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Ice Thickness Measurements in Mac.Robertson Land, 1957-1959

BY

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CONTENTS

ILLUSTRATIONS

TEXT-FIGURES

PLATES
(at back of Bulletin)

SUMMARY

Field parties based on Mawson in Mac.Robertson Land, Antarctica, during the period from 1957 to 1959 used seismic and gravity methods to determine ice thicknesses on traverses extending 400 miles south from Mawson as far as the southern Prince Charles Mountains.

The results confirmed the continental character of this part of Antarctica and showed an average inland ice thickness of about 6000 ft and reaching a maximum of 9271 ft.

The maximum seismic velocity recorded in the ice was 12,780 ft/s reached at a depth of 680 ft.

A westerly, sub-glacial extension of the northern Prince Charles Mountains was discovered; these, together with the eastern and southern Prince Charles Mountains, form a rim of igneous and metamorphic rocks enclosing a large sedimentary depression on three sides. The western limit of the depression was not explored. North of the sub-glacial range is a deep valley, an expression of a major tectonic event, separating the Framnes and northern Prince Charles Mountains.

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1. INTRODUCTION

During the period of the International Geophysical Year (IGY), 1 July 1957 to 31 December 1958, twelve countries co-operated in a programme of co-ordinated geophysical exploration in Antarctica. This Bulletin describes a part of that programme, the part carried out by the Australian National Antarctic Research Expedition (ANARE) of the Department of External Affairs, on ice thickness measurements. These were made in Mac.Robertson Land, in the Australian sector of the Antarctic ice sheet. For the purpose of making these measurements, a geophysicist from the Commonwealth Bureau of Mineral Resources, Geology & Geophysics (BMR) was attached to ANARE during each of the two years covered by the IGY. They were members of two successive teams of about 25 men based at the ANARE station Mawson.

The ice thickness measurements were made using seismic and gravity methods on one traverse about 10 miles south-west of Mawson and two regional traverses extending up to 400 miles south of Mawson. Apart from ice thickness measurements, glaciological and meteorological observations were carried out. The traverses were made by parties of five or six men, including a mechanic and wireless operator. All members of the parties assisted with the seismic operations when their other duties permitted. The personnel engaged on the traverses are listed in Appendix A.

The seismic cab and shot-hole drill, together with all transport, living accommodation, and supplies, were provided by ANARE, which was responsible for the general administration of the research station. The seismic equipment, gravity meter, and microbarometers were provided by the Bureau of Mineral Resources. Details of the equipment are given in Appendix B.

The importance of ice thickness measurements

Over the greater part of their areas, Antarctica and Greenland are overlain by permanent and continuous ice cover, which constitutes about 99 percent of the Earth's land-supported ice. The most obvious result of measuring the thickness of the ice cover is a geographical outline of the underlying rock surface. This is of definite interest in itself, but the main importance of the measurements is that from them can be estimated the total mass of ice; this mass, in the form of ice or water, has played an important part in geological history and will strongly influence future conditions on the Earth. When taken in conjunction with information on the rates of accumulation and recession and the rates of flow of the ice, these measurements of ice thickness will extend our present knowledge of the mass economy of the ice sheets, i.e. the amounts by which the mass of ice is tending to increase or decrease. Changes in the total mass of ice retained in the polar ice sheets are certainly related to long-term changes in the climates of the world, but much more information is necessary before the exact relation can be defined.

Most of the Earth has been covered at some time or another by ice during the several Ice Ages of geological history, for example Northern Europe and North America during the Pleistocene period. A study of present-day ice sheets provides information which will enable the effects of the earlier Ice Ages to be more fully understood. Also, by examining in detail the variation of ice conditions with depth, namely density, temperature, and physical structure, a picture is provided of the weather of the past as each successive layer of snow was added to the ice sheets.

It may be possible to establish a relation between ice thickness, surface topography, and direction and rate of flow of the ice; these may be of value in understanding some characteristics of the continent.

A necessary adjunct of the seismic method of ice thickness measurements is the evaluation of the velocity of the seismic waves through the various shallow layers of ice and through the homogeneous ice beneath them. These velocity values can be correlated with other physical properties of the ice, such as density and temperature, and also with glaciological data. It is possible that there may be a relation between the velocity of the refracted seismic waves and their direction of propagation, which would indicate a preferred orientation of the ice crystals in relation to the direction of the ice-flow.

Long-range refraction shooting may provide velocity values for the propagation of seismic waves in the rocks under the ice and thus help to indicate the geological nature of the rocks.

Previous measurements

Indirect methods have been used to compute the volume of ice on Antarctica (Thiel, 1962) and so provide an estimate of the average thickness of ice over the continent, but the most satisfactory method of measuring ice thickness so far developed is the seismic reflection method.

Early experiments on glaciers in the Austrian Alps (Brockamp & Mothes, 1930) showed that the seismic method of geophysical prospecting could be used to measure ice thickness, and it was subsequently used in Greenland by the German Greenland Expedition (Brockamp, Sorge, & Wölcken, 1933) and in Antarctica by the Second Byrd Antarctic Expedition, 1933-35 (Poulter, n.d.).

After World War II, improved means of transport on inland ice, particularly in the use of the 'Weasel' (a light, tracked vehicle developed for amphibious landings during the Pacific campaigns), led to more extensive exploration of the Greenland and Antarctic ice sheets with seismic equipment.

Although the techniques developed in Greenland proved valuable for the Antarctic expeditions, there is a vast difference in the two continents that necessitates a different approach, both technically and logistically.

In Antarctica, the first detailed profile of ice thickness to be measured on the inland ice sheet was between 1949 and 1952 when the Norwegian-British-Swedish Antarctic Expedition based at Maudheim ran a seismic traverse inland for 385 miles (Robin, 1953). Between 1951 and 1952, Expéditions Polaires Françaises made four seismic soundings on a traverse running 187 miles inland from Port Martin (Imbert, 1953).

In such a large continent as Antarctica, which supports about 90 percent of the Earth's grounded ice, these expeditions, although providing valuable information, were very limited, and it was only with the large programme planned for the IGY that the work received a fresh impetus that is still effective now several years after the end of the IGY.

2. OBJECTIVES OF THE SURVEY

The objectives of the survey, made on the expectation of two years' work, were as follows:

(a) To measure the thickness of the ice burden on the Antarctic Continent over as wide an area as possible, and in particular to run a main traverse from Mawson extending as far south as practicable.

(b) To study the land configuration underlying the ice along short traverses within 100 miles of Mawson in an attempt to define the coastline where it is obscured by ice.

(c) To measure variations in seismic velocity with depth by refraction or reflection methods or both.

(d) To measure variations in seismic velocity of compressional and shear waves near the surface of the ice by small-scale refraction shots and by 'uphole' shooting, together with measurements of temperature and ice density at various depths in the holes.

(e) To attempt to relate seismic velocity variations to temperature and density variations; this would provide a quick means of determining temperatures and densities from seismic velocity measurements. It may be possible to extrapolate the results to velocities deep in the ice to help determine the structure and temperature at depth.

Figure 1 LOCALITY MAP

(f) To measure seismic velocity variations with azimuth, both at the surface and at depth, as a means of investigating variations of velocity with ice crystal orientation brought about by glacial flow.

(g) To supplement the seismic information by gravity measurements at the seismic stations and intermediate stations.

3. PROGRAMME AND SELECTION OF TRAVERSES

Of the above objectives, (a), (b), and (f) were important in the selection of traverses; the others could be pursued along any traverses finally decided upon.

The programme originally envisaged consisted of three main parts:

Part 1

Between late January and March 1957, it was planned to run localised traverses towards the Masson Range and MacKenzie Bay (Fig. 1). The main purpose was to establish operating procedures and assess the capabilities of the equipment in order to be able to plan the main southward traverses in more detail, and to determine the interrelation of seismic measurements with glaciological and other studies; in addition, useful ice-thickness measurements would be made.

Unfortunately this part of the programme received an immediate setback. The arrival of the expedition's vessel *Kista Dan* at Mawson was delayed by about a month owing to impenetrable pack ice near Mawson, and it was not possible to have the equipment ready for field work before the onset of winter. This meant that, in order to take full advantage of the following field season (November 1957 to February 1958), it was advisable to postpone this work until the second year and concentrate on traversing inland.

The planned work was replaced by a traverse between Mount Henderson and the Casey Range, about 10 miles from Mawson, which was carried out between March and May 1958. It had lost its main purpose of establishing operating procedures; its new importance was to investigate the ice thickness and the underlying land surface near the edge of the ice shelf in an attempt to correlate these factors with the rate and direction of ice-flow, which were being examined by a line of glaciological flow-stakes.

Part 2

Between late October 1957 and March 1958 it was planned to make the main southward journey and penetrate as far inland as possible. Details of the programme planned for this traverse included the following:

(a) Set up two and possibly three seismic stations per day at about 20-mile intervals, shooting a reflection cross-spread at each station.

(b) Every two or three days, replace one of the reflection spreads by shallow refraction work.

(c) About once a week carry out a reflection velocity shoot, using one-mile split spreads in areas where good reflections are obtained.

(d) About every two weeks, carry out deep refraction studies, which may take one or two days to complete.

(e) Take gravity meter readings at each seismic station and at intermediate stations about five miles apart. Drift readings should be taken over about half an hour at each station and overnight when applicable.

(f) Drill one deep hole (about 100 ft) per day for detailed glaciological coring, the hole to be used as a seismic shot-hole.

A well-established route from Mawson to the Prince Charles Mountains (Plate 4) was pioneered by Dovers in 1954 and extended by Béchervaise in 1955 and Bewsher in 1956 (Crohn, 1959). However, the route was not suitable for the seismic traverse because local crevassing made it very difficult even for the light Weasel. The much heavier D4 tractors could not be expected to penetrate far along it in safety. Also it was felt that a route which kept away from mountain ranges would give results more typical of the continent as a whole.

The area due south from Mawson had been subjected to only cursory aerial examination but was believed to be free of mountain ranges for at least 400 miles inland. A radar altimeter flight in this area had indicated that the surface elevation increased to about 10,000 ft within 200 miles south of Mawson. This appeared to hold promise for a traverse running due south, which would be ideal from the point of view of inland penetration.

