INTERPRETATION OF MAGNETIC ANOMALIES OVER HORSESHOE ISLAND, GRAHAM LAND

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Abstract. Total-field land and aeromagnetic anomaly maps are presented for geophysical surveys completed over Horseshoe Island between 1963 and 1977. The complex geology of the northern part of the island is reflected in the anomaly pattern. Amplitudes of 6000 gamma have been recorded. Two-dimensional interpretation indicates maximum depths of 2.2 km to the base of the source rocks, considered to be gabbroic and dioritic representatives of the Andean plutonic suite. Qualitative analysis suggests that much of the north-western part of the island may be underlain by gabbroic rocks.

Horseshoe Island (lat. 67° 51′ S, long. 67° 12′ W) is situated in Marguerite Bay off the west coast of the Antarctic Peninsula and was first visited in 1937 by the British Graham Land Expedition. The Falkland Islands Dependencies Survey occupied a station at Sally Cove (Figs. 1 and 2) from 1955 to 1960. Detailed topographical and geological surveys have been completed, the most recent work being that of Matthews (in press).

From 1963 to 1977, British Antarctic Survey geophysicists completed gravity and total-field land and airborne magnetic surveys over Horseshoe Island (Kennett,

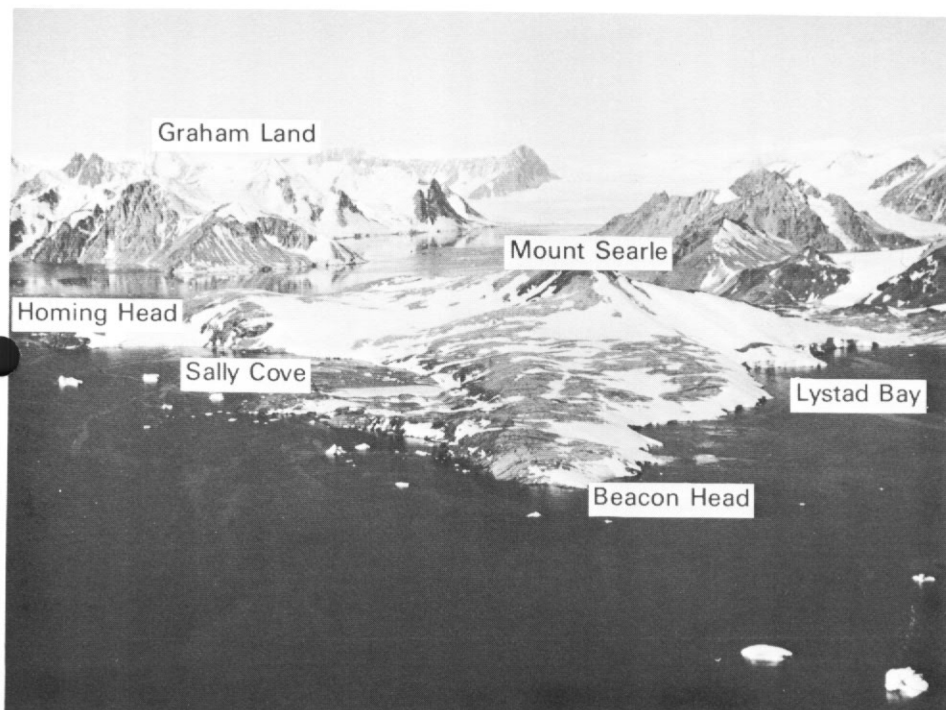

Fig. 1. Aerial photograph of northern Horseshoe Island.

1965; Ross, 1966; Smith, 1973*a*, *b*; Renner, 1976). The land geophysical surveys have taken place during the Antarctic winter when sea-ice permits convenient access. These surveys have always been secondary to the geophysical reconnaissance of the mainland, and therefore only progressed on an opportunistic basis when access to the mainland was prevented.

Physiography

Topographically, Horseshoe Island is divided into two distinct parts by a 1.5-km-wide isthmus trending between Gaul Cove and Lystad Bay (Fig. 2). Over the northern half a low-lying, relatively ice-free terrain prevails except for the isolated peak of Mount Searle (537 m). The southern part of the island has a greater cover of snow and ice, and is more mountainous, reaching a height of 878 m at Mount Breaker. This severe topography, and an almost unscalable ice cliff fringing the southern coast, greatly restricts land operations. The island's largest glacier is Shoesmith Glacier which flows north-west from Trifid Peak to calve in Lystad Bay and Gaul Cove. The presence of glacial striations with a predominantly east–west trend (Matthews, in press) suggests that in times of glacial maxima the northern and central parts of the island were covered by ice flowing west from the mainland.

