RECONNAISSANCE GRAVITY AND MAGNETIC SURVEYS OF PART OF THE LARSEN ICE SHELF AND ADJACENT MAINLAND

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ABSTRACT. The results of gravity and magnetic traverses across part of the Larsen Ice Shelf are used to delineate the sub-ice topography of much of the east coast of Graham Land. In general, depths to bedrock are considerably greater than hitherto suspected. Surveys on Churchill Peninsula show that the peninsula comprises several higher areas separated by deep channels extending below sea-level. A traverse across the Antarctic Peninsula in lat. 68°30′S. shows that the Bouguer anomaly reaches a minimum over the central part of the peninsula, indicating some degree of regional compensation, but irregular free-air anomalies suggest incomplete local compensation.

IN the southern summer of 1963–64 reconnaissance gravity and magnetic surveys were undertaken across the Antarctic Peninsula in lat. 68°30′S. and over the Larsen Ice Shelf between lat. 68°30′ and 65°30′S. The area covered by the survey is shown in Fig. 1.

Throughout most of its length the peninsula consists of an unbroken mountain chain capped by a narrow ice plateau of unknown thickness. The average elevation of the plateau is about 1,700 m. above sea-level. Both coasts of the peninsula are generally steep and difficult of access but in lat. 68°30′S. a series of broad valley glaciers offers a relatively easy route across the peninsula. The Larsen Ice Shelf fringes the greater part of the east coast of the Antarctic Peninsula. Although it is considerably smaller in area than the better-known Ross and Filchner Ice Shelves, it appears to be broadly similar in topography and structure.

Gravity measurements were made with a Worden gravity meter (No. 556) at an average station interval of 6 km. but in certain areas of interest this distance was smaller. An Elsec proton magnetometer was used for the total-field magnetic survey. With the exception of a few stations at the beginning of the traverse, magnetometer readings were made at the same sites as the gravity observations.

Heights were obtained by using four 4·5 in. (11·5 cm.) Walker aneroid barometers, which were on loan from the Directorate of Overseas Surveys. Station positions were fixed by compass and sledge-wheel methods with some control from previously determined astronomical fixes at identifiable sites.

SURVEY OF PART OF THE LARSEN ICE SHELF

Heights

The average surface height of the ice shelf has been assumed as the altitude datum for the geophysical surveys. Most of the gravity stations were on the ice shelf but some were sited on adjacent peninsulas and therefore require correction for height. These heights above ice-shelf level were determined with four Walker aneroid barometers. The synoptic meteorological charts of the area were used in conjunction with local closures in the reduction of the data (Kennett, 1965). Repeat determinations at two stations, each several hundred feet above the ice shelf, gave standard deviations of ±33 ft. (10·1 m.) and ±7 ft. (2·1 m.), respectively. Comparison of the synoptic charts with diurnal pressure changes measured in the field showed that the maximum likely error under normal working conditions is ±65 ft. (19·8 m.).

The assumption that the surface of the ice shelf is level is an over-simplification. In fact, it undulates gently over much of the area, but the accuracy of the barometric method is not sufficient to allow measurement of the amplitude of the undulations, which is estimated to be of the order of 100 ft. (30·5 m.).

An attempt was also made to determine the height of the ice-shelf surface above sea-level by correlating the aneroid barometer readings with the meteorological charts. The average height of 16 stations on the ice shelf was 261±56 ft. (79·6±17·1 m.) above sea-level. Heights of stations between Philippi Rise and Cape Disappointment were consistently lower, averaging 216±41 ft. (65·9±12·5 m.) above sea-level. Although these figures are only to be regarded as tentative, the standard deviations quoted are surprisingly low; moreover, they combine errors in correlation with actual variation in surface altitude from one station to another.