Further reconnaissance flights in RAAF (Antarctic Flight) aircraft confirmed that there were no serious obstacles to a southerly traverse until about 400 miles from the coast, where mountain outcrops together with belts of heavy crevassing were seen. These ranges did not appear to extend more than a few miles to the west of a proposed southerly traverse along meridian 62° East, and it seemed likely that they could be skirted by a minor westerly deviation. Particular attention would have to be given to picking a route through the Masson, David, and Casey Ranges (referred to collectively as the Framnes Mountains), which lie about ten miles south of Mawson and have belts of heavy crevassing associated with them.

This traverse was carried out as planned and reached a distance of 400 miles south of Mawson.

Part 3

The third part of the programme, to be carried out during the second year of the survey, between late October 1958 and February 1959, depended on the results of the previous traverses and was planned to consist of more detailed profiling to augment the previous results.

The plan that ensued was to proceed as rapidly as possible to the fuel depot established during the first survey at the 237-mile point (Shot-point 25), and from there to run traverses in the form of loops approximately 100 miles square to the east and west extending between Shot-point 25 and the southern extremity of the first regional traverse. Both loops were intended to study sub-glacial extensions of the Prince Charles Mountains; the loop to the west was intended also to study ice surface elevations, which were believed to rise considerably in this direction, and to find if possible the westerly limits of ice drainage into the Lambert Glacier system.

This programme had to be modified in practice, owing to extremely bad weather and accidents to vehicles.

4. FIELD WORK

The field work consisted essentially of three traverses:

(1) The first regional traverse — a 400-mile traverse running for most of its length due south along meridian 62°07′ E. The work covered a period of 100 days between 9 November 1957 and 16 February 1958.

(2) The Henderson-Casey traverse — a detailed east-west traverse with two short gravity cross-traverses, totalling 25 miles, along a line of glaciological flow stakes situated in the region 10 miles south of Mawson. The work covered a period of 56 days from 22 March to 16 May 1958.

(3) The second regional traverse — a total of 280 miles of traverse in the form of two loops, one loop 30 miles wide to the west and lying between points 88 and 237 miles south of Mawson on the first regional traverse, and the other loop to the east, being triangular in shape, 15 miles across at the apex and lying between 25 and 70 miles south of Mawson on the first regional traverse. The work covered a period of 110 days from 30 September 1958 to 17 January 1959.

First regional traverse

The first twenty-five miles involved several changes of direction to clear the Framnes Mountains and outlying nunataks (Plate 7). Over this stretch the surface was almost entirely 'blue ice', from which all loose and uncompacted snow had been ablated. This so-called 'ablation zone' is characteristic of the immediate coastal fringe of the ice sheet, and represents an area where total annual surface accumulation (from precipitation and wind transport) is less than total annual ablation (sublimation, melting, and wind scouring). The high ablation arises from higher summer temperatures due to low altitude, and from steep slopes downwards to the north; these present a surface more nearly normal to incident solar radiation, and thus absorb more radiant energy. This high ablation rate exposes, at the surface, snow that is very compact, having been subjected to the pressure of overlying layers during its slow progress to the coast. The ranges of the Framnes Mountains run almost due north-south, thus channelling the ice as it flows northwards between them. This was the area envisaged for the velocity/azimuth studies which had to be postponed. Only one station was shot on the blue ice and results were unsatisfactory, probably because of high surface-wave noise, but only a short time was spent there because the area was unrepresentative of the main ice sheet.

As soon as the party had cleared the Framnes Mountains the character of the surface changed to much softer névé, which was found over the remainder of the route (Plate 4). This appears to be composed of very small particles of wind-blown snow that has been compacted in varying degrees by wind and radiation. As the snow becomes overlain by successive layers of wind deposition, pressure increases the compaction until at sufficient depth the snow changes to almost pure ice. The strong winds, being largely katabatic in origin, are comparatively constant in direction; under their influence the surface is cut into small sharp-edged formations called 'sastrugi', which were normally less than one foot high but were occasionally more than four feet high. Other larger formations of more rounded profile called 'dunes' were also encountered, particularly beyond 100 miles inland.

The party proceeded over these surfaces without serious difficulty, but with numerous delays because of bad weather, until on 4 January 1958 at a point 335 miles due south from the coast, the ranges previously sighted from the air were seen ahead. Between leaving the Framnes Mountains and sighting these inland ranges, no other rock outcrops were seen. Surface slopes were gentle with the exception of a few steep undulations; cracked and crevassed surfaces were encountered at the following distances from the coast:

(1) 67 to 80 miles.

(2) 94 to 120 miles.

(3) 160 to 185 miles.

From the air the first belt is seen to run almost continuously for at least twenty miles to the east and west of the point where the traverse crossed it, but no rock outcrops were visible. The second belt occurs at about the same distance inland as Depot Peak (6100 ft), which lies 62 miles east of the traverse. The altitude at this point of the traverse is about 6500 ft. The third belt occurs at about the same distance inland as the northernmost peaks of the Prince Charles Mountains, which lie 50 miles east of the traverse. These peaks are around 7200 ft high, and the surface elevation at the corresponding part of the traverse is about 7500 ft.

Altitudes along the traverse progressively increased to about 8000 ft at a point about 200 miles inland, and then commenced to fall gently along the remainder of the southerly traverse.

After the inland ranges had been sighted, the surface was found to become increasingly more dangerous owing to cracking and crevassing until, a further 15 miles south, it became necessary to start deviating west to clear these ranges. Course was altered to south-west and a further 40 miles was run. At this point crevassed ice domes were visible all around, and scouting by the Weasel showed that further progress was impossible owing to treacherous surfaces in all directions except along the approach route. It was now necessary in any case to commence the return journey to ensure time being available for refraction work on the way. A further short traverse of 8 miles was run roughly south-easterly from the mid-point of the deviation route (see Plate 4) before returning to the main traverse running due north and south.

Levelling. Owing to the length of the traverse, levelling by surveyor's staff and theodolite was out of the question. It was necessary to rely on barometric methods completely. To reduce errors arising from horizontal pressure variations (Brombacher, 1944), pressure and temperature of the air were measured simultaneously at the ends of five-mile sections along the traverse. Altitude differences obtained thus were then progressively added to obtain the altitude of each station.

Positioning. Positioning was generally by dead reckoning, using a compass and the Weasel speedometers, but checks were made at most seismic stations by taking theodolite shots on the sun. At the southern extremity of the traverse an astrofix was carried out (Plate 4).

Gravity readings. In using the gravity meter it was decided that, because of the slow rate of travel, it would be impracticable to use the normal 'leapfrog' method, in which the instrument is re-read at a previous station after several hours in order to determine the drift rate of the instrument. Instead it was decided to rely on drift rate readings at each station over as long a period as possible. These may not, of course, coincide with the actual drift occurring between stations. It was generally found, however, that the drift rates before and after a day's travel were very similar and it was assumed that the intermediate drift rate was a mean of the values obtained. The occasions when the drift rates were dissimilar could generally be associated with a rapid fall in temperature several hours earlier, or when the temperature was very low, the instrument drift rate becoming erratic below —15°C. In these cases a drift rate curve had to be assumed.

Errors due to wrong drift corrections are not expected to be cumulative; when using gravity meter readings to interpolate for ice thickness between seismic stations, where the thickness is measured relatively accurately, the errors are not likely to be large compared with anomalies produced by a variation in height of the ice/rock interface.

Gravity readings were taken at each seismic station and at each intermediate station, generally at five-mile intervals, where altitude measurements were made. A total of 80 gravity stations were read.

The gravity meter was carried in a shock-mounted, unheated, weatherproof container on one of the tractors.

Seismic operations. Ice thickness measurements were made by reflection methods at the 24 stations marked SP1 and SP3 to SP25 in Plate 4. Generally, the interval between stations was 20 miles but the interval was reduced in regions of particular interest such as the belts of undulations described previously.

When time permitted, short refraction spreads were shot for shallow velocity information, and at two stations, Shot-points 13 and 25, long refraction spreads continuing for several miles from the shot-point were shot for deeper velocity information. Even at distances up to about four miles, good energy transfer was obtained with five pounds of explosives in a 15-ft hole.

Shooting methods. Seismic shooting on the Antarctic ice is similar to conventional land shooting in that there is a low-velocity layer of ice (analogous to the weathered layer on land) which overlies the consolidated blue ice of the ice sheet. The low-velocity layer represents the transition from snow to ice that has been compacted by the pressure of the overlying layers. Single-hole shots have to be made below this low-velocity layer for efficient transfer of energy into the consolidated ice; rays originating near the surface are subject to a defocusing effect.

Another difficulty of energy transfer in the low-velocity layer, which does not arise in land shooting, is that the snow absorbs a large amount of the energy of the explosion in melting the ice near the charge (Poulter, n.d.). Also there is the difficulty of providing efficient tamping of the charge. On the other hand, however, attenuation of seismic energy is much less on the ice sheet than on ordinary land, and only relatively small charges are in fact required.

Because the need for drilling deep holes arose in connexion with measurements of ice temperature and density, the method of exploding the seismic charge in a single deep hole was adopted on this traverse. The average depth of shot was about 90 ft and the deepest shots (at Shot-points 13 and 15) were 125 ft. Charge sizes used in reflection shots ranged between one-quarter and five pounds, with one experimental charge of 20 lb at Shot-point 16. Good reflections were generally obtained with charges of one-quarter and one pound, but at Shot-point 16 only the 20-lb charge gave a satisfactory reflection.

Two other methods of shooting were tried in comparison with the single-hole method but with inferior results. They were:

(a) At Shot-point 9, a square pattern of nine shallow holes, 2 ft deep and 20 ft apart, each containing 4 oz of explosives. The shot-point was offset 600 ft from the nearest geophone.

(b) At Shot-point 20, a triangular pattern of seven 4-oz charges suspended 4 ft above the surface on bamboo stakes. The shot-point was offset about 2500 ft from the nearest geophone.

Geophone arrays. In the preliminary stages of the work, different geophone arrays were tried for recording reflection information (Fig. 2). The arrays used were:

'R' spread. The geophones are laid in a line at equal intervals, with the shot-hole on the same line and one geophone-interval from the end.

Offset 'R' spread. The same geometric arrangement as for the 'R' spread but with the shot-hole several times the inter-geophone distance from the nearest geophone.

'S' spread. This is the 'split spread' used most frequently in oil search surveys. Geophones were laid at equal intervals along a line with the shot-hole at the mid-point.

'X' spread. The geophones are laid at equal intervals in the form of a rectangular cross with the shot at the centre.

'L' spread. Effectively two 'R' spreads with only six geophones in each, laid at right angles and with the shot-hole at the vertex.

