Residual anomalies*

The residual profiles were examined for features which cut across several profiles. It was not possible to compile a contour map from the residual profiles because of the rapid changes in magnetic field which occur along each profile. However, in the vicinity of the base stations, where two or more profiles intersect, it was possible to obtain an indication of the trend of the residual anomalies. This trend was found to be generally east–west, the same as that of the main anomaly. A three-dimensional model of the residual profiles for the western part of this area was assembled (Fig. 5). This shows a fairly well-defined boundary situated

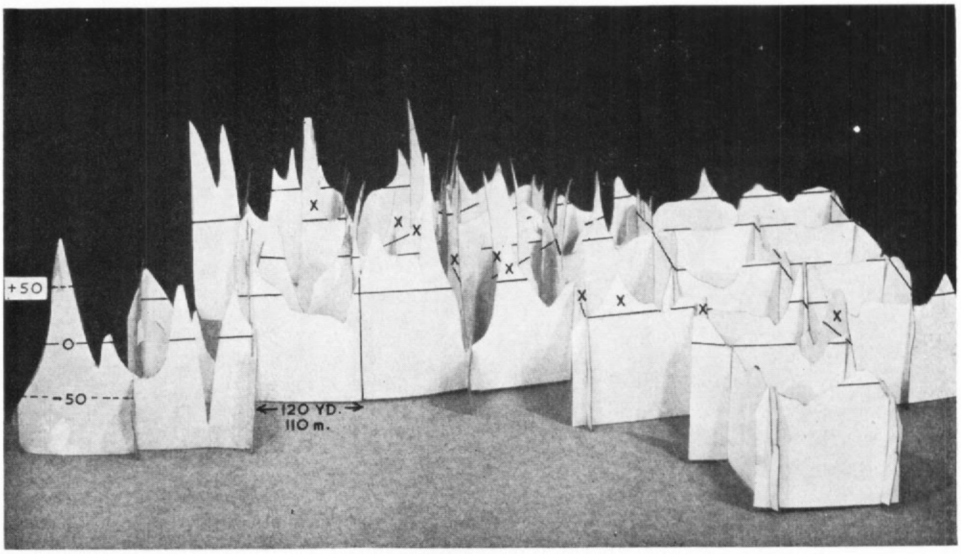

Fig. 5. View from the south of a three-dimensional model of the residual profiles for the western part of the area surveyed. The zero datum is shown by the horizontal lines, and the scale of the magnetic values (in gammas) is on the left-hand side of the model. Crosses indicate the trend of the magnetic anomaly interpreted.

close to the eastern 90 gamma contour of Fig. 3 which separates a region containing anomalies of large amplitude from one containing only those of small amplitude. A line-up of positive anomalies with comparable half-widths of 80–100 ft. (24–30 m.), trending approximately east–west, with amplitudes of 50 to 200 gamma is shown in Fig. 5. As this elongated anomaly is nowhere completely isolated, any attempt at interpretation must be little more than qualitative. Two depth estimates were obtained by using the approximate models of a line of magnetic poles and a line of magnetic dipoles (Smellie, 1956) which can be compared in geological terms with the upper surface of a narrow dyke. The depths obtained were 30–50 ft. (9–15 m.) and 80–105 ft. (24–32 m.), respectively. It is possible that the anomaly may be due to a dyke intruding the greywackes of the Trinity Peninsula Series and, therefore, the depth estimates give an indication of the maximum thickness of the morainic cover. If the width of the dyke is appreciable when compared with the depth, the depth will be less than that estimated for the assumed models. None of the remaining anomalies could be traced across more than two or three profiles, so they could result from either short dykes or large concentrations of igneous erractics within the moraine.

Conclusion

The volume susceptibility calculated during the interpretation of the main anomaly ($1 \cdot 25 \times 10^{-3}$ c.g.s. units) falls within the range given by Ashley (1962) for the dioritic rocks of the Andean Intrusive Suite. Therefore, one geological interpretation of the calculated magnetic body is that it is a small diorite intrusion. There could be alternative solutions: if the sediments in the thermal aureole of the diorite intrusion have a susceptibility of the same magnitude as that of the diorite itself, then the anomaly may be due to combinations of different susceptibilities and thicknesses of both the diorite and the sediments. Except in the special case when the susceptibilities of the diorite and the sediments are the same, the dimensions of the magnetic body may have to be altered slightly. Furthermore, if the body were the more weakly magnetized gabbro, similar to that exposed at Nobby Nunatak (Ashley, 1962), then highly magnetized thermally metamorphosed sediments are needed to account for the observed magnetic anomaly. The depth of 1,500 ft. (460 m.) to the base of the body used above is close to the depth suggested by Ashley (1962, p. 23) for the upper surface of solution 3 for the Tabarin Peninsula intrusion anomaly. However, by altering the susceptibility contrast and the slope of the eastern side of the body, good fits with Ashley's solutions 1 and 2 (1962, p. 18 and 20) could almost certainly be obtained. The depth to the upper surface of the intrusion in these two solutions is approximately 3,000–4,000 ft. (915–1,220 m.).

The depth to the base of the magnetic body, superimposed on the Tabarin Peninsula intrusion postulated by Ashley, is not well defined, but its general configuration and depth fall within fairly narrow limits. This is true irrespective of the precise geological interpretation of the magnetic body.

Acknowledgements

I should like to thank Professor F. W. Shotton of the Department of Geology, University of Birmingham, for providing laboratory facilities, and the staff of the Sub-department of Geophysics, especially Dr. D. J. Blundell, for most helpful discussions during the course of the work. I am grateful to J. L. Franks for his invaluable assistance during the field work.

MS. received 2 January 1964

REFERENCES

Ashley, J. 1962. A Magnetic Survey of North-east Trinity Peninsula, Graham Land. I. Tabarin Peninsula and Duse Bay. *Falkland Islands Dependencies Survey Scientific Reports*, No. 35, 35 pp.

Croft, W. N. 1946. Notes on the Geology of the Hope Bay Area. (F.I.D.Sc. Bureau No. E.89/47.) [Unpublished.]

Gay, S. P., *jr*. 1963. Standard Curves for Interpretation of Magnetic Anomalies over Long Tabular Bodies. *Geophysics*, **28**, No. 2, 161–200.

Henderson, R. G. *and* I. Zietz. 1957. Graphical Calculation of Total Intensity Anomalies of Three-dimensional Bodies. *Geophysics*, **22**, No. 4, 887–904.

Peters, L. J. 1949. The Direct Approach to Magnetic Interpretation and Its Practical Application. *Geophysics*, **14**, No. 3, 290–320.

Smellie, D. W. 1956. Elementary Approximations in Aeromagnetic Interpretation. *Geophysics*, **21**, No. 4, 1021–40.

Vestine, E. H., Laporte, L., Cooper, C., Lange, I. *and* W. C. Hendrix. 1947. Description of the Earth's Main Magnetic Field and Its Secular Change 1905–1945. *Publ. Carneg. Instn*, No. 578, 532 pp.