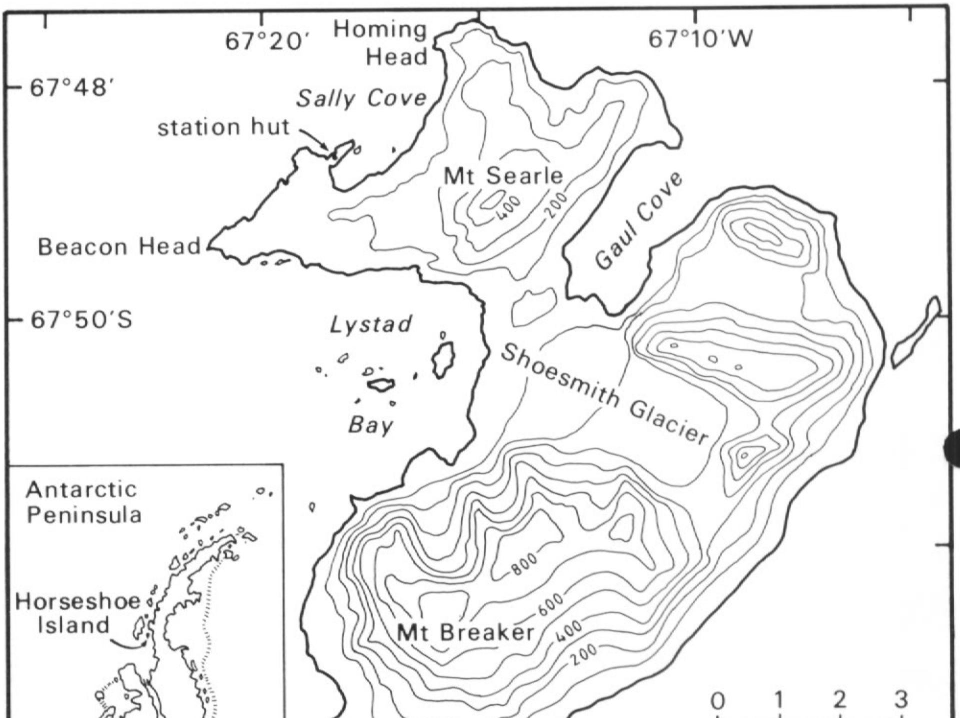

Fig. 2. Topographic map of Horseshoe Island. Contour interval: 100 m.

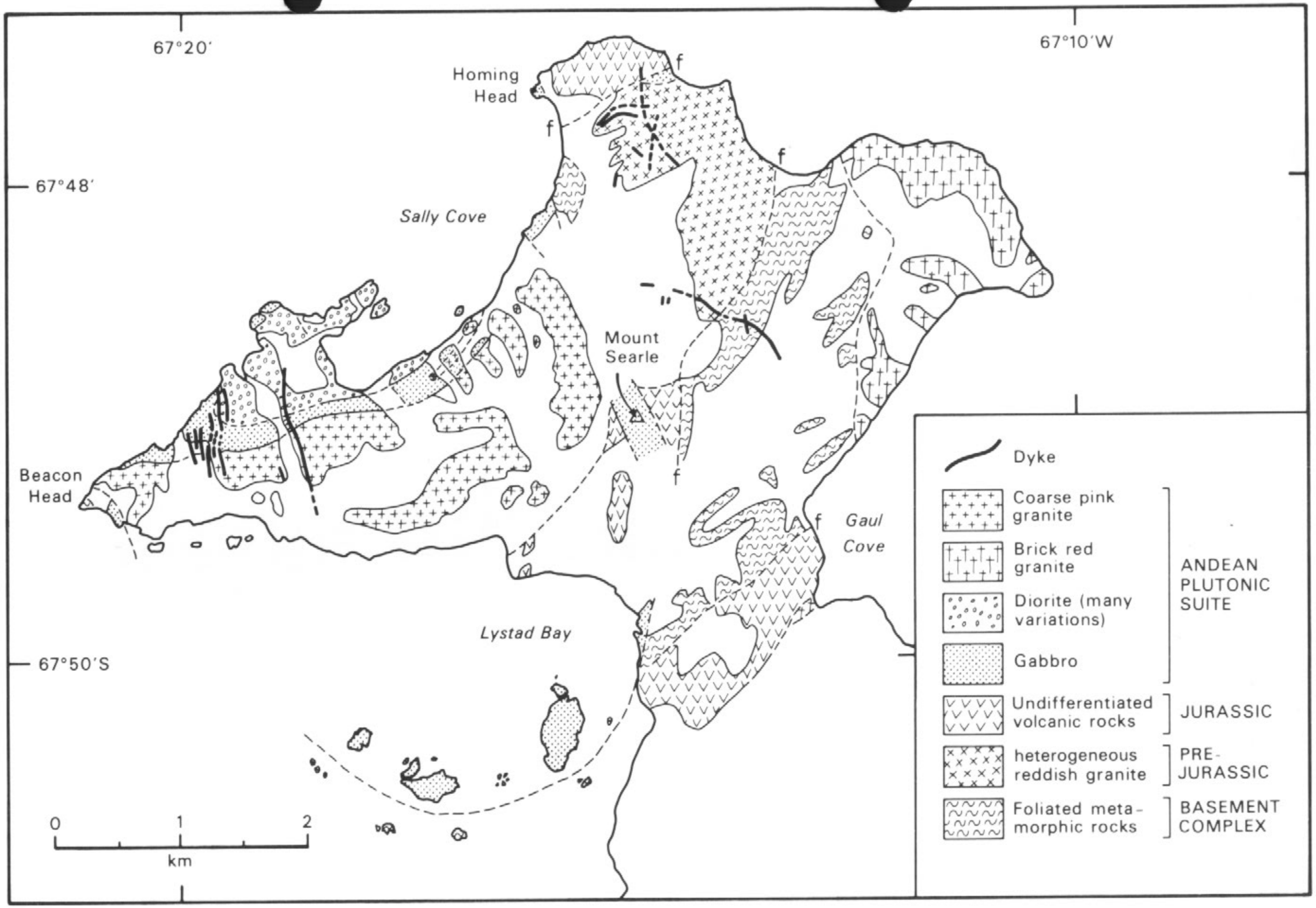

Fig. 3. Geological map of north-western Horseshoe Island.