Offset 'L' spread. The same geometric arrangement as the 'L' spread but with a gap between the shot-hole and the nearest geophone on each leg of several times the distance between geophones.

On all types of spreads, geophone intervals of 50 ft, 70 ft, and 100 ft were tried. The most successful type of spread was the Offset 'L' type, using a geophone spacing of 100 ft and an offset distance of 600 ft. From Shot-point 6 to Shot-point 25 this type of spread was used almost exclusively. The normally prevalent windy conditions necessitated the use of an offset spread because the wind on the vehicles and sleds produced noise, which was transmitted through the ice to the geophones. By offsetting the geophones, this effect was reduced. Also it was required to record both components of dip of the underlying rock surface with one shot. An 'X' spread with an offset in each arm would have been ideal for this purpose, but it would have required more seismic cable than was available. Consequently the Offset 'L' spread (virtually half an Offset 'X' spread) was adopted.

To reduce wind noise, geophones were buried between one and two feet below the snow surface. On 'blue ice', where this would have been prohibitively time-consuming, the geophones were recessed with the tops flush with the surface.

An attempt was made to record shear wave reflections by laying geophones on their sides, but with no success, as the geophone mechanism appeared to stick in this position.

Filters. In the early stages of the work, filters were set fairly widely, bracketing the reflection frequency, close to 100 c/s, reported by earlier workers. It was found that record quality improved when the high-cut filters were set to cut off sharply at the closest setting above this frequency, but that no improvement resulted from a sharp cut-off at the low-frequency end. The low-cut filters were consequently set to cut off around 70 c/s to retain as much reflection 'character' as possible. Precise settings were varied slightly from station to station, but the optimum setting was found to be K70 KK120, which means that the attenuation of frequencies between 70 c/s and 120 c/s was less than 6 decibels; for frequencies below 70 c/s the cut-off slope was 18 decibels per octave and for frequencies above 120 c/s the cut-off slope was 36 decibels per octave.

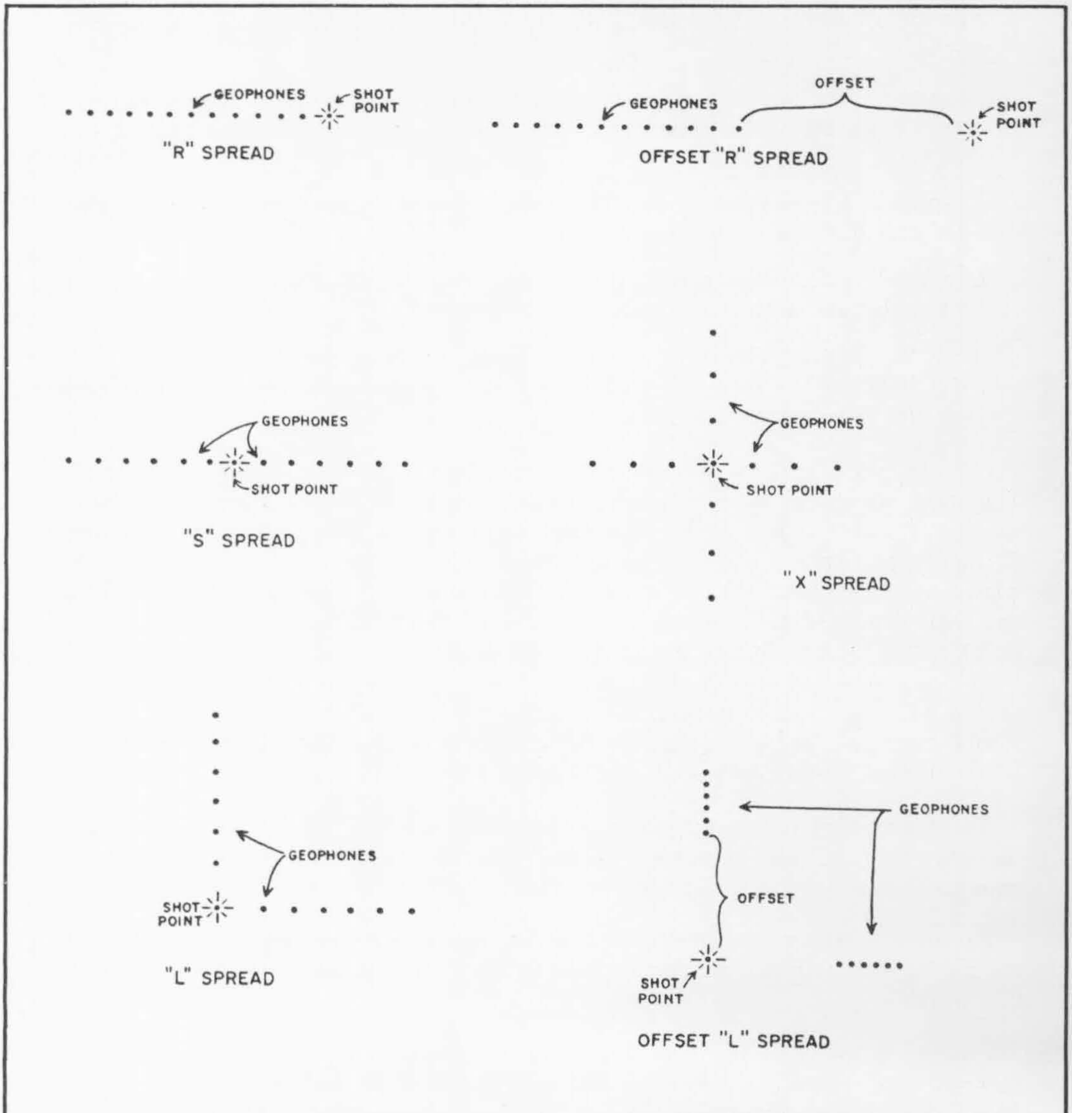

Figure 2. SEISMIC GEOPHONE ARRAYS

Henderson-Casey traverse

It will be seen from Plate 7 that about ten miles inland from Mawson there are four principal ranges, namely Mount Henderson and the Masson, David, and Casey Ranges. Early in 1957 a line of stakes was established and surveyed to the north of these ranges with the purpose of measuring the surface rate of ice flow. The positions of the stakes were fixed relative to the rock outcrops (Mellor, 1959).

A seismic traverse was run along this line of stakes and was supplemented by gravity measurements along two of the valleys roughly perpendicular to the main traverse.

Progress was very slow on this traverse, mainly because of bad weather. Out of a total of 56 days, 21½ days were lost owing to blizzards and severe blowing snow. Also, with the approach of winter the days became rapidly shorter. Troubles experienced with the ice drill, including the difficulty of starting its motor when cold, and digging out lost drill pipe, contributed to the slow progress.

Levelling and positioning. The seismic shot-points were levelled and positioned using a theodolite, by observations of mountain peaks of known position and height. Gravity stations were levelled by the differential barometric levelling method and their positions were determined by Weasel speedometer, using the levels and positions of the shot-points as control points.

Gravity readings. On the seismic traverse, gravity readings were taken at each of the eight shot-points and also at half-mile intervals between Shot-points 30 and 33. On the gravity cross-traverses, readings were taken every half-mile.

Along the sections where the gravity stations were at half-mile intervals, the normal leapfrog method was used, in which a drift tie is made back to a base station after a period of several hours. Travel was slow, however, and this restricted the frequency of return to a base station, the normal return period of two hours being extended to three or four hours when necessary.

A total of 50 gravity readings was made.

Seismic operations. The programme started with the intention of shooting at one-eighth-mile intervals, but it soon became obvious that this was impracticable, and the interval was increased to one-mile intervals for three miles. This was then increased to four miles for three more intervals making a total of eight shot-points over a traverse length of 15 miles.

Reflection records were obtained at each of seven of the shot-points. Shallow refraction work was carried out at Shot-points 27, 28, and 33 in order to determine the depth and velocity of the low-velocity layer. Deep refraction work was also carried out between Shot-points 28, 29, and 30 using a maximum shot-to-geophone distance of 10,120 feet.

Shooting methods. The traverse was mainly on blue ice, but with a thin snow cover in some parts. Single deep shot-holes were used as they were also required for glaciological work. Although a depth of 90 ft was aimed at, it was rarely achieved (see Appendix C) and the shots were fired at depths ranging from 30 ft to 90 ft. At two shot-points, Shot-points 31 and 33, four- and five-hole diamond-shaped pattern shots were fired respectively, with holes between 15 ft and 18 ft deep and 20 ft apart, but owing to drilling difficulties it was not possible to compare the results with single deep holes.

Explosive charges of between one-quarter pound and one pound were used.

Geophone arrays. Two types of spread were used, starting with an 'X' spread with three geophone stations in each arm, the nearest being 400 ft from the hole at the centre of the cross with others at 55-ft intervals. This appeared to give good results at first, but subsequent shot-points indicated that a split spread was preferable in order to have six geophone stations on each arm rather than three. In the split spread the nearest geophones to the holes were at 200 ft with the others at 55-ft intervals.

Filters. Considerable interference from surface noise was experienced, and several filter settings were tried. The best results were obtained using a filter pass band of 90 c/s to 160 c/s.

Second regional traverse

After travelling for about 30 miles from Mawson, the party ran into difficulties at a belt of crevasses, which had not been detected because of poor surface and light conditions (partial whiteout). One tractor fell into a crevasse and, while returning to Mawson for extra lifting equipment, the second tractor also broke into a crevasse. This delayed the party 16 days while the tractors were recovered, sledges repaired, and the tractor trains dug out of the huge snowdrifts that had accumulated. The ice drill was so seriously damaged during this incident that only two further holes could be drilled, and for the remainder of the seismic work air-shooting techniques had to be used.

Surface conditions were very bad following the worst winter in the history of Mawson, making progress very slow. The worst example of this was on 14 December when it took three hours to travel 1.6 miles, the tractors becoming bogged 14 times in soft snow.

Altogether, the bad weather caused the loss of 44½ days out of a total of 110, through blizzards, drifting snow, whiteout, and a period of extreme cold when for six days it was not possible to start the engines (except for the d.c. generator).

Because of the soft surface during the journey to the 237-mile depot, more fuel had been consumed than had been anticipated and this, together with the loss of time, put the original programme out of reach; it had to be shortened and reviewed at each stage of progress. The proposed eastern loop traverse was abandoned completely and the western one was made north of the depot instead of south.