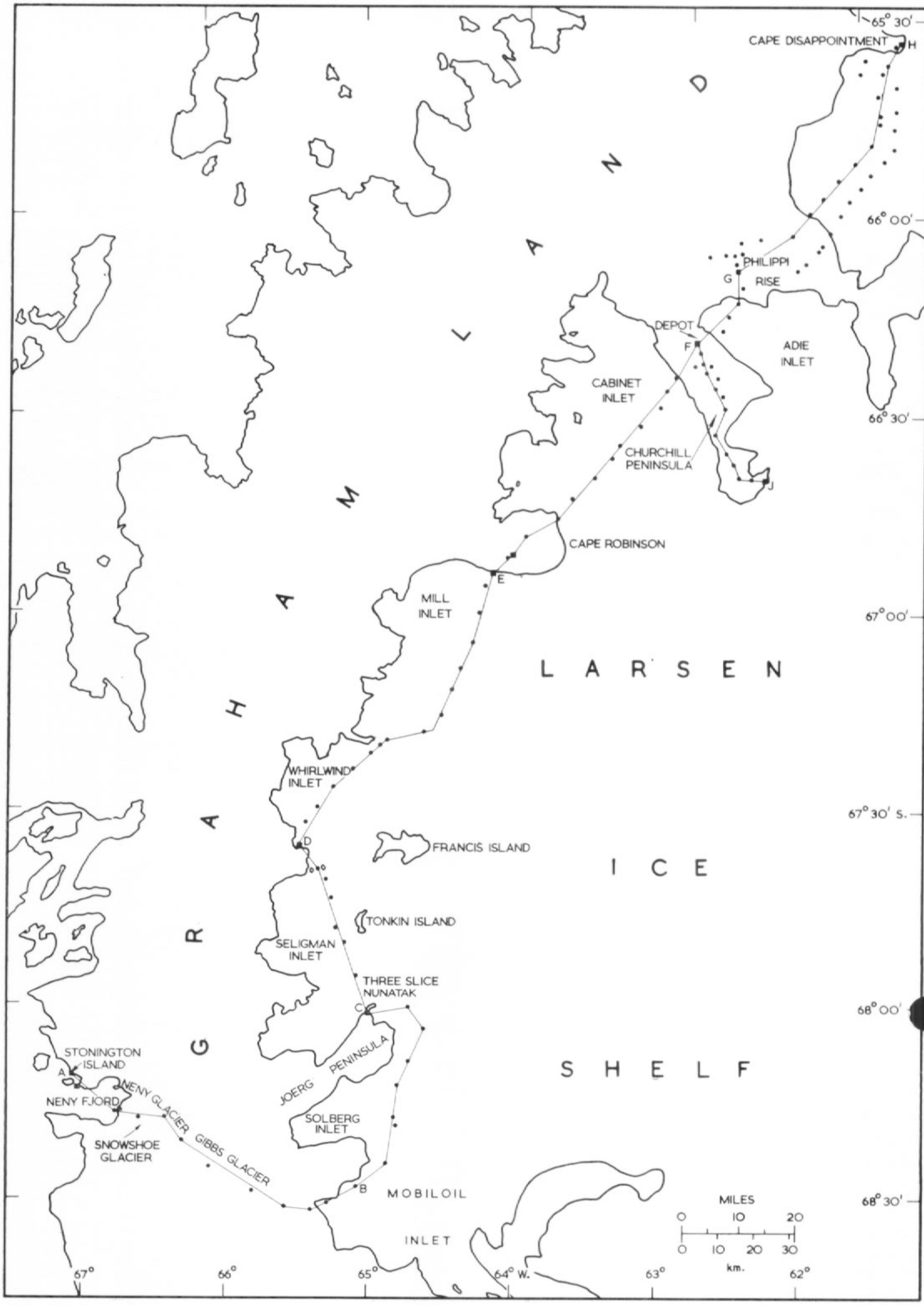

Fig. 1. Map of part of Graham Land and the Larsen Ice Shelf showing geophysical stations and lines of profile (lettered A to J).

● Gravity and magnetic stations on ice. ■ Gravity and magnetic stations on rock.

Gravity survey

The starting point for the gravity traverse, Stonington Island, had already been connected to the South American network via Montevideo and Buenos Aires. By this means, an absolute value of 982·5125 cm. sec.$^{-2}$ has been derived for Stonington Island and the estimated standard error for the link is $\pm 1 \cdot 4$ mgal (0·0014 cm. sec.$^{-2}$) (Griffiths and others, 1964). After allowing for instrumental drift, absolute gravity values can therefore be assigned to all stations on the traverse. This was facilitated by extracting the drift measured during overnight periods and applying an average drift rate, determined previously for the gravity meter, to the readings taken whilst travelling. The long single outward traverse from Stonington Island to Churchill Peninsula may be subject to cumulative errors in the drift correction, resulting in a maximum likely error of ± 5 mgal at Churchill Peninsula. During work done after arrival at Churchill Peninsula travelling times were shorter and closures frequent, so errors of no more than a few tenths of a milligal were added to any initial error.

The latitude correction was obtained from standard tables compiled from the International Gravity Formula. Station positions are assumed to be accurate to within $\pm 0 \cdot 5$ km., corresponding to an error of $\pm 0 \cdot 3$ mgal in the latitude correction. Stations on the ice shelf require no correction for either free-air or Bouguer effects but for stations on the peninsulas and glaciers above ice-shelf level, free-air corrections were applied initially. The resulting free-air anomalies are plotted in Figs. 2–5. The effect of the material between the station and ice-shelf level was then allowed for in the Bouguer correction. A density of 2·67 g. cm.$^{-3}$ was used to correct for the column of material between stations on rock and ice-shelf level but exact Bouguer anomalies could not be calculated for stations on land ice, owing to the unknown relative amounts of ice and rock beneath them. For these cases limits were calculated, between which the true Bouguer anomaly must lie, assuming first an all-rock column and then an all-ice

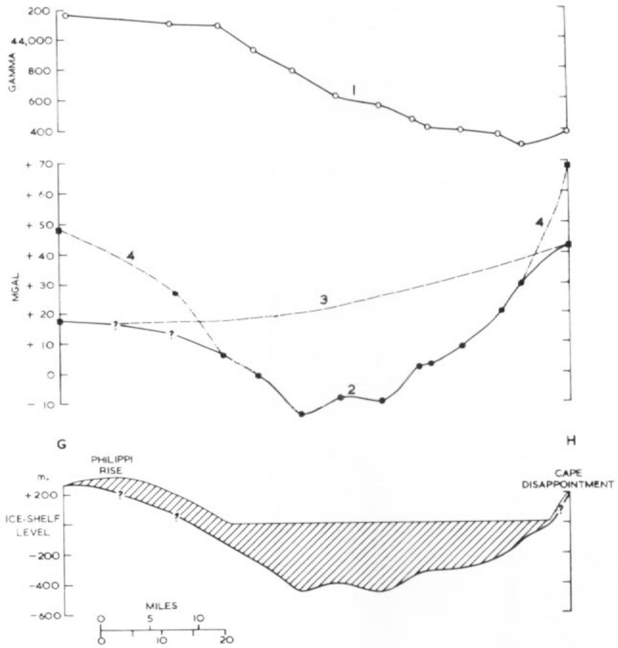

Fig. 2. Gravity and magnetic profiles along the line G–H. The sub-ice topography is calculated for the condition where the ice is grounded throughout the length of the profile.

1. Total-field magnetic anomaly.
2. Bouguer anomaly relative to ice-shelf level.
3. "Regional" Bouguer anomaly.
4. Free-air anomaly relative to ice-shelf level.

● Station on ice. ■ Station on rock.

column between the station and ice-shelf level. The Bouguer anomalies are also shown in Figs. 2–5. Errors in the heights of stations above the adjacent ice shelf could lead to errors of up to $\pm 3 \cdot 9$ mgal in the Bouguer anomaly for a station on rock and $\pm 5 \cdot 4$ mgal for a station situated on an all-ice section. The heights of stations on the ice shelf could be up to ± 50 ft. ($15 \cdot 2$ m.) from the mean ice-shelf level because of the undualtions. This would give rise to an error in the Bouguer anomaly of up to $\pm 4 \cdot 1$ mgal. In some circumstances, this error should be added to the existing error in the heights of peninsula stations, giving a total error of about ± 6 mgal.