Geology

Stratigraphy

The geology of Horseshoe Island (Fig. 3) is complex but the stratigraphy where known is given in Table I. The oldest identified rocks occurring on Horseshoe Island are banded biotite–gneisses and granite–gneisses. These may belong to a true metamorphic crystalline basement or to a later orogenic event. The older plutonic rocks are, in general, unfoliated granites assumed to be younger than the metamorphic complex rocks; they are visibly intruded by Andean granite. The Antarctic Peninsula Volcanic Group is represented by a limited volcanic succession of tuffs, agglomerates and andesitic lavas. They have been assigned an Upper Jurassic age by analogy with events elsewhere in Marguerite Bay. Quartz–mica–schists of probable volcanogenic origin, arenaceous sediments, shales and siltstones of uncertain age are also found (Exley, 1957; Matthews, in press). Andean (Cretaceous–early Tertiary) plutonic rocks which outcrop extensively on the island are of varied composition, typically fresh, and undeformed and represent at least three different phases of intrusion. In the north, Andean plutons form most of the large, well-exposed area of low-lying land between Mount Searle and Beacon Head, as well as the peninsula on the north side of Gaul Cove and the islands of Mane Skerry. Matthews (in press) interprets the Andean igneous activity in northern Horseshoe Island as an intrusive gabbro–granite–gabbro–diorite sequence with a roughly concentric arcuate disposition. In the more mountainous southern half of the island, granites and diorites predominate.

The Geophysical Surveys

In 1963, gravity (Kennett, 1965) and total-field magnetic surveys were commenced in the Horseshoe Island area by field parties operating from Stonington Island (lat. 68°11′S, long. 67°00′W). In 1969, Smith (1973*a*) completed a detailed gravity survey on Shoesmith Glacier. The same author (1973*b*), after collating several seasons of gravity survey in northern Marguerite Bay, interpreted two profiles across the Beacon Head peninsula and concluded that the observed positive gravity anomaly could be caused by a cylindrical gabbroic body of 2.5-km radius, 2.25-km depth and centred 1 km south of Sally Cove.

Using an Elsec total-field proton magnetometer, Ross (1966) completed a detailed local magnetic survey (Fig. 4) of north-western Horseshoe Island, occupying 650

Table I. The stratigraphy of Horseshoe Island (after Matthews, in press).

Age	*Type*	*Lithology*
Upper Cretaceous to	Hypabyssal rocks	Acid, basic and composite dykes
Lower Tertiary	Andean plutonic suite	'Diorite complex', gabbros, granites granodiorites and diorites
Upper Jurassic	Hypabyssal rocks	Basic dykes
	Antarctic Peninsula Volcanic Group	Tuffs, agglomerates and andesitic lavas
		–?–?–?–?–
	(?)	Sediments, partly volcanogenic
Upper Palaeozoic(?)	Plutonic suite	Granites
	Metamorphic rocks	Banded paragneisses
		–?–?–?–?–
		Foliated granite–gneisses