The first attempt at heading west from the depot at Shot-point 25 was stopped after about 12 miles (Plate 4) when the tractors, which were losing power because of the increase in altitude, became bogged down in soft snow. A further attempt was made after travelling 27 miles to the north, where surface conditions had improved slightly. After travelling west for 16 miles, the party turned north and ran parallel to the first regional traverse for 102 miles before turning north-east to complete the loop at a point 150 miles north of the depot.

The return to Mawson was made along a different route from that followed by the first party, producing two further small loops. The northerly triangular-shaped loop was the result of a new route through the Masson, David, and Casey Ranges, the nunataks just south of the ranges, and many large ice domes, which, being badly crevassed, make the area very unsafe for travel with heavy equipment.

Levelling. In order to reduce the time taken to reach Shot-point 25, the starting point of the traverse, no levelling was carried out between Mawson and Shot-point 25 on the outward journey. The standard method of differential barometric levelling was again adopted, using Fuess aneroid barometers (see Appendix C), but the station interval was reduced from five miles (as used on the first regional traverse) to three miles; considerably more altitude information was obtained on this traverse than on the first regional one, to supplement and to improve the results previously given for the first traverse. In particular, during a six-day halt at the depot camp at Shot-point 25, for maintenance and repairs to the transport equipment, detailed records were made of atmospheric variations. These were found to correlate well with records kept at Mawson over the same period and, together with differential levelling carried out during the traverses, were used to derive a revised value for the altitude of the depot camp. Other altitudes were adjusted to fit this value and to eliminate misclosures around the loops.

Positioning. As on the first regional traverse, positioning of stations was generally by dead reckoning. Sun shots were taken at Shot-points 36 and 39; Station G129 was fixed accurately by taking bearings on five nearby peaks of known position.

Gravity readings. Gravity measurements were made in the same way as on the first regional traverse, but the interval between stations was reduced to three miles. A total of 90 gravity stations were read, including readings at the seven shot-points, i.e. at all the 92 stations where levelling readings were taken, except for Stations G45 and G47.

Seismic operations. The seismic operations were very limited on this traverse owing to the shortage of time, and only seven reflection shot-points were recorded; no refraction work or low-velocity layer work was done.

Shooting methods. The surface was always snow or, in two cases, hard névé. Only two holes were drilled and in each case an Offset 'L' spread was used with the hole 200 ft from the nearest geophone in each arm; the other geophones were spaced at 100-ft intervals.

Following the breakdown of the drill, standard air shooting procedure (Poulter, 1950) was used with nine one-pound charges in a square pattern with 30 ft separation between charges. These charges were suspended on bamboo poles five or six feet above the surface of the snow. With air shooting the standard split spread was used with 200 ft to the nearest geophone on either side of a centre point, and the other geophones at 100-ft intervals. The shot-point was offset from this centre point at right angles to the geophone spread at a distance of 2000 ft; this offset distance was reduced to 1500 ft at Shot-point 40, where it was suspected that the ice thickness would be smaller.

At Shot-point 38, where reflections were very poor, a pattern of 13 one-pound charges was tried, but with no improvement.

Photographic processing. Photographic processing became rather difficult on this traverse. After the stoppage of the 32-volt d.c. generator, there was no cab heating and photographic solutions rapidly cooled in the cab, where the ambient temperature was of the order of minus 10°Fahrenheit. This also resulted in an ice layer forming over the equipment from condensation of vapour from the hot solutions. It was thus necessary to shoot all the shots at each point and rapidly process all the records together at the end. This resulted in lack of control over the shooting and consequently some loss of quality.

At the start of air shooting, which had failed to produce results when tried in this area during the previous year, processing of records was essential between shots, and reheating the chemical solutions made shooting very slow.

Filters. The filter settings for shots on this traverse were the same as for the first regional traverse.

5. REDUCTION AND ACCURACY OF RESULTS

Levelling

On the Henderson-Casey traverse, the microbarometer readings were converted to heights, corrected for instrument temperature, air temperature, and barometer comparisons, and then adjusted to the control heights at the shot-points. The standard error of these altitudes is probably about ± 10 ft.

For the regional traverses the accuracy of the altitudes depends largely on the value obtained at Shot-point 25, since at this point the most detailed records were obtained of atmospheric variations; also, being a common point on the two traverses, its altitude could be determined from two independent sets of measurements. The value of altitude derived for Shot-point 25 is 7483 ft with a standard deviation of 380 ft.

From this determination of the altitude at Shot-point 25, and considering that the error in the measurement of altitude at a particular traverse station is inversely proportional to the station's distance from Mawson, it is estimated that the standard error in the elevation measurements on the regional traverses is about ± 1.5 ft per mile of traverse distance from Mawson. The term 'standard error' is used in this report as equivalent to standard deviation.

The regional traverses form two loops: Mawson-SP5-Mawson and SP5-SP25-SP5; the errors due to misclosures have been distributed around these loops.

Positioning

On the Henderson-Casey traverse, the seismic stations were positioned by theodolite bearings on mountain peaks; hence their positions will be accurate to within ± 50 ft. The intermediate gravity stations were located by Weasel speedometer readings and are probably positioned to within ± 200 ft.

In the regional traverses the positions of Shot-points 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 17, 18, 21, 22, 25, 36, and 38 were determined by sun shots. Station G129 was fixed by theodolite bearings on five adjacent mountain peaks, and an astrofix was done on the southern extremity of the traverses as shown in Plate 4. The accuracy of these positions should be within ± 500 ft. All intermediate stations were fixed by dead reckoning and are probably accurate to within plus or minus half a mile. Between Shot-points 36 and 38 the error may be as great as plus or minus one mile.

Gravity

The gravity meter readings were corrected for meter drift as described in the section on 'Field Work', and values of observed gravity relative to Mawson were obtained. Over the traverse loops formed, any misclosures have been distributed around the loops by the method of least squares. The standard error of the observed gravity values is estimated to be about ± 3 mgal.

The normal latitude and free-air corrections have been applied to the observed gravity values to give free-air anomalies, shown in Plates 1, 2, and 3. A further correction has been made for the gravitational attraction of ice between the station and sea level, assuming the ice to be a slab of infinite horizontal extent with a density of 0.9 g/cm^3. This gives a Bouguer-type anomaly (here to be called the B_1 anomaly and listed in Tables 1, 2, and 3), its main components being a regional effect and a rock surface elevation effect. At the joint seismic and gravity stations, the rock surface elevation is known from the seismic reflection results and thus the rock surface elevation component of gravity can be calculated assuming an infinite plane parallel layer of rock of density 2.67 g/cm^3. The difference between this rock surface elevation effect and the B_1 anomaly gives the regional effect (here to be called the B_2 anomaly to avoid confusion). Between the seismic stations the regional effect is assumed to be linear and its values at the intermediate gravity stations are found by interpolation. The difference between the B_2 and B_1 anomalies gives the rock surface elevation effect at the gravity stations, and this is converted into rock surface elevation by applying the conversion factor of 44.4 ft/mgal obtained from the above density-contrast assumptions. The results are shown in Plates 1, 2, and 3.

It was decided to use the B_1 anomalies instead of free-air anomalies to interpolate between the seismic ice thickness values, because the free-air anomalies reflect to some extent changes in the elevation of the ice.

The Bouguer anomalies (B_2) shown in Plates 1, 2, and 3 are due to a combination of several effects:

(a) Bedrock terrain effect, which can be considered negligible in comparison with the accuracy of the results. The maximum calculable terrain effect occurs at Shot-point 26 on the Henderson-Casey traverse, and amounts to 2.7 mgal.

(b) Effects due to relatively shallow changes in density, either vertically or horizontally.

(c) Effects due to a deep change of density such as occurs at the base of the Earth's crust.

The last two effects are not easily separable, but by making certain assumptions, some attempt to analyse them can be made; this will be done in the next section.

The accuracies of the gravity anomalies on the regional traverses depend mainly on the accuracy of the ice elevation measurements. For an average height of 5000 ft, the standard error in measurement is about ± 240 ft, which contributes a standard error to the free-air anomalies of ± 8 mgal, and to the Bouguer (B_1 and B_2) anomalies of ± 7 mgal. Combining these errors with the standard errors in the observed gravity values, it is seen that the free-air anomalies have a standard error of ± 9 mgal and the B_1 anomalies a standard error of $\pm 7\frac{1}{2}$ mgal. The B_2 anomalies have an additional source of error due to the seismic ice thickness measurement; this amounts to about $\pm 1\frac{1}{2}$ mgal (± 70 ft at 44.4 ft/mgal), making the total standard error ± 8 mgal.

These errors seem excessively large, but when it is considered that the errors from elevation measurements are probably cumulative rather than random, they become less serious. The relative standard error of adjacent stations probably does not exceed ± 2 mgal.

In view of the large errors in the B_2 anomalies, the use of any refined method for the determination of crustal thickness from them will have little value. It is doubtful in any case to what extent these anomalies are due to crustal thickness variations. Use has been made of Woollard's (1959) empirical relations to provide the rough scales shown in Plates 1 and 2 to read off crustal thickness against the B_2 anomaly values.