It has not been possible to calculate terrain corrections, because of the lack of suitable topographical maps. Stations on the ice shelf would not be much affected but those on peninsulas could be up to several milligals too low because of this omission.

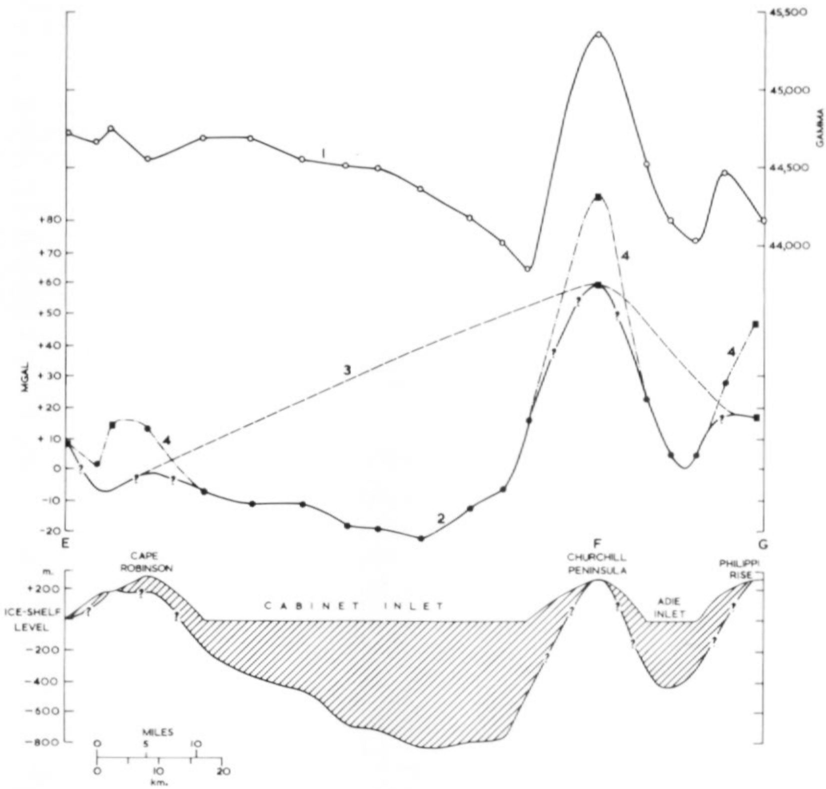

Fig. 3. Gravity and magnetic profiles along the line E–C. The sub-ice topography is calculated for the condition where the ice is grounded throughout the length of the profile.
1. Total-field magnetic anomaly.
2. Bouguer anomaly relative to ice-shelf level.
3. "Regional" Bouguer anomaly.
4. Free-air anomaly relative to ice-shelf level.
● Station on ice. ■ Station on rock.

The gravity anomalies exhibit similar features throughout the area of the survey. Over most of the ice shelf both the free-air and Bouguer anomalies are considerably less than on the adjacent peninsulas. In the Bouguer reduction, material lying above ice-shelf level has been allowed for, so the negative Bouguer anomalies indicate a large mass deficiency beneath the ice shelf in comparison with the peninsulas.

The variation in the density of rock specimens from four different localities ranged from $2 \cdot 56$ to $2 \cdot 76$ g. cm.$^{-3}$, but the difference between the average density of rock ($2 \cdot 67$ g. cm.$^{-3}$)

and that of ice (assumed as 0·9 g. cm.$^{-3}$) is about ten times greater than this. It is therefore most likely that the low anomalies over the ice shelf are caused either by a great thickness of ice or the presence of water between the base of the ice and the bedrock, rather than mere changes in density within the bedrock itself.

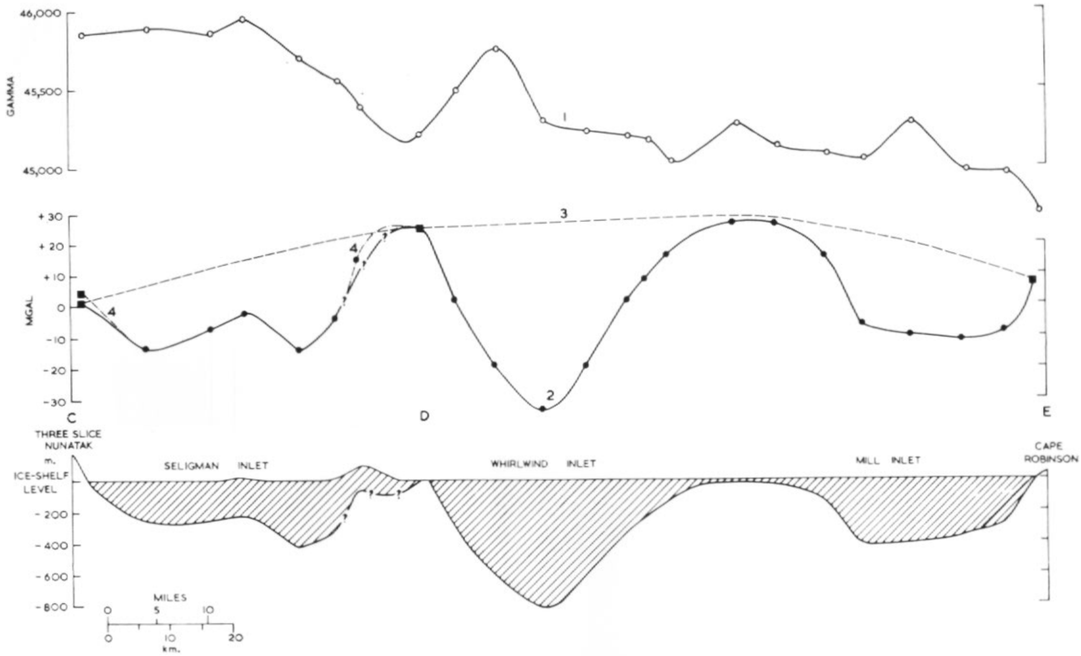

Fig. 4. Gravity and magnetic profiles along the line C–E. The sub-ice topography is calculated for the condition where the ice is grounded throughout the length of the profile.
1. Total-field magnetic anomaly.
2. Bouguer anomaly relative to ice-shelf level.
3. "Regional" Bouguer anomaly.
4. Free-air anomaly relative to ice-shelf level.
● Station on ice. ■ Station on rock.