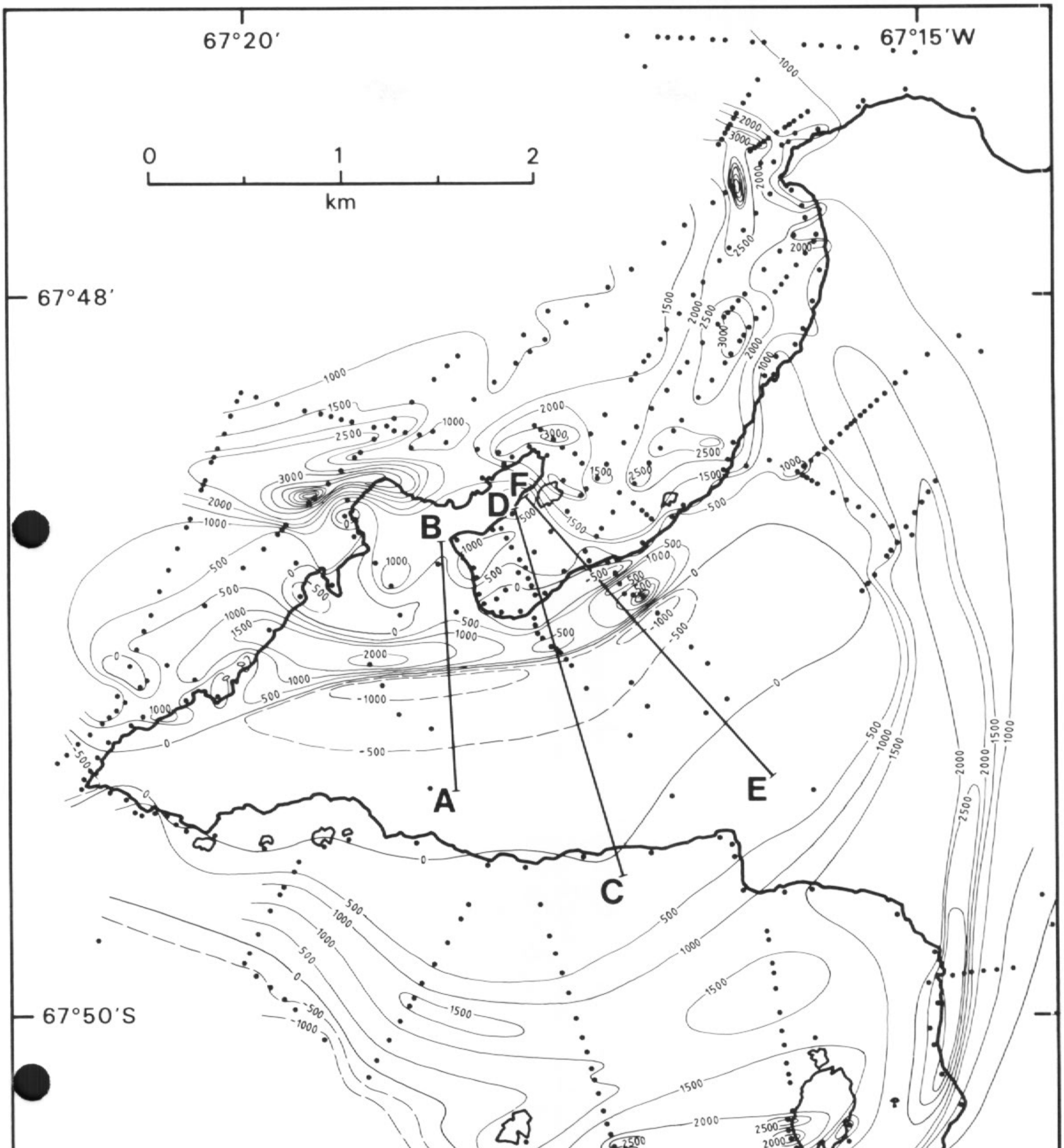

Fig. 4. Land magnetic anomaly map of north-western Horseshoe Island. Contour interval: 500 gamma.
• Station position.

stations at intervals of 20 m to 1.6 km. Stations were positioned by compass and sledge-wheel techniques. Ross removed a constant regional field value of 46 100 gamma from all field measurements. This has resulted in a small, residual, regional gradient as Renner (1980) calculated that the Earth's total magnetic field gradient in this area increases to the south and west by 7.7 and 3.4 gamma/km, respectively. Diurnal and secular variation corrections were available using values from the geomagnetic observatory at Faraday (lat. 65° 15′ S, long. 64° 16′ W). These are considered applicable in spite of the intervening distance (Renner, 1980).

BAS commenced aeromagnetic operations in 1973 when a Geometrics G-803 total-field proton magnetometer was installed in a de Havilland Twin Otter aircraft. Whilst the magnetometer was initially intended for reconnaissance surveys, the system has been used for more detailed grid networks over localized areas of particular geological interest. During 1973–4, such a network was flown over Horseshoe Island (Renner, 1976). A flight-line spacing of 2 km (Fig. 5) was planned

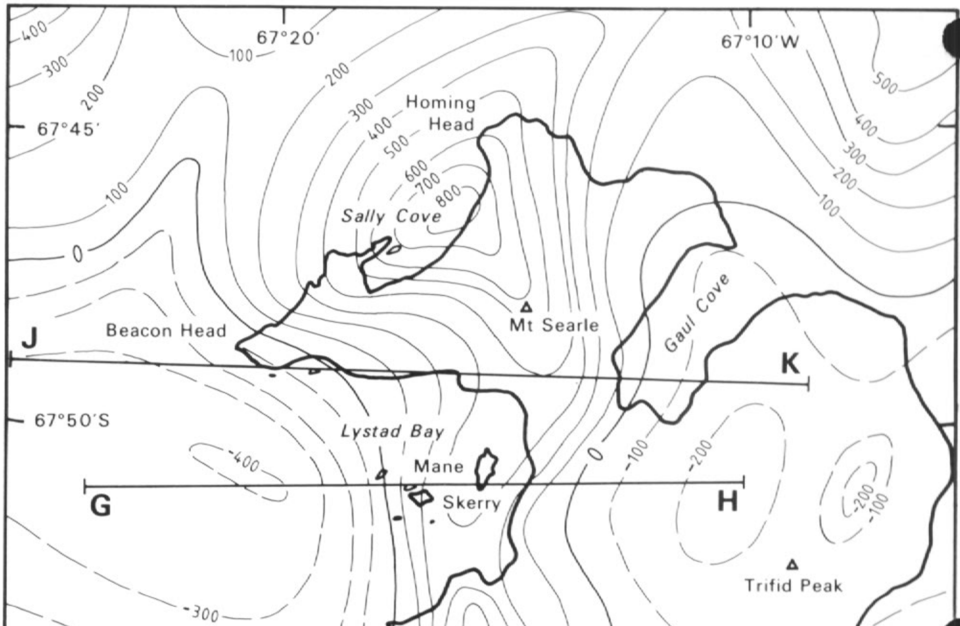

Fig. 5. Aeromagnetic anomaly map of Horseshoe Island. Inset shows the flight-line network. Contour interval: 100 gamma.