On the Henderson-Casey traverses, the elevations were measured more accurately and contribute a standard error of less than ± 1 mgal to the gravity anomalies. The

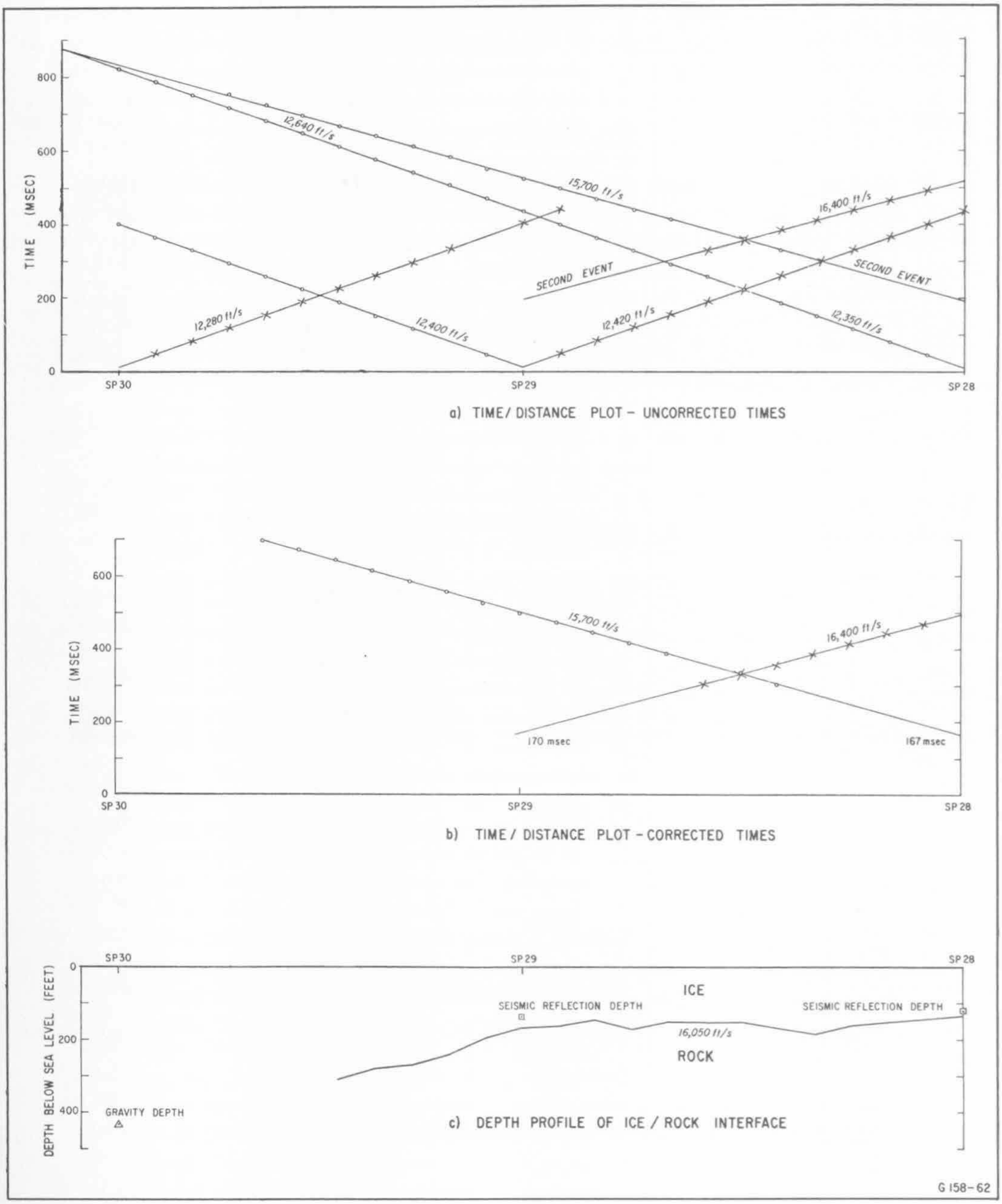

Figure 3. SEISMIC REFRACTION RESULTS, HENDERSON-CASEY TRAVERSE

free-air and B_1 anomalies have a standard error of about ± 3 mgal. On Traverse A the B_2 anomalies have a standard error of about $\pm 4\frac{1}{2}$ mgal, allowing for possible error in the seismic depths. For Traverses B and C, each of which has only one seismic control point, the regional gravity effect has been deduced from the regional traverses. This is reasonable for Traverse C, which runs almost parallel and in close proximity to the regional traverses, but for Traverse B it may be the cause of a slight additional error in the B_2 anomalies.

In computing the absolute gravity anomaly values from the observed gravity readings relative to Mawson, the most recent estimate by the Bureau of Mineral Resources of the absolute gravity at Mawson, 982,462.3 mgal, has been used.

During geological surveys in the Framnes and Prince Charles Mountains made by I. R. McLeod and D. S. Trail, geologists of the Bureau of Mineral Resources, representative rock samples were collected. Density measurements made on these samples are shown in Table 5.

Seismic velocity distribution

Henderson-Casey traverse. The velocity information for this traverse has been derived from three short weathering spreads, first-break times on reflection records, uphole travel times, and one deep refraction profile.

The results show three distinct layers of snow and ice, the first layer being very shallow — no more than about two feet thick and with a velocity of the order of 1000 ft/s. This is the thin layer of snow covering the blue ice on parts of the traverse. Below this is a layer of ice ranging from 20 ft to 70 ft in thickness and from 5650 ft/s to 8000 ft/s in velocity. The velocity increase with depth does not appear to be continuous but jumps from this range of values to a range of 11,800 ft/s to 12,500 ft/s.

The results from the long refraction spreads (see Fig. 3) show that the velocity in the ice reaches a maximum value of about 12,640 ft/s. The results were not sufficiently good to determine very accurately at what depth the maximum velocity was reached, but it was probably about 200 ft below sea level. From below the ice, second-event refraction waves were recorded from the underlying rock surface, having a true velocity of 16,050 ft/s. This is of the order of velocity expected for the granitic-type rocks found in the region of Mawson and the Framnes Mountains.

Regional traverses. Beyond the coastal zone, where the surface elevation rises above about 2400 ft the surface conditions change from blue ice to névé and the velocity distribution becomes representative of the inland ice sheet. In these areas the velocity increases with depth until a maximum value of velocity is reached; below this depth the velocity remains constant.

The velocity distribution shown in Figure 4 was computed from the results of the long-range refraction work at Shot-point 25. The results at Shot-point 13 were not so comprehensive and also were less reliable than these because of very strong winds.

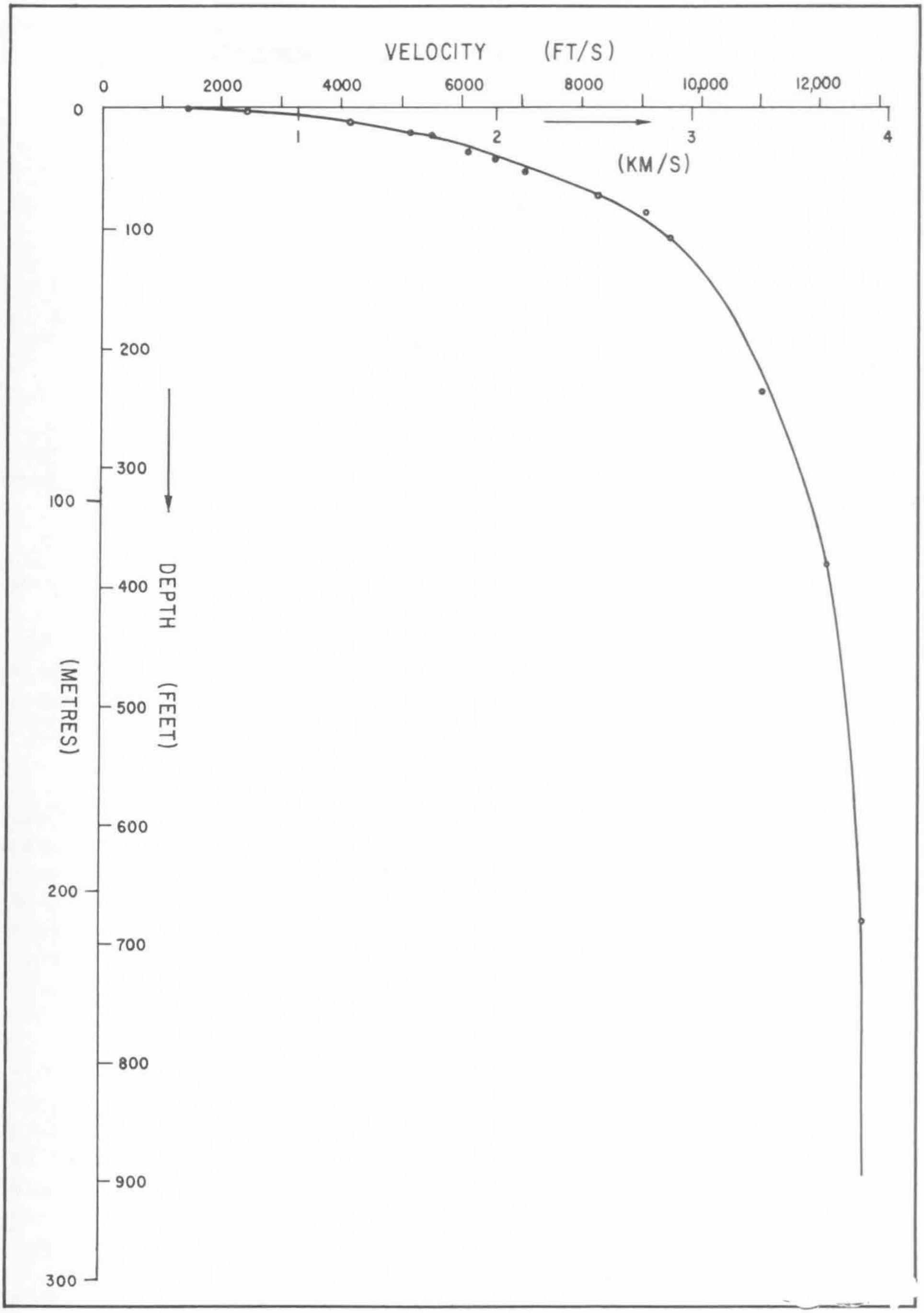

Figure 4. VELOCITY DISTRIBUTION, SP 25

A travel-time curve, corrected, for depth of shot as outlined in Appendix D, was constructed from the results, and the velocity was computed as a function of depth from the relation

$$Z_x = \frac{1}{\pi} \int_{X=o}^{X=x} \cosh^{-1}(V_x/V_X).\ dX \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where Z_x is the maximum depth penetrated by a refracted wave first received at a shot-to-geophone distance x with a velocity V_x. V_X is the arrival velocity at any point X between O and x.

The maximum velocity of 12,780 ft/s was first recorded at a shot-to-geophone distance of 4510 ft and was recorded continuously up to a shot-to-geophone distance of 21,890 ft; it was found to occur at a depth of 680 ft.

The part of the curve for the velocity distribution down to the maximum velocity can be expressed in the form:

$$Z + K = e^{aV} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where K and a are constants. In this particular case K = 2.114 and a = 5 x 10^{-4}.

Although the maximum velocity was not recorded at any shot-point other than SP25 and SP13, short refraction spreads and first-break times from reflection records gave information at most shot-points on the velocity distribution down to shallow depths. From these results the distributions at Shot-points 13, 14, 15, and 25 appear to be very similar, while at all other shot-points, the velocity is increasing more rapidly with depth, suggesting possibly a shallower depth for the maximum velocity, and also possibly a smaller thickness of névé.