If the ice shelf is grounded, the problem becomes simply one of comparing ice of assumed density 0·9 g. cm.$^{-3}$ with rock of assumed density 2·67 g. cm.$^{-3}$, and quantitative estimates of ice thickness can then be made. If, however, the ice is floating, this cannot be done by using the gravity results alone, since the ice could then be underlain by an unknown depth of water. But there is an empirical relationship between the height above sea-level of the surface of a floating ice shelf and its thickness (Thiel and Ostenso, 1961) and, if supplementary evidence suggests that the ice shelf is floating, its assumed surface elevation can then be used to estimate its thickness.

Profiles have been constructed along the line of traverse (Figs. 2–4) and depths to bedrock calculated for a situation where the ice is grounded throughout. Although profiles for the floating ice-shelf condition are not shown in the figures, in general the sub-ice topography will be similar in shape to that calculated for the grounded-ice model but up to 5 per cent shallower.

The ice thicknesses for the grounded-ice models were calculated on the assumption that the residual anomaly at each station is caused by an infinite horizontal slab of ice. The error involved in this assumption is not great, because the thickness of ice is small in comparison with its surface area. The choice of the regional anomaly is, however, quite arbitrary. It was not possible to carry out sufficient field work to enable an accurate determination of the regional field to be made. The "regional Bouguer anomaly" curves (Figs. 2–4) were derived simply by joining Bouguer anomaly values for stations on rock with the smoothest curve possible. Any inaccuracy in the regional curve over the intervening ice shelf would be reflected in the residual anomalies and hence in the ice-thickness estimates. The extent of the possible error is very difficult to estimate but it could feasibly be up to about 50 per cent in some instances. Ice–rock interfaces beneath the peninsulas are also only approximate, because of the degree of uncertainty in the Bouguer anomaly mentioned previously.

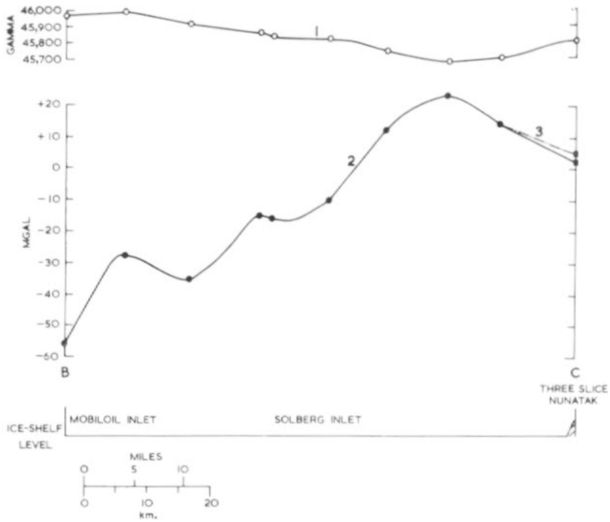

Fig. 5. Gravity and magnetic profiles along the line B–C.
1. Total-field magnetic anomaly.
2. Bouguer anomaly relative to ice-shelf level.
3. Free-air anomaly relative to ice-shelf level.
● Station on ice. ■ Station on rock.

The field evidence suggests that much of the Larsen Ice Shelf covered by the present survey is afloat. With the exception of parts of Solberg and Mill Inlets where there are severe undulations, its surface appears to be extremely level. This is substantiated by the low deviation from the mean in the determination of the height above sea-level of 16 stations on the ice shelf (Kennett, 1965). If the ice shelf was grounded throughout its length on "foothills" beneath the main cliffs of the coastline, as envisaged by Stephenson (1951), one would expect the surface everywhere to show considerable variation in relief. The presence of strand cracks at every point where the traverse crossed from the ice shelf to land ice provides more support for the floating theory. In each case the junction was marked by a series of cracks, several centimetres wide, trending parallel to the coastline. At Three Slice Nunatak and at Cape Disappointment the cracks were observed to be "working".

Each section of the traverse is now considered in detail.

Area between Philippi Rise and Cape Disappointment. On the grounded-ice model (Fig. 2) the maximum thickness of ice is 450 m. Strand cracks are well developed along each side of the ice shelf in this area, so the bulk of it can be assumed to be afloat. If the height of the ice-shelf surface is 66 m. above sea-level, then it must be of the order of 430 m. thick for hydrostatic equilibrium to apply (Thiel and Ostenso, 1961), and therefore the depth of water beneath the ice shelf cannot be very great. The double trough in the Bouguer anomaly appears on both parallel sections of the traverse and it coincides with the eastward continuation of Flask and Leppard Glaciers, pointing to overdeepening of the rock floor relative to the rest of the inlet. In general, Bouguer anomaly values on the eastern traverse are higher than those on the western one, suggesting that the bedrock is nearer the surface in the east.

Adie Inlet. The maximum thickness for grounded ice is 440 m. (Fig. 3). Hair-line cracks, similar to normal strand cracks, occur over most of the ice-shelf surface in Adie Inlet. The height of the ice shelf in this area is thought to be about 79 m. above sea-level; hence for hydrostatic equilibrium, it would have to be 560 m. thick. It is therefore probable that the ice in this part of the inlet is a grounded re-entrant of a mass of floating ice farther to the east which is still susceptible to tidal movements.

Cabinet Inlet. The maximum thickness of ice on the grounded-ice model for Cabinet Inlet is 820 m. (Fig. 3). Strand cracks are again well developed along the junctions with Cape Robinson and Churchill Peninsula, so the ice is undoubtedly floating in a considerable depth of water. The deepest part of the inlet is along its eastern side, suggesting that erosion along the extensions of Bevin, Attlee and Eden Glaciers has been greater than that of the glacial valleys on the western side of the inlet. The linearity and steepness of the south-western coast of Churchill Peninsula also implies that it may be fault-controlled.