though strong local winds affected their orientation. A constant barometric altitude of 1 000 m was selected (severe topography precluded contour flying). When possible a ground speed of 130 knots was maintained with data being sampled every second and recorded in both digital and analogue form. Navigation was controlled by map reading, using vertical fixes, bow and beam fixes and position lines. An on-line photographic record was also made.

Diurnal variations were removed using values from the geomagnetic observatory at Faraday station. These showed that over the duration of the survey conditions were magnetically quiet with a maximum amplitude of 13 gamma. The highest measured absolute value of the Earth's magnetic field approached 45 800 gamma over the Sally Cove anomaly. Removal of the International Geomagnetic Reference Field was in accordance with Fabiano and Peddie (1969). The residual values were used in the compilation of the aeromagnetic anomaly map (Fig. 5). Cross-over errors at flight line intersections were of the order of 100 gamma in areas of steep magnetic gradients but elsewhere typical errors were less than 50 gamma. These errors resulted from the navigation techniques used and the inaccuracies in the available topographic maps. Instrumental heading errors were considered to contribute less than ± 5 gamma.

Interpretation Methods

Modelling of selected profiles (Herrod, 1981) was carried out using a computer program developed by G. K. Westbrook, Department of Geological Sciences, University of Durham. It uses a non-linear method to derive a polygonal two-dimensional body which gives a best fit to a particular magnetic anomaly. The program employs a measure of the closeness of the fit defined as the sum of the squares of the residuals between observed and calculated values, divided by the number of observations. This objective function is then minimized by the use of the Simplex direct search method (Nelder and Mead, 1965).

The surface geological control (Fig. 3) for modelling was based on Matthews (in press) and approximate body depths from the gravity interpretation of Smith (1973*b*). Available susceptibility measurements (Table II) and representative values of magnetization for members of the Andean plutonic suite (Renner, 1971, 1980) provided a reference level for magnetization strengths. Magnetization within any given body was assumed constant.

The azimuth and inclination of the Earth's present field over Horseshoe Island is 20.5° east of north and 299° (61° UP) respectively. During model computation the dip of the magnetization of each body in the plane of the profile was initially assumed to be parallel or nearly parallel to that of the Earth's present field. In addition, the background field was allowed to vary without constraint because any restriction imposed by a specified, uniform, planar, regional field was considered unjustified in such a magnetically complex area.

Table II. Susceptibilities of gabbro rocks from Horseshoe Island.

Locality	*No. of samples*	*Susceptibilities × 10^6 (rationalized system)*
Within 500 m of station hut	6	45 955
Mane Skerry	2	30 549
Homing Head	2	184 801

Interpretation

Land magnetic survey

The land magnetic anomaly map (Fig. 4) reveals several interesting anomalies:

1. *Beacon Head–Sally Cove:* A sharp, linear, short-wavelength anomaly of 1 800–2 600 gamma amplitude and striking west–east. It is associated with a known gabbro–granite contact.
2. *Lystad Bay:* A short-wavelength anomaly of amplitude up to 3000 gamma coincident with outcrops of the Mane Skerry gabbro.
3. *Lystad Bay–Mount Searle:* An arcuate magnetic feature trending south-west–north-east between known gabbro outcrops.
4. *Sally Cove:* Two intense, short-wavelength anomalies of 6000 and 5000 gamma amplitude.

For the interpretation of the Beacon Head–Sally Cove anomaly, profiles AB, CD and EF (Fig. 4) were selected. Profiles CD and EF lay parallel and close to magnetic survey traverse lines and are therefore well constrained. The Beacon Head granite was assumed to be non-magnetic. Models were computed for each profile for a variety of magnetizations, dips and body depths, but those for depths less than 0.5 km and greater than 2.2 km resulted in poor quality fits. The models presented are considered to be representative of those giving acceptable geological and geophysical correlations.

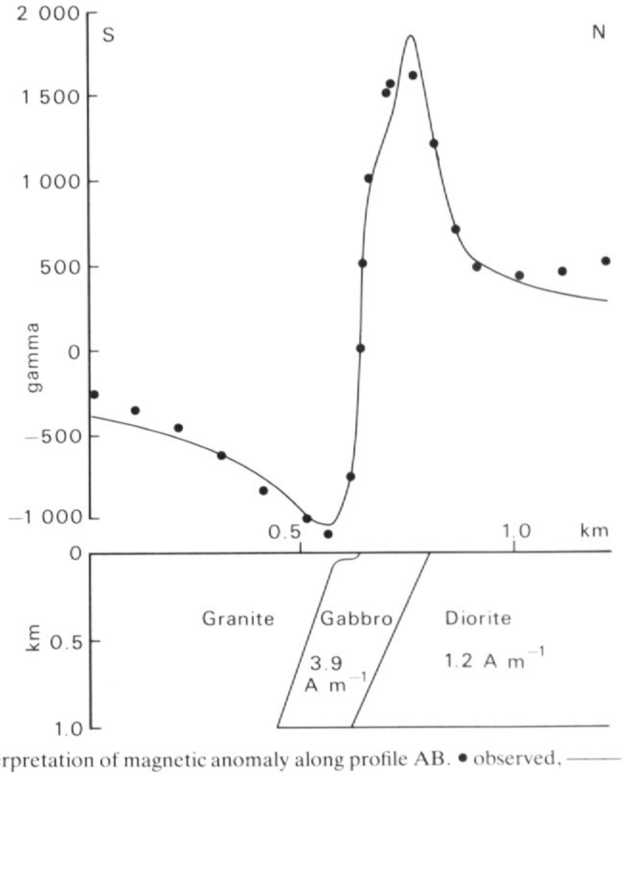

Fig. 6. Interpretation of magnetic anomaly along profile AB. • observed, —— calculated.

Profile AB. The anomaly (Fig. 6) along this profile shows a minimum value to the south of the granite–gabbro contact, increasing steeply over the contact giving a maximum amplitude of 2600 gamma.

Attempts to attribute the anomaly to a single semi-infinite slab, with sloping end-face, met with only partial success so a second body was introduced. Fig. 6 is typical of that giving an acceptable fit between computed and measured anomalies. The values of magnetization of 3.5 A m^{-1} for the Sally Cove gabbro and 1.2 A m^{-1} for the Sally Cove diorite are comparable to those measured for samples from the Andean plutonic suite of Graham Land (Renner, 1971, 1980). Acceptable fits were also obtained with the dip of the magnetization vectors varying by up to 22° from that of the Earth's present field, and the dip of the granite–gabbro contact and of the gabbro–diorite contact varying between 65° and 85°.

Profile CD. This profile (Fig. 7) although of similar signature to profile AB differs in that it has a double positive peak and a field which increases to the north over the Sally Cove diorite. The calculated sub-surface irregularities shown in Fig. 7 can account for the twin maxima. The calculated magnetization of the gabbro in this profile is slightly lower than that for profile AB, whereas that of the diorite is higher. This may reflect the heterogeneous nature of the Sally Cove diorite (Matthews, in press). The stepped upper sub-surface of the gabbro body could account for the metamorphic effects observed by Matthews within the granite. These are in evidence for up to 200 m from the gabbro contact, including a 20-m-wide reaction zone at the

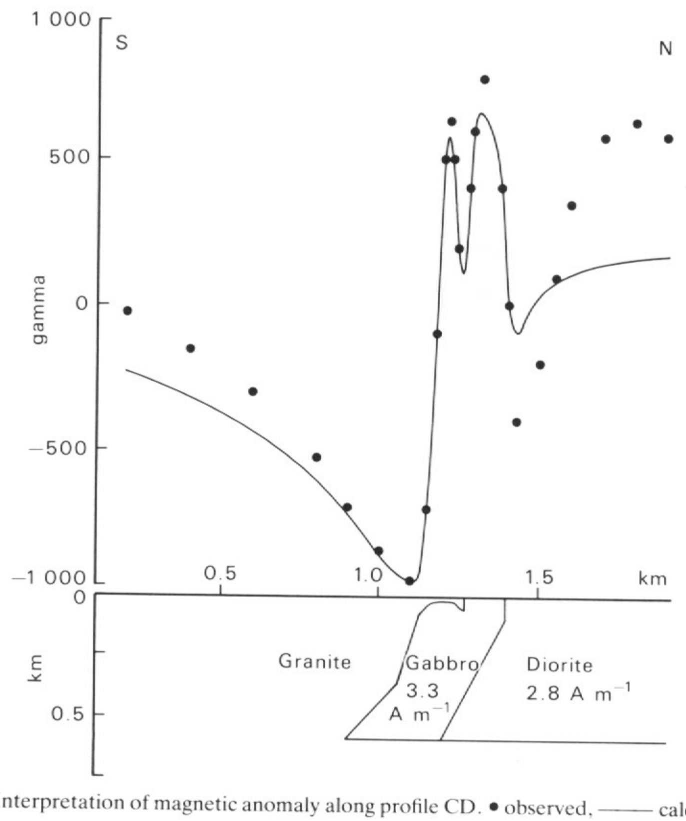

Fig. 7. Interpretation of magnetic anomaly along profile CD. • observed, —— calculated.

contact itself. The poor correlation between the observed and calculated values over the northernmost 0.5 km of the profile probably indicates the influence of a further offshore magnetic body as is evident from Fig. 4.

Profile EF. This is of similar form to the previous profiles but here the magnetic trough (Fig. 8) between the maxima is coincident with an exposed raft of granite (Fig. 3) lying parallel to the geological strike. The computed sub-surface distribution of the intrusive rocks is comparable to that interpreted for profiles AB and CD and the granite raft is calculated to be less than 40 m in depth. The discrepancy between the observed and calculated values over the northernmost 0.5 km of this anomaly is again attributed to the same magnetic body as proposed for profile CD.

The intense, short-wavelength anomaly of 6000 gamma situated in Sally Cove, offshore and to the north-west of the interpreted profiles, is probably caused by extension of the Beacon Head gabbro (Fig. 3). Similarly the 5000 gamma anomaly situated west of Homing Head could be a reflection of the very high susceptibility gabbro (Table II) found onshore at that locality.

Aeromagnetic survey

The intense high amplitude anomalies measured during the land magnetic survey are not apparent from the aeromagnetic flights suggesting that near surface geological features of limited extent are responsible.

The aeromagnetic anomaly map (Fig. 5) shows a broad, intense, positive anomaly of 800 gamma amplitude centred over Sally Cove with a southerly limb extending to Mount Breaker. The anomaly correlates with the Sally Cove intrusive complex and

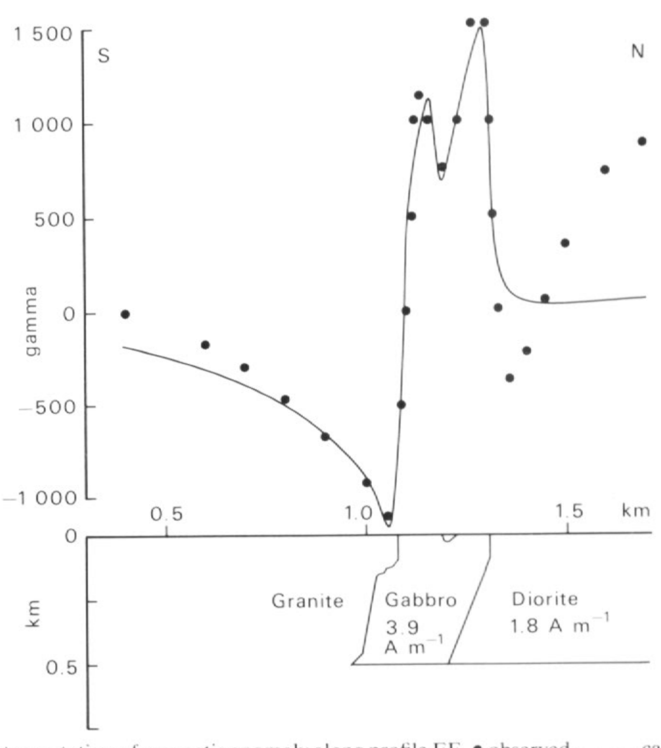

Fig. 8. Interpretation of magnetic anomaly along profile EF. • observed, —— calculated.

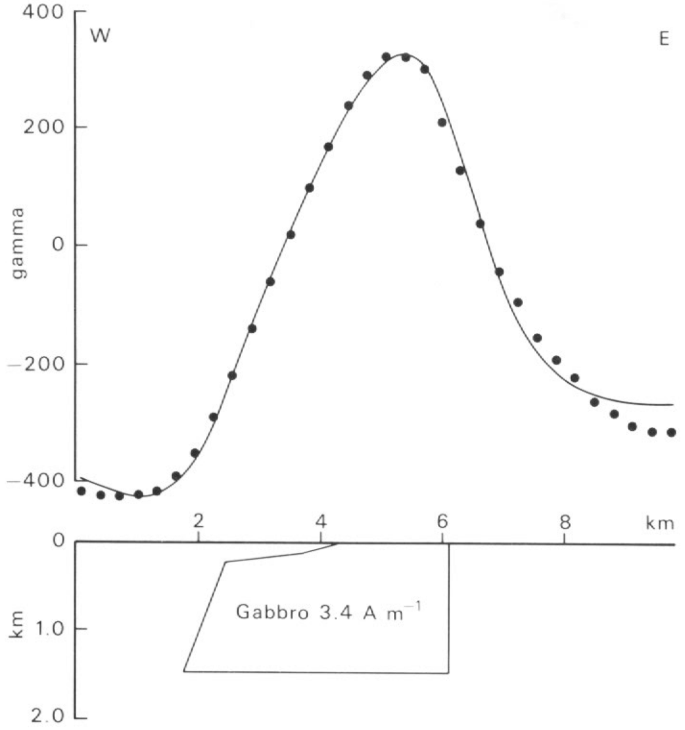

Fig. 9. Interpretation of aeromagnetic anomaly along profile GH. • observed, —— calculated.

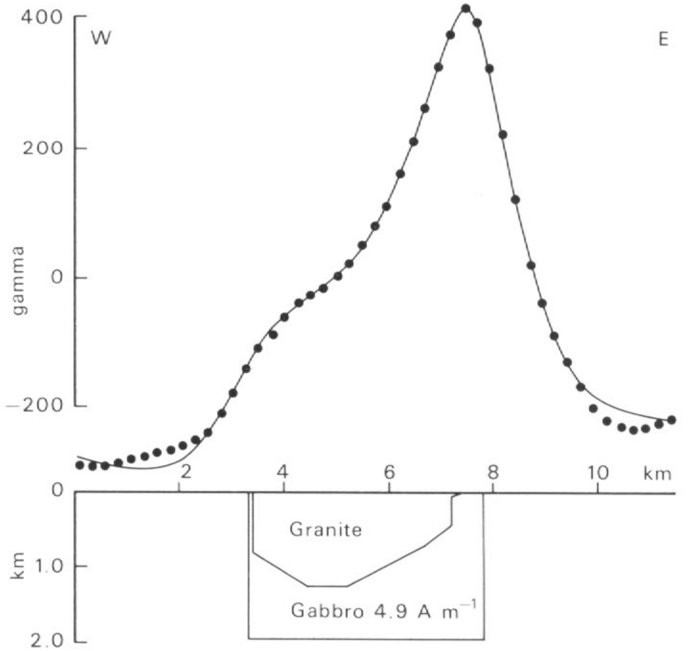

Fig. 10. Interpretation of aeromagnetic anomaly along profile JK. • observed, —— calculated.

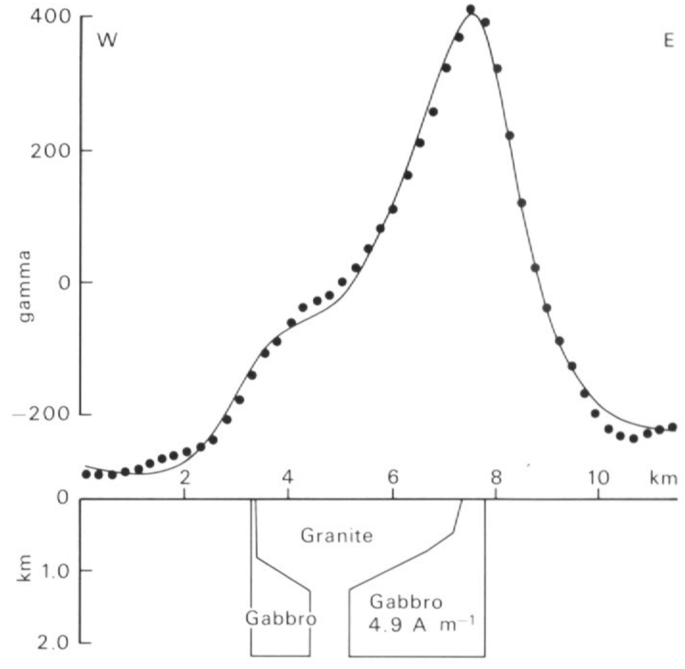

Fig. 11. Interpretation of aeromagnetic anomaly along profile JK. • observed, —— calculated.

with the known outcrops of gabbro on Mount Searle and in Lystad Bay. Both the profiles (GH and JK) selected for interpretation were coincident with flight lines.

Profile GH. The upper surface of the proposed body was held at sea level for the section through Mane Skerry where gabbro is known to outcrop. Further west, the bedrock surface was allowed to dip gently to conform to the known bathymetry. Fig. 9 represents a best fit selected from several trial bodies, all of which gave geologically acceptable models differing in detail only. The computed dip of the magnetization vector for the gabbro lies within a few degrees of the Earth's present field.

Profile JK. For this section, the undifferentiated, intermediate-to-acid tuffs on Mount Searle, as well as the Beacon Head granite, have been assumed to be non-magnetic. The ambiguity of magnetic interpretation is illustrated by Figs. 10 and 11, which indicate geologically acceptable models satisfying the observed anomaly. Both sections show the granite to be underlain by the older gabbroic rocks, suggesting that much of the north-west area of Horseshoe Island may be similarly underlain.

Despite being geographically close, the profiles GH and JK have presented markedly differing interpretations. The reason lies primarily in the outcropping geology (Fig. 3) which provides the control for the respective models. The heterogeneous nature of the gabbro and a possible magnetization contribution from the granite could partially explain the variation in magnetization strengths between the two interpretations.

The southernmost extension of the positive aeromagnetic anomaly is probably attributable to outcrops of gabbro, and diorite north-west of Mount Breaker (Matthews, in press).

Summary

The complex and varied lithologies of north-west Horseshoe Island are reflected by the total-field magnetic survey. The anomalies mirror the arcuate nature of the intrusions and the interpretation of representative profiles indicates that gabbroic and dioritic members of the Andean plutonic suite are the major causative bodies. These conclusions are in accordance with known surface geology, and the sub-surface step feature interpreted at the Beacon Head granite–Sally Cove gabbro contact may also account for the observed metamorphic features. The calculated angles of contact between the Beacon Head granite, Sally Cove gabbro and Sally Cove diorite appear consistent between all the models. Interpretation of the two aeromagnetic profiles provides supporting evidence for the sub-surface distribution of the igneous rocks. At the same time it illustrates the ambiguity of magnetic interpretation.

From the quantitative and qualitative analysis of the land and aeromagnetic anomaly maps it is suggested that the Mane Skerry gabbro continues north-west beneath Lystad Bay to the small exposure of gabbro at Beacon Head. More significantly, it may extend north-east to outcrop as the Mount Searle gabbro and to the exposures at Sally Cove and Homing Head.

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