It has been observed (Thiel & Ostenso, 1961) that velocity distributions from refraction shooting and from borehole logging differ in that the borehole logging gives higher velocities, particularly at shallow depths; this was anticipated by Robin (1958, cited by Thiel & Ostenso, 1961) from theoretical considerations. The difference arises from the fact that the thickness of each ice layer is small compared with the wavelength of the refracted ray, and this results in a reduction in velocity. Since borehole logging simulates the conditions applied for the determination of low-velocity-layer corrections, i.e. a vertical travel path, it seems likely that the corrections deduced from use of the velocity distributions from refraction shooting may be in error. It is estimated that this error may be as large as five milliseconds on the regional traverses, but of the order of two milliseconds on the Henderson-Casey traverse.

At depths below that at which the maximum velocity in ice has been reached, the conditions for an infinite medium prevail and the vertical velocity should be the same as the refraction velocity, if the ice is isotropic. However, the ice is rarely isotropic since flowing ice tends to cause a preferred direction of ice crystal orientation, making the velocity in the direction of flow slightly less than the velocity in the direction perpendicular to the direction of flow. Theoretical reasoning (Thiel & Ostenso, 1961) gives a maximum difference of about four percent in the case of complete crystal orientation. This means that the seismic velocity of 12,780 ft/s taken for computing the seismic depths of reflections on the regional traverses may be too low. If the true vertical velocity were 13,000 ft/s (and it is doubtful that it would much exceed this value) the error in the average depth of 5000 ft would be 78 ft, which is equivalent to a t_0 error of 12 ms (t_0 is the reflection time vertically below the shot-point).

On the Henderson-Casey traverse, the average depth of about 1500 ft could be in error by about 50 ft, which is equivalent to a t_0 error of 8 ms.

Seismic corrections

To correct for the depth of shot, for reflection records, the uphole time has been added to the reflection time. In the case of air-shots the seismic velocity in air has been taken to be 1100 ft/s. For refraction shots, the method of computing corrections for depth of shot is given in Appendix D.

Geophone spreads were laid, wherever possible, on flat stretches of ice, and elevation differences along the spreads were not measured. Consequently no elevation corrections can be applied, which affects the accuracy with which dips of reflections can be measured and also the accuracy of t_0 determinations in the case of offset spreads.

In the case of shot-holes offset in line with the geophone spreads, corrections have been made for shot-to-geophone distance and for the dip of the reflector (Table 4) in the determination of t_0. Where the shot-hole is offset at right angles to the geophone spread, as in the case of air-shots, the dip of the reflector has been assumed to be flat at right angles to the spread and a correction has been made for shot-to-geophone distance.

The corrections to be applied for the low-velocity layers of ice can be divided into two sections, one for the Henderson-Casey traverse in the coastal zone, and the other for the regional traverses on the inland ice sheet as follows:

Henderson-Casey traverse. For each shot-point, velocities of 1000 ft/s, 6700 ft/s and 12,200 ft/s have been assumed for the three layers of snow and ice for the purpose of evaluating corrections for the low-velocity layers. An average velocity of 12,400 ft/s has then been used to convert the corrected reflection times to depths.

Regional traverses. For the purpose of making corrections for the shallow low-velocity section of the ice, it has been assumed that the same limiting velocity of

12,780 ft/s is reached under all points on the traverse, but not necessarily at the same depth. The depth at which this limiting velocity is reached has been determined at each shot-point by computing values for K and a in Equation 2 from the shallow depth velocity distributions found at each shot-point. These depths were then converted into equivalent times from

$$T = a \int (1/\log_e Z)\, dZ \quad \ldots \ldots \ldots \quad (3)$$

The evaluation of this expression is a tedious one. An alternative method is to divide the velocity/depth curve into a number of straight-line segments, the time for each segment being given by:

$$T = (1/b)(\log_e V_2 - \log_e V_1) \quad \ldots \ldots \quad (4)$$

where b is the slope of the line and V_1 *and* V_2 are the velocities at the ends of the segment.

Once the time to travel the depth to the limiting velocity has been determined, the correction is simply twice the difference between this time and the time that would be taken for a ray to travel the same depth at the limiting velocity.

The limiting velocity of 12,780 ft/s was then used to convert the corrected reflection times to depths.

It is estimated that the maximum errors associated with the corrections for the low-velocity layers amount to ±3 ms, which includes errors in timing of the records, errors in the computation of the corrections, and errors in the uphole times.

Seismic depths

As shown on the traverse cross-sections, Plates 1, 2, and 3, the seismic reflections have been divided into three grades of reliability — good, fair, and poor.

A reflection of good reliability is one whose dip can be measured accurately enough to contribute an error to t_0 of only ±2 ms, and which is of sufficient energy to allow the first arrival of the reflected group of waves to be estimated within one cycle, i.e. with a possible maximum error of —10 ms. Examples of good reflections are shown in Plate 10.

A reflection of fair reliability is one whose dip can be measured accurately enough to contribute a possible maximum error in t_0 of ±10 ms, and which is of sufficient energy to allow the first arrival of the reflected group of waves to be estimated within two cycles, i.e. with a possible maximum error of —20 ms. Examples of fair reflections are shown in Plate 11.

Combining these errors with the estimated errors involved with the computation of the corrections for the low-velocity layers (maximum error ± 3 ms) and the errors that may be associated with the velocity distribution (maximum error $+17$ ms for the regional traverses, and $+10$ ms for the Henderson-Casey traverse), the possible maximum error in t_0 for a reflection of good reliability becomes $+22$, —15 ms, or $+140$, —96 ft for the regional traverses, and ± 15 ms, or ± 96 ft for the Henderson-Casey traverse.

Similarly, for a reflection of fair reliability, the possible maximum error in t_0 becomes $+30$, —33 ms, or $+192$, —210 ft (i.e. approximately ± 200 ft, or a standard error of ± 70 ft) for the regional traverses, and $+23$, —33 ms, or $+147$, —210 ft for the Henderson-Casey traverse.

A reflection of poor reliability, examples of which are shown in Plate 12, is simply one of doubtful existence; it may be a line-up of noise, and the true reflection if any is not visible. There are seven of these altogether, those at Shot-points 9, 12, 13, 32, 36, 37, and 38. Of these, all except Shot-point 32 are in the area of the submerged inland range. The depths at these shot-points have been selected by considering the Bouguer anomaly (B_2) curves shown in Plates 1, 2, and 3. Although the Bouguer anomalies can give no conclusive evidence on ice thicknesses, as so many other unknown variables may be incorporated in them, their trends can be used as a guide to suggest a range of depths at which reflections should possibly occur. For instance the reflection at Shot-point 9 (Plate 1) seems reasonable as it gives a Bouguer anomaly value that lies on the smooth anomaly curve. Between Shot-points 11 and 14, where fair reflections were recorded, a smooth interpolation of the Bouguer anomaly curve would give ice thicknesses of up to 1500 ft less than those shown. But on the seismic records of Shot-points 12 and 13 no events occur at a time equivalent to these shallower depths. The nearest events that could possibly be reflections occur at times equivalent to the depths shown. Now it is possible that these events are not true reflections, in which case the ice thickness could possibly be 1500 ft less than that shown at Shot-point 13 and about 900 ft less at Shot-point 12. On the other hand the Bouguer anomaly curve suggests that it is unlikely for the ice thickness to be greater than that shown at these points.

Similar arguments can be applied to the poor reflections at Shot-points 36, 37, and 38 in Plate 2. The ice thickness shown at Shot-point 36 gives a Bouguer anomaly value that lies on the smooth interpolated curve between Shot-points 35 and 39, where fair and good reflections were obtained respectively. At Shot-point 37 two events were noted on the seismic records giving depths similar to that expected from the smooth anomaly curve. An average of these two depths has been taken as the ice thickness. At Shot-point 38, if the depth shown is not representative of a true reflection event, then the ice thickness could possibly be less at this point by about 700 ft.

The ice thickness shown for Shot-point 32 (Plate 3) agrees well with the gravity results and is considered quite reasonable.

Dips of the good and fair reflections are listed in Table 4. They can only be expressed to the nearest degree as the dips of the surface ice were not measured.

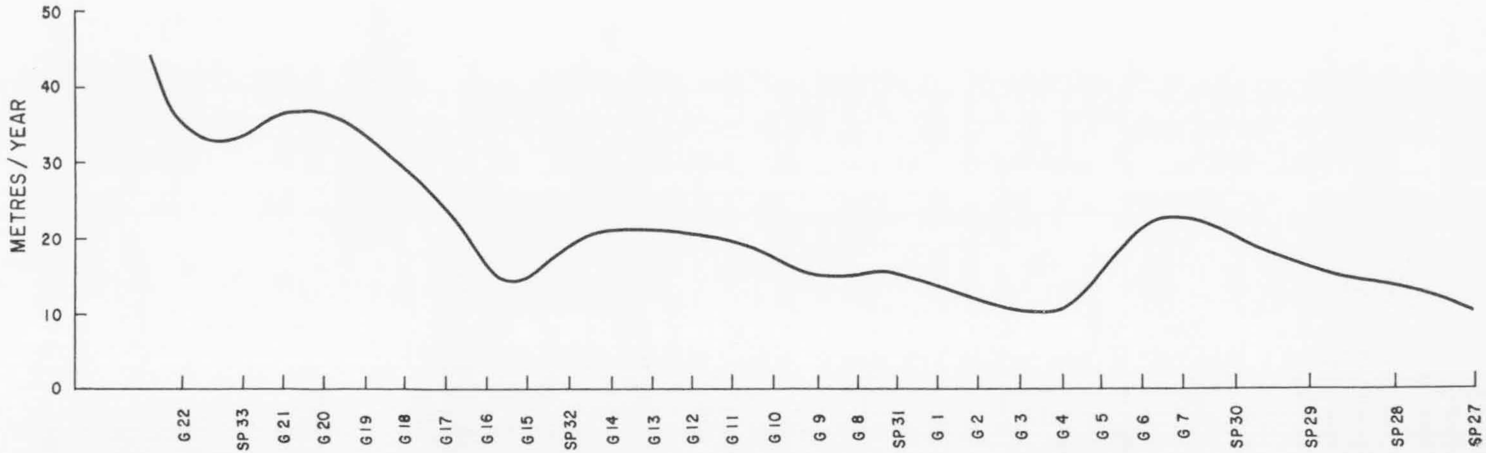

Figure 5. SURFACE ICE FLOW RATES, HENDERSON – CASEY TRAVERSE A

The quality of the seismic results is generally good. It is significant that five out of the seven shot-points at which poor reflections were obtained were in the region of highest altitude, i.e. between 7500 ft and 8500 ft, and consequently in the region of lowest temperature. Reverberations in the recrystallised ice of the névé are more persistent at very low temperatures and produce a noise level sufficient to swamp out the seismic reflections. From shallow velocity measurements, the thickest layers of névé are within the region between Shot-points 13 and 15, where fair to good reflections were obtained. Thus it would appear that reflection quality depends more on the temperature of the névé than on its thickness.