Mill and Whirlwind Inlets. No control point could be established on rock in between these two inlets; hence the shape of the regional anomaly between the southern margin of Whirlwind Inlet and Cape Robinson is largely conjectural. However, it must be similar to that shown in Fig. 4 in order to clear the large positive anomaly in the southern part of Mill Inlet. On this assumption, the deepest part of Mill Inlet is 420 m. beneath the ice-shelf surface for a grounded-ice model. In the southern part of Mill Inlet the underlying rock must be within a few tens of metres of the surface, but no accurate estimate can be given because of the uncertainty in the value of the regional anomaly. The area of the positive anomaly is marked by large surface undulations and considerable crevassing in the ice shelf, lending support to the view that the anomaly is due to rock at shallow depth.

The negative anomaly in Whirlwind Inlet could be caused by grounded ice with a maximum thickness of 810 m. but it is more likely to be due to a thick mass of ice floating in several hundred metres of water.

Seligman Inlet. The two minima in the Bouguer anomaly correspond to grounded-ice thicknesses of 420 and 270 m., respectively (Fig. 4). Both margins of this inlet are marked by "working" strand cracks, which were also noted on either side of a slight rise in the ice-shelf surface, corresponding to the rise in anomaly in the centre of the inlet. This would suggest that the ice beneath the two anomaly minima is floating whilst elsewhere it is grounded. Nevertheless, the estimates show that there is insufficient depth for complete hydrostatic equilibrium, if the ice-shelf surface is 79 m. above sea-level.

Solberg and Mobiloil Inlets. An insufficient number of control points could be obtained to enable quantitative estimates of ice thickness to be made in this area. However, the Bouguer anomaly is strongly positive in the northern part of the area and it is therefore likely that rock approaches very near to the surface here (Fig. 5). Again, the part of the ice shelf which is marked by the positive anomaly (off the north-eastern end of Joerg Peninsula) is badly buckled and crevassed.

Magnetic survey

In addition to recording changes in the magnetic properties of the rocks, magnetometer readings are subject to diurnal variation in the Earth's magnetic field. This effect can best be removed by reference to a fixed station where the magnetic elements are continuously observed. Magnetometer readings must also be reduced to a particular date (or epoch) to correct for long-term secular changes. The nearest magnetic observatory which could supply the necessary information was the one at the Argentine Islands. The magnitude and time of occurrence of diurnal changes varies over the Earth's surface, hence the correlation of events recorded at the Argentine Islands with those on the Larsen Ice Shelf was checked by reading the magnetometer at half-hourly intervals over a period of 15 hr. Two such checks were made at different parts of the ice shelf, one on a magnetically disturbed day in October 1963, and the other on a quiet day in December 1963. Events were found to occur at precisely the same time and were of comparable amplitude. On the disturbed day the standard deviation between the two sets of half-hourly values was ± 10 gamma but on the quiet day it was ± 2 gamma. The Argentine Islands' records have therefore been applied in their original form to correct for diurnal changes on the Larsen Ice Shelf. All diurnal corrections were within +31 and −41 gamma. All magnetic readings have been reduced to 30 September 1963, assuming the same rate of secular variation as at the Argentine Islands, i.e. 10·5 gamma/month.

An independent check on the accuracy of the Elsec proton magnetometer and the correction for the diurnal and secular variations was obtained by occupying a station established six weeks previously at Cape Disappointment by J. Mansfield. The two observations agreed to within 1 gamma after correction for diurnal and secular effects.

Station spacing throughout the magnetic survey was not sufficiently close to allow any quantitative interpretation of the data. However, the magnetic anomalies are useful on a qualitative basis when used in conjunction with the gravity results.

An estimate of the regional field could only be made in the northern part of this area, where the two parallel traverses cross from Philippi Rise to Cape Disappointment (Fig. 1). The magnetic contours appear to strike in a north-west to south-east direction, a trend similar to that noted at sea off the north-west coast of Graham Land by Griffiths and others (1964, fig. 26).

The magnetic field across part of Adie Inlet and the eastern side of Cabinet Inlet (Fig. 3) is disturbed by the edges of a large anomaly on Churchill Peninsula, which is described on p. 57. Otherwise, the field over Cabinet Inlet is smooth with only minor variations near the outcrop of intrusive rocks at Cape Robinson.

Across Mill Inlet the field is less regular (Fig. 4). The anomaly on the southern side of the inlet is probably due to the near-surface rock implied by the gravity anomalies. The anomaly in the central part of the inlet cannot be explained by this, since the ice here is thought to be several hundred metres thick; the cause must therefore be a change in polarization of the rock floor of the inlet.

The large anomaly in the southern part of Whirlwind Inlet (Fig. 4) is equally difficult to explain on the basis of variations in the topography of a magnetic basement. The anomaly is unlikely to be directly associated with the rock outcrop, since it is offset too far to the north. Again it is probably due to polarization changes within the rock underlying the inlet.

The small magnetic high in the central part of Seligman Inlet (Fig. 4) corresponds to the peak in the gravity anomaly. This provides confirmation of a westward extension of the rocks of Tonkin Island, which from a distance appear to be dark volcanic rocks cut by dykes.

The magnetic field over Solberg and Mobiloil Inlets (Fig. 5) is very smooth and bears no relation to the gravity anomaly, so it can only be assumed that the bedrock beneath the inlets is of relatively non-magnetic material.

Survey of the Churchill Peninsula Area

Churchill Peninsula is an ice-mantled ridge trending south-eastward from the mainland for a distance of 50 km. Rock is only exposed at the north-western end of the peninsula, at its south-eastern tip and at an isolated nunatak 7 km. from the junction with the mainland. The north-western outcrop consists of coarse-grained acid and basic intrusive rocks, whereas the south-eastern one is composed of flat-lying tuffs, and the isolated exposure is an altered diorite.

Gravity and magnetic observations were made along the top of Churchill Peninsula at an average station spacing of 4 km. (Fig. 6).

Gravity survey

With the exception of a station on rock at each end of the traverse, all stations were situated on ice. Bouguer anomalies cannot be calculated in the usual way by reduction to ice-shelf level, because of the unknown distribution of ice and rock beneath each station. Free-air and Bouguer anomalies were therefore reduced to a datum 500 m. above ice-shelf level, and the extra height above each station was assumed to be filled with ice of density 0·9 g. cm.$^{-3}$ (Fig. 7). A "regional" field was then derived for the traverse by adding the calculated Bouguer effect of the imaginary ice above each station on rock to the measured Bouguer anomaly at the same point. The depth of the ice–rock interface below the 500 m. datum was then obtained from the residual Bouguer anomaly at each station on ice (Fig. 7).

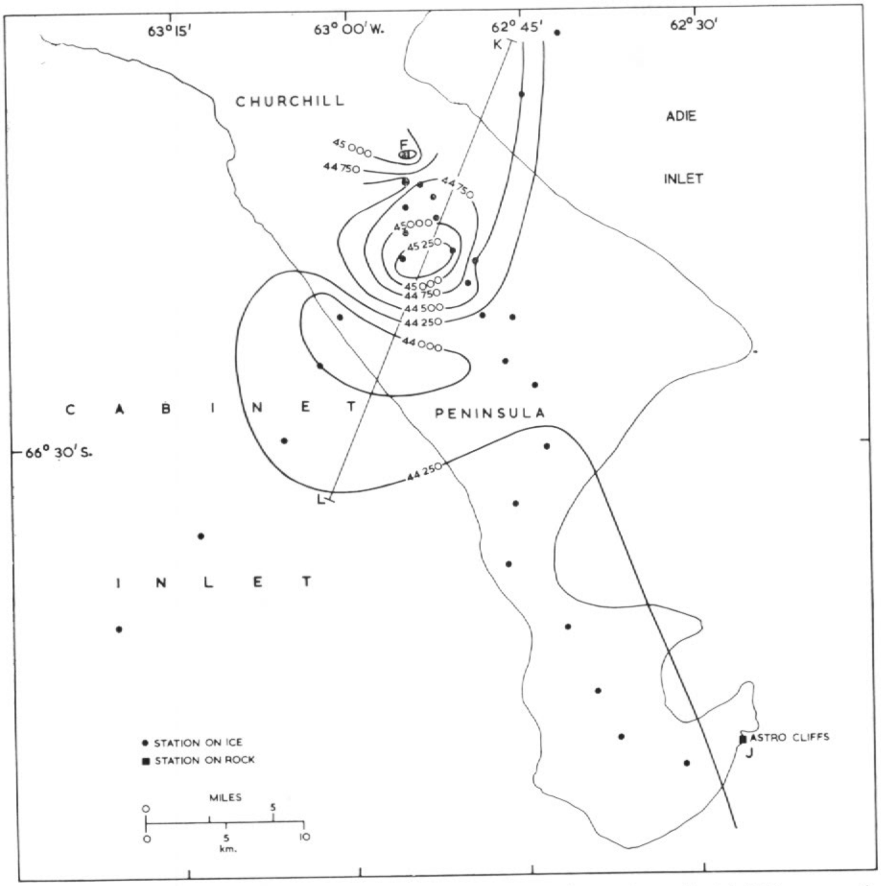

Fig. 6. Map of Churchill Peninsula showing gravity and magnetic stations. Total-field magnetic anomaly contours at an interval of 250 gamma are shown. The profile along the line K–L is given in Fig. 8.

Again, it has been assumed that the contrast between the ice and rock densities is essentially constant. In the calculation of ice thicknesses the ice beneath each station has also been assumed to be an infinite horizontal slab. This assumption is clearly less justifiable than on the ice shelf, since Churchill Peninsula is more diverse in topography and limited in areal extent. The thickness of ice shown in the profile is therefore likely to be an underestimate. Uncertainty of the "regional" field could also lead to large errors. The accuracy of the profile is, however, sufficient to show that the sub-ice topography of Churchill Peninsula is very deeply dissected. The isolated diorite outcrop is separated from the mainland by a deep trough, the base of which appears to be below ice-shelf level and probably approaches sea-level. The volcanic rocks of Astro Cliffs are also separated from the mainland by a well-marked depression, the base of which is also probably below sea-level.

Magnetic survey

The most prominent feature of the magnetic contour map (Fig. 6) is a positive anomaly centred around the diorite intrusion and associated with the shallow negative anomaly to the south-west (Fig. 8). An initial estimate of the depth of the body producing the anomaly was obtained by assuming its source to be a single point (Smellie, 1956). This resulted in a maximum depth of 3·6 km. to the top surface of the body.

Since the anomaly is slightly elongated in a north-west to south-east direction, an attempt was made to match the entire anomaly with standard curves calculated for dyke-like features

(Gay, 1963). A good fit was obtained with a curve corresponding to a "dyke" 4·7 km. thick dipping at 80° to the south-west. The top surface of the "dyke" would be 1·6 km. beneath the surface.

Because the stations upon which the depth estimates are based are rather widely spaced, the effect of near-surface changes will not be apparent. The figures are therefore overestimates of the true depths, but they serve to show that the anomaly is due to a large steep-sided mass approximately 5 km. across and approaching the surface. The measured susceptibility of the

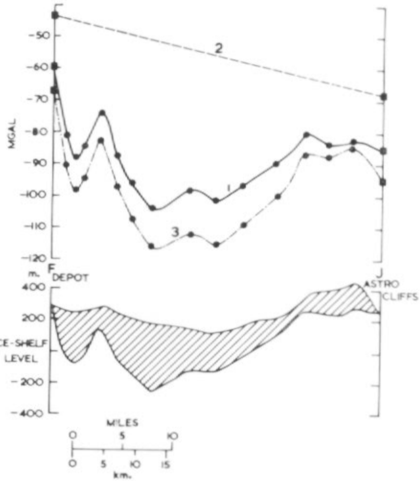

Fig. 7. Gravity profile along the line F–J showing the calculated sub-ice topography.
1. Bouguer anomaly relative to a datum 500 m. above ice-shelf level.
2. Calculated "regional" Bouguer anomaly.
3. Free-air anomaly relative to a datum 500 m. above ice-shelf level.
● Station on ice. ■ Station on rock.

diorite is 4×10^{-3} e.m.u. cm.$^{-3}$, in contrast with 4×10^{-4} e.m.u. cm.$^{-3}$ for the volcanic rocks of Astro Cliffs and 1×10^{-4} e.m.u. cm.$^{-3}$ for the grandiorite of nearby Gulliver Nunatak. It is therefore most likely that the anomaly is due to a diorite batholith, of which the isolated outcrop is the sole surface expression.

Traverse across the Antarctic Peninsula

Gravity survey

The free-air anomaly curve for the traverse across the Antarctic Peninsula was calculated relative to sea-level and is shown in Fig. 9. The greatest error in the anomaly is introduced by uncertainty in the heights of stations. The period of the survey coincided with large changes in atmospheric pressure and hence the heights obtained by using aneroid barometers may be up to ± 30 m. in error. However, the heights measured during the present survey agree within these limits with those determined in previous years by other workers. An error of ± 30 m. introduces an error of ± 9 mgal in the free-air anomaly.

Since all the stations were on ice, the same difficulty as before was experienced in calculating the Bouguer anomaly. Initially, two Bouguer anomaly curves were plotted, one assuming an all-rock column of density 2·67 g. cm.$^{-3}$ between the station and sea-level and the other assuming an all-ice column of density 0·9 g. cm.$^{-3}$ between the station and sea-level (Fig. 9). The greatest error in the anomaly results from doubt in the height of the station; this is ± 6 mgal for the all-rock column and ± 8 mgal for the all-ice column. An attempt was also made to derive a more representative Bouguer anomaly by allowing for an estimated thickness of ice beneath each station. These thicknesses were obtained by drawing topographical cross-sections of the glaciers at each station and extrapolating the curve of the glacier walls beneath the ice. The most feasible profiles were drawn initially but then both shallower and deeper possible profiles were added. The Bouguer effect of the composite column beneath each station

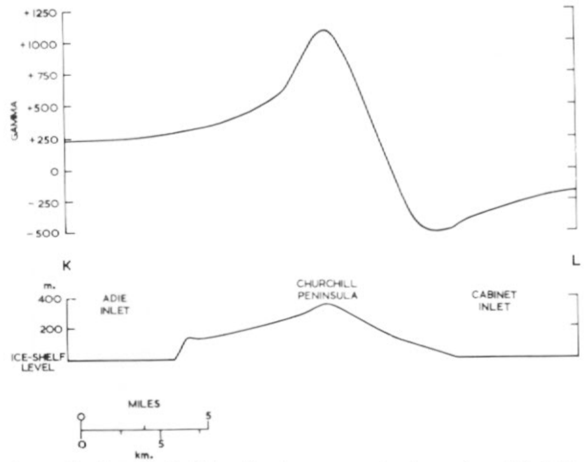

Fig. 8. Magnetic profile along the line K–L (Fig. 6). An approximate regional field has been removed.

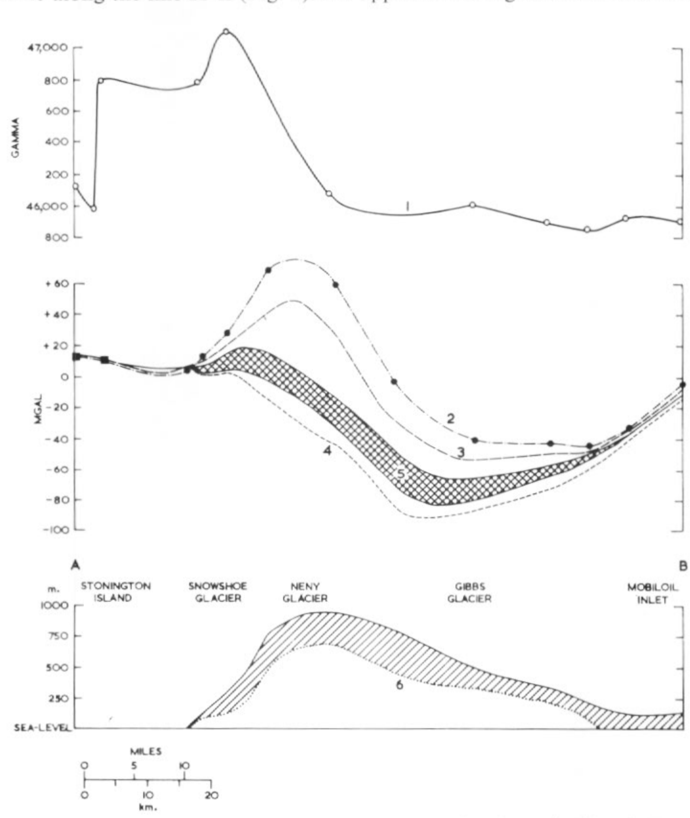

Fig. 9. Gravity and magnetic profiles across the Antarctic Peninsula along the line A–B.
1. Total-field magnetic anomaly.
2. Free-air anomaly relative to sea-level.
3. Bouguer anomaly assuming all ice between stations and sea-level.
4. Bouguer anomaly assuming all rock between stations and sea-level.
5. Bouguer anomaly for assumed ice distribution shown in the profile.
6. Assumed rock–ice interface.
● Station on ice. ■ Station on rock.

was then calculated, using the same densities as given above and assuming infinite horizontal slabs of material. The resulting Bouguer anomaly is represented in Fig. 9 by the shaded area.

Approximate terrain corrections have been calculated for all stations using Hammer zones G to M and assuming a rock density of $2 \cdot 67$ g. cm.$^{-3}$ for each compartment. The available topographical maps were of too small a scale to allow calculation of the effect of zones A to F, but in almost every case stations were on gently sloping glacier surfaces with no appreciable irregularity in the near zones. Country lying outside zone M could still exert some influence on the final result but this is likely to affect each station by the same amount. The value of the terrain correction varies between $0 \cdot 6$ and $5 \cdot 6$ mgal, and the Bouguer anomaly curves (Fig. 9) have been corrected for this.

Since the free-air reduction does not allow for the influence of the material between the stations and sea-level, part of the free-air anomaly may be due to anomalous mass distributions above sea-level which are not compensated by changes in density at depth or by changes in crustal thickness. Generally, free-air anomalies in areas of low relief average zero whatever the elevation of the region, thus indicating that the area is essentially in isostatic equilibrium. In many areas of rugged relief the free-air anomalies are largely dependent upon the relief, demonstrating that the topographical irregularities are not completely compensated locally (Woollard, 1959).

In this area there is considerable variation in the free-air anomaly. At stations on each coast it is approximately zero but inland it reaches a peak of $+75$ mgal, slightly west of the highest point of the traverse, and then drops to a minimum of -44 mgal over Gibbs Glacier. Part of this variation could be explained by changes in ice thickness, which is at present unknown. However, in considering the limiting conditions of an all-rock column extending to sea-level beneath the peak of the anomaly and an all-ice column extending to sea-level below the lowest point, there is an anomaly difference of only 24 mgal. The occurrence of rocks denser than $2 \cdot 67$ g. cm.$^{-3}$ beneath the peak of the anomaly or overdeepening of Gibbs Glacier beneath the anomaly minimum might account for a further part of the anomaly, but it is probable that it would still show considerable variation. The possibility of this part of the peninsula being incompletely compensated locally cannot therefore be eliminated.

The Bouguer anomaly calculated on the assumption that all the material between each station and sea-level is ice of density $0 \cdot 9$ g. cm.$^{-3}$ still generally follows the free-air anomaly, reaching a peak of $+50$ mgal in the same position as the free-air anomaly peak and a minimum of -52 mgal slightly west of the minimum in the free-air anomaly. The Bouguer anomaly calculated for an all-rock column shows marked differences. The anomaly decreases from each coastline to a minimum of -90 mgal in a position corresponding approximately to the mid-line of the peninsula. These two curves therefore define the limits within which the true Bouguer anomaly must lie.

Until ice-sounding equipment becomes available the interpretation of the Bouguer anomaly represented by the shaded area in Fig. 9 must remain the subject of speculation rather than rigorous analysis. From a zero value on the west coast, it rises to a slightly positive value and then drops to a minimum of -65 to -80 mgal over the mid-line of the peninsula, rising again to about zero as the east coast is approached. This trend has been noted throughout the length of the Antarctic Peninsula wherever the gravity survey has penetrated the mainland in the various fjords and inlets (Griffiths and others, 1964). So far, no other complete crossings of the peninsula have been possible. On this traverse, and throughout the rest of the Antarctic Peninsula, the horizontal gravity gradients are small, suggesting that the anomaly pattern is a result of deep-seated changes rather than differences in near-surface geology. These could either take the form of a decrease in the density of the material at depth or a deepening of the base of the crust beneath the centre of the peninsula in order to maintain regional isostatic equilibrium. There are, however, insufficient data to distinguish between these two possibilities, or to infer the degree of completeness of regional compensation of the peninsula.

Magnetic survey

The field magnetometer readings (Fig. 9) were corrected in the same way as those of the survey on the Larsen Ice Shelf.

The results of the magnetometer survey are insufficiently detailed to allow a reliable quantitative interpretation. However, detailed work in the Neny Fjord area has shown that the very steep gradient off Roman Four Promontory is part of a well-marked linear feature. This steep anomaly is probably caused by the juxtaposition of two blocks of markedly different polarization, the top surfaces of which are very near the sea-floor. The continuation of the positive anomaly over the initial part of the traverse presumably indicates the persistence of the highly magnetized block at least as far as the head of Snowshoe Glacier.

Discussion

Although the results of the gravity and magnetic surveys must be regarded as tentative, several features of interest have emerged which would be worthy of further investigation should the opportunity arise.

The thickness of the Larsen Ice Shelf appears to be greater than hitherto suspected. Previous estimates have been based upon observations made at rifts and pressure cracks, which seem to be anomalous in comparison with the main area of the ice shelf. The present survey was conducted in latitudes where the ice shelf is at its widest. Most of the traverses were relatively close to the mainland and the ice shelf here already appears to be fully developed. Most of its area covered by the present survey is almost certainly afloat. Those parts which are aground appear to be marked by intense buckling and crevassing, whereas the surface of the floating ice shelf is level or gently undulating. If the depth estimates derived from the gravity data are substantially correct, then it would appear that the sea-floor beneath the ice shelf is at a depth comparable to that off the south coast of Trinity Peninsula, where it has been measured by echo-sounding techniques. If the ice shelf is floating, then it could not have been responsible for eroding the deep depressions in the bedrock surface beneath. This could have been accomplished by a former eastward extension of the present valley glaciers. Deglaciation by at least 365 m. is known to have occurred on both the east and west coasts of the Antarctic Peninsula in relatively recent times. It is therefore possible that these glacial valleys could have been cut at a time when the ice in this area was thicker than at present. The rise in the bedrock surface recorded on the eastern traverse between Philippi Rise and Cape Disappointment suggests that in fact there may be glacial overdeepening close inshore.

The deep dissection of Churchill Peninsula is somewhat surprising, since the topography of the peninsula gives the impression of a rock ridge supporting a thin veneer of ice. It now appears, however, that the central part of this peninsula is underlain by a trough in the bedrock; were the ice to melt, Astro Cliffs and probably the isolated diorite intrusion would become islands.

No conclusive statement can be made regarding the interpretation of the traverse across the Antarctic Peninsula until measurements of ice thicknesses have been carried out. It would seem, however, that the regional gravity trend of the more northerly parts of the peninsula continue, suggesting that it is a structural entity at least partly compensated on a regional basis.

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