In the Wilkes area, Jewell (1962) and Walker (1966) of the Bureau of Mineral Resources obtained no reliable reflection results from shot-points at altitudes greater than about 8000 ft. With the work of Sorokhtin, Kondrat'ev, and Avsyuk (1960) south of Mirny, the critical altitude was about 7500 ft.

In seismic reflection work above an altitude of about 7500 ft, special techniques are required. It is generally considered (see for example Kapitza & Sorokhtin, 1963) that shot-depths of not less than 150 ft below the surface and filter settings of 150-200 c/s give improved results, but limited experiments along these lines at Mawson gave no confirmation of this.

The survey objective of relating variations in seismic velocity to variations in temperature and density of ice was not achieved. Density measurements could not be made on core samples from shot-holes because of the persistent jamming of the core-barrel, and although temperature measurements were made at intervals down several shot-holes (Mellor, 1960), it was considered that both the temperature and velocity determinations were too inaccurate to provide a meaningful relation between the two.

The attempts to record shear waves were not successful.

6. DISCUSSION OF RESULTS

Henderson-Casey traverse

The results of the coastal area work are shown as contour maps of ice elevation (Plate 7) and rock elevation (Plate 8), and a map of ice thickness isopachs (Plate 9). Rock profiles are shown in Plate 3.

The ice elevation contours have been drawn from all available information, and show the contours running roughly parallel to the coast and forming a wide shallow ice valley between coastward extensions of the Casey and Masson Ranges wtih a small ridge as an extension of the David Range. The contours follow generally the trend of the submerged rock contours, but the latter show up details which are not so evident from the ice surface.

The most conspicuous feature of the rock surface contours is the valley just west of the North Masson Range. The presence of the valley is not obvious from the ice contours, but it is suggested by the ice stream that is noticeable on the surface and shown in Plates 7-9. This ice stream flows in a northerly direction just to the west of the Masson Range before entering the area of the general rock depression between G2 and Shot-point 29. McLeod and Jesson (1961), whose measurements of rates of movement of surface ice along Traverse A are shown in Figure 5, comment on the low rate of movement of surface ice in this area, considering the size of the depression. They also make the comment that 'there is probably a considerable westward component to the flow between' Shot-point 29 and G5. The low rate of flow and the small northerly component of flow could indicate that Mount Henderson and Fischer Nunatak are part of the North Masson Range and that the depression between G5 and Shot-point 29 does not extend far to the south. Other supporting evidence for this is the ice surface rise between Fischer Nunatak and the North Masson Range.

The —400-ft rock surface contour has been extrapolated to show a possible ridge from G141 to Mount Henderson, which, besides accounting for the ice surface ridge in this area, explains the presence of ice streams flowing north-west from Mount Henderson, and also the westerly flow of ice from Fischer Nunatak.

The ice flow pattern (Plate 8) suggests that the rock surface slopes down gradually to the east from the David Range, and the ridge between G2 and G12 is probably a northerly extension of the range. On its western side, the ice stream noticeable on the surface seems to indicate a steep downward slope to the west, as with the Masson Range.

Between the Casey and David Ranges, there is a large ice valley, as shown by the 2000-ft ice contour, and judging by the increased rate of flow of surface ice west of G16 (Fig. 5) there is probably also a large valley in the rock surface. The Forbes Glacier and the ice streams to the east of it suggest that the Casey Range may, like the David and North Masson Ranges, also slope down steeply on the western side and gradually on the eastern side. Crohn (1959) mentions that 'a series of heavily crevassed ice-domes and ice-ridges occupies a belt of some three miles wide along the eastern flank of the Casey Range'. His suggestion that this may be due to irregularities in a shallow buried bedrock topography supports the proposition of a gradual easterly dip. The —300-ft rock contour has been extrapolated westwards in what may reasonably be the general trend of the contours in that region. The small ridge north of G22 may be the cause of the reduced ice flow rate between Shot-point 33 and G22.

It is interesting to note the possible steep west slopes and gradual east slopes of the ranges of the Framnes Mountains, but whether they have any geological significance or not is not known.

The rock outcrops of the Framnes Mountains are mainly metasediments and intermediate charnockites. The geology of the area has been discussed in detail by Crohn (1959) and McCarthy and Trail (1963). The average density of the few rock samples taken in the area and shown in Table 5 is about 2.80 g/cm^3.

The gravity anomalies along the Henderson-Casey traverses are shown in Plate 3. The Bouguer anomalies (B_2) are of a regional nature decreasing in value from west to east and from north to south. The free-air anomalies are mainly positive and increasing to the south; this is emphasised in the results of the regional traverses (Plates 1 and 2), and is consistent with a coastal continental mountain range of high-density rocks.

Regional traverses

The results from the regional traverses are shown as ice surface contours (Plate 4), rock elevation contours (Plate 5), ice thickness isopachs (Plate 6), and cross-sections (Plates 1 and 2).

The main feature of these results is the buried range of mountains between latitudes 68°50′ and 70°25′, most probably a north-westerly extension of the northern Prince Charles Mountains, which rise through the ice about 50 miles to the east of the traverse. In outcrop they are about 7000 ft above sea level, but in the region of the traverses they rise to no more than about half this height. They could possibly extend another 50 miles north-west to where the Hansen Mountains crop out through the ice to a height of about 7000 ft.

South of this range is a large sub-sea-level rock depression as far as latitude 72°21′ where the buried foothills of the southern Prince Charles Mountains start to rise. The depression is probably semicircular in shape forming a huge reservoir from which ice overflows into the several glaciers of the Prince Charles Mountains. The western limit of the reservoir is not known as the programme planned to investigate it had to be abandoned. An isolated mountain peak rises from the depression at GG31.

North of the submerged mountain range is a deep channel or valley at latitude 68°41′ opening to the east and separating the Prince Charles Mountains from the Framnes Mountains, which extend as far south as latitude 68°24′, about 55 miles from the coast.

The ice surface contours are seen to have some dependence on the topography of the underlying rock. For instance, the ice valleys near GG14 and Shot-point 14 are associated with deep rock valleys beneath them. The ridge of ice running west from GG27 is about 15 miles south of the southern ridge of the buried range; this displacement is probably due to the rate of flow of ice to the north-east being greater than to the south-east. The general trend of the ice contours in this region suggests that the range of mountains could extend at least another 100 miles due west of G67. The westerly increase of ice elevation does not necessarily mean a corresponding increase in rock elevation, but that the rock topography to the west is such that the balance between the accumulation and the rate of flow of ice maintains a greater ice thickness.

The two regions of cracked and crevassed ice noticed along the first regional traverse between 67 and 80 miles (GG11 and Shot-point 7) and between 94 and 120 miles (GG15 and Shot-point 9) are to the north and south of the deep valley in latitude 68°41′ and are probably associated with ice movements due to it. A similar band of crevassed ice, between 160 and 185 miles (GG23 and GG26), lies above the southern ridge of the submerged range and is probably due to the transition from north-flowing ice to south-flowing ice. These disturbed areas of ice do not necessarily signify shallow rock surfaces.

The free-air anomalies for the first regional traverse (Plate 1) show an overall average of about zero, the local variations being associated with the variations in the bedrock elevations; this indicates general isostatic equilibrium in the area.

The Bouguer (B_2) anomalies along the traverse are all negative and have a generally regional character, especially between Mawson and Shot-point 11 where the anomaly decreases smoothly south from the coast to a minimum value of —144 mgal beneath the centre of the buried mountain range. There is then a general increase in anomaly between Shot-points 11 and 20 corresponding to the bedrock depression between these two points, followed by a further decrease which probably continues towards the centre of the southern Prince Charles Mountains.

The free-air and B_2 anomalies as outlined above are typically continental in character.

A closer look at the free-air anomalies shows them to fall into three broad, but distinct, divisions: from Mawson to GG13, from GG13 to Shot-point 18, and from Shot-point 18 to Shot-point 21.

Although the B_2 anomalies show a steep, but smooth, decrease southwards across GG13, the free-air anomalies show a sharp drop from positive anomalies to negative anomalies at GG13. This drop in free-air anomaly value is from an average of about +20 mgal to about —20 mgal, a total drop of 40 mgal; such a large drop cannot be explained purely in terms of increased isostatic compensation. There is possibly a marked decrease in density of the rock south of GG13, suggesting that the deep valley at Shot-point 7 is a major tectonic feature geologically separating the Framnes Mountains from the northern Prince Charles Mountains.

Between GG13 and Shot-point 18, the free-air anomalies are generally negative, which implies either that the average density of the crustal column in this area is less than in neighbouring areas or that, on accepted hypotheses, isostatic compensation is not exact in this area. The buried range, if a continuation of the northern Prince Charles Mountains, as seems likely from previous considerations, would be of high-grade metamorphic rocks of the Precambrian shield (McLeod & Trail, 1963) with an average density of about 2.70 g/cm^3, but it is possible that the rock of the valleys at Shot-point 7 and Shot-point 14 and the depression between Shot-points 25 and 19 are sedimentary. The only sedimentary rocks of any extent to be found in outcrop in the area are at Beaver Lake, where there is an estimated thickness of about 1600 ft of Permian sediments. It is quite feasible that sediments of much larger extent and thickness occur in the depression between the northern and southern Prince Charles Mountains. If this region of negative free-air anomalies is due to a lack of isostatic compensation, it may mean that the ice cap in this area is becoming thinner, and isostatic restoring forces have not had time to fully compensate.

The decrease in B_2 anomaly values towards the centre of the buried range at Shot-point 11 indicates an increase in the thickness of the Earth's crust beneath the range, supporting the evidence of the free-air anomalies for general isostatic equilibrium. The B_2 anomalies may, however, be low owing to the mass of low-density material in proximity to the buried range, and values of crustal thickness derived from the Bouguer anomalies may be slightly excessive. The minimum B_2 anomaly of —144mgal leads, from Woollard's (1959) empirical relation, to a crustal thickness of 44.5 km. A determination of crustal thickness from the average equivalent rock elevation between Shot-points 9 and 13, also by use of Woollard's empirical relation, leads to a value of about 43.0 km. The latter value is probably the more reliable.

Some of the variations in the B_2 anomaly between Shot-points 11 and 18 are of a localised rather than a regional character, notably at Shot-point 14, Shot-point 25, and between Shot-points 17 and 18, probably representing localised changes in densities.

The elevated bedrock between Shot-points 18 and 21 is accompanied by a large increase in both B_2 and free-air anomalies. This increase is probably due to an increase in density at about GG44, which may mark the beginning of the southern Prince Charles Mountains. Trail (1963) points out the difference between the high-grade gneiss of Binders Nunataks and the low-grade quartzite of the Goodspeed Nunataks, and associates the difference with the possible rock surface depression between them shown in Plate 1 between Shot-point 21 and GG54. He suggests that this depression could be occupied by a major tectonic discordance. The gravity results support this suggestion, as the higher density of the rock between Shot-points 18 and 21 may be representative of the gneiss of Binders Nunataks, to wnich the peaks at GG48 and GG51 are probably linked.

From Shot-point 21 to Shot-point 22 and Shot-point 23, the B_2 anomaly decreases sharply towards the southern Prince Charles Mountains, suggesting an increase in crustal thickness beneath the range.

A similar pattern of gravity anomalies is found for the second regional traverse (Plate 2), but generally their values are more positive. The change in density south of the Framnes Mountains is not so marked as for the first regional traverse, but it is certainly present at G113.

The larger free-air anomaly values for the main buried mass of the Framnes Mountains are interpreted as higher rock elevations to the east of the first regional traverse.

The more positive free-air anomalies in the region of the buried range between G99 and G68 are consistent with the more positive B_2 anomalies in the same region, and may be due to a westerly decrease in isostatic compensation owing to the increased distance from the main bulk of the Prince Charles Mountains, or alternatively they may be due to a westerly decrease in the amount of sedimentary rocks. The latter explanation is favoured because evidence previously discussed suggests a considerable westerly extension of the buried range.

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APPENDIX A

PERSONNEL

First Regional Traverse, 9 November 1957 to 16 February 1958

K. B. Mather — Officer in Charge, Mawson
R. L. Willing — Medical Officer
M. Mellor — Glaciologist, acting Navigator
M. J. Goodspeed — Geophysicist
N. Collins — Engineer
B. Shaw — Radio Officer

Henderson-Casey Traverse, 22 March to 16 May 1958

F. A. Smith — Officer in Charge of field party and Engineer
E. E. Jesson — Geophysicist
G. A. Knuckey — Surveyor
J. E. G. Channon (from 28 April) — Medical Officer
I. R. McLeod (to 28 April) — Geologist, acting Glaciologist
P. W. King (to 28 April) — Radio Officer
R. E. T. Oldfield (from 28 April) — Radio Officer

Second Regional Traverse, 30 September 1958 to 17 January 1959

I. L. Adams — Officer in Charge, Mawson
F. A. Smith — Engineer
J. R. Blake — Physicist, acting Navigator, Glaciologist, and Meteorological Observer
E. E. Jesson — Geophysicist
D. A. Brown — Radio Officer

APPENDIX B

DESCRIPTION OF EQUIPMENT

Ice Drill

This drill was supplied by Australian National Antarctic Research Expeditions for use in glaciological studies and the drilling of shot-holes for seismic work.

Manufacturer — Goldfields Diamond Drilling Company Pty Ltd Victoria, Australia.

Vertical movement — Hydraulically powered in both directions by two pistons. Vertical travel 5 ft.

Rotational movement — Reversible hydraulic motor mounted on a platform that rises and falls with the vertical movement of the drill.

Drill pipe — 4-ft lengths fitted with auger flights for clearing the cuttings. Outside diameter 3½ in.

Cutting heads — A variety of types was supplied.

Power — Hydraulic system driven by a 10-hp 2-cylinder Deutz diesel engine fitted with electric preheater and starter.

Capacity of drill — 200 ft.

Seismic Equipment

This equipment was supplied by the Bureau of Mineral Resources, Geology & Geophysics and was the standard type of equipment used for oil exploration.

Amplifiers and control system

Manufacturer — Texas Instruments Incorporated (formerly Houston Technical Laboratories), Houston, Texas, USA.

Model — 7000-B Seismic Amplifier System.

Number of channels — 12.

Logarithmic Level Indicator (LLI) — The signal from channel 6 is rectified and displayed on a logarithmic scale.

Frequency ranges of amplifiers — 5 c/s to 500 c/s.

Automatic Gain Control (A.G.C.) — Linear amplification or A.G.C. (at one of three speeds) can be applied.

Filters — A wide range of cut-off frequencies and cut-off slopes can be applied.

Oscillograph camera

Manufacturer — Clevite Corporation Texas Division (formerly Technical Instruments Company), Houston, Texas, USA.

Model — 521 system oscillograph camera (modified for use with HTL 7000-B amplifier system).

Number of traces — 25.

Disposition of channels — Traces 1-12 show the outputs of channels 1-12 recorded unmixed.

Traces 13-24 show the outputs of channels 1-12 with 25% unilateral mix, direction selected from amplifier control system. 'Uphole' break is recorded on Trace 24 with suppression on.

Trace 25 — time break and, after suppression trip, either the 'bleeper' signal from tuning fork or the LLI output, selected by switch on camera.

Width of photographic paper — 15 cm.

Shooting boxes

Two shooting boxes were used:

(a) Manufacturer — Clevite Corporation Texas Division, Houston, Texas, USA.

Model — T.I.C. 90-volt shooting box, condenser-battery system.

(b) Manufacturer — South-western Industrial Electronics Company (SIE), Houston, Texas, USA.

Model — SCD-2000A, 2000-volt condenser-generator system.

Geophones

Manufacturer — Clevite Corporation, Houston, Texas, USA.

Numbers & Models — 16 standard 20-c/s geophones Model 241/L and 50 standard 6-c/s geophones, Model 310.

Seismic cables

Manufacturers — Vector Manufacturing Company, Houston, Texas, USA.

Description — 13 conductor pairs, rubber-covered, silicone-filled, double-ended cables with 13 moulded take-outs at 115-ft intervals, total length 1500 ft.

Number — 5 (two plastic-covered cables were taken out originally, but were replaced in 1958 by two rubber-covered ones, which retain their flexibility and do not crack in the cold).

Explosives

These were selected for stability at low temperatures, and consisted of the following:

(a) Manufacturer — Imperial Chemical Industry, Nobel Division, Glasgow, Scotland.

Type — 704, TNT blasting cartridges in 4-ounce charges.

(b) Manufacturer — Defence Department Production, Victoria, Australia.

Type — RDX/TNT in 1-pound charges with CE primer attached.

(c) Manufacturer — Imperial Chemical Industry Australia and New Zealand, Nobel Division, Victoria, Australia.

Type — No. 8 submarine electric detonators with 360-inch leads.

Seismic cab

This cab was supplied by Australian National Antarctic Research Expeditions for housing and transporting the seismic equipment.

Manufacturer— Texas Instruments Incorporated, Houston, Texas, USA.

External Dimensions — 6 ft 6 in long; 4 ft 10 in wide; 5 ft 6 in high.

Construction — All external walls were constructed of double-layer heavy plywood with an air gap loosely filled with insulating material. The outside was sheathed with polished aluminium sheeting.

Internal partitioning — The cab was divided internally into (a) a compartment for housing the seismic equipment, developing tanks, and radio transceiver;

(b) an electrical compartment containing power supplies and general wiring;

(c) a compartment for housing the lead-acid batteries for powering the equipment.

Heating — The equipment and battery compartments were fitted with electrical strip heaters, which can be controlled by a thermostat. The developing tanks were provided with a separate immersion heater system.

Mounting — The cab was mounted in a steel cradle frame sprung-mounted on a sledge. The d.c. generator set was mounted on the same sledge.

D.c. Generator Set

The generator was supplied by Australian National Antarctic Research Expeditions for heating and charging batteries in the seismic cab and general use by the field party.

Manufacturer — Mitchell and Co. Ltd, Victoria, Australia.

Engine — Lister single-cylinder diesel, 3 hp.

Description — 32 volts, 1.5 kW d.c. generator.

Barometers

Two types were used; the first type was supplied by the Bureau of Mineral Resources, Geology & Geophysics, and the second type by Australian National Antarctic Research Expeditions. They were as follows:

(a) Manufacturer — Askania-werke A.G., Berlin, Germany.
Model — Microbarometer Gb5, with an evacuated helical spring tube.
Number — Three.

(b) Manufacturer — Fuess, Germany.
Model — 15T4, aneroid.
Number — Two, on second regional traverse only.

Gravity Meter

Manufacturer— Texas Instruments Incorporated, Houston, Texas, USA.

Designation — Worden Geodetic Model, Serial Number 169.

Transport

There were two types of transport used:

(a) Manufacturer— Caterpillar, Peoria, Illinois, USA.
Model — D4 Caterpillar. Diesel tractor.
Number — Two, one with a bulldozer blade, the other with a 'Hyster' winch at the rear. Both were used as towing vehicles.

(b) Manufacturer — Wartime vehicle, constructed mainly by Studebaker, USA.
Model — 'Weasel' M-29, petrol-driven cargo carrier.
Number — One as scout vehicle.

APPENDIX C

PERFORMANCE AND SUITABILITY OF EQUIPMENT

Ice Drill

For the drilling of holes in snow such as was found on the inland plateau on the regional traverses, it was found that three-wing drag bits only one-quarter of an inch larger in diameter than the auger flights produced a clean hole quite satisfactorily. Larger bits resulted in about 20 ft loss of hole owing to the ice cuttings falling back into the hole as the drill pipes were withdrawn.

In the denser, more brittle, blue ice, however, as was found in the coastal region of the Henderson-Casey traverse, the smaller bit resulted in the cuttings packing tightly around the auger flights and bits, causing the bit to jam. Many 'twist-offs' occurred where the unions between lengths of drill pipe sheared. This was later found to be due to a crystallographic fault in the metal of the unions, caused by use of the wrong metal. By using bits of diameter three-eighths of an inch larger than the auger flights, a clean hole was produced with no jamming.

In both cases it was necessary to leave the drill to rotate freely at 20-ft depth intervals for about five minutes without downward motion in order to clear the hole of cuttings.

The core barrel, supplied for taking core samples at various depths for density and crystallographic studies, could not be used because of persistent jamming.

The engine that powered the drill was extremely difficult to start at low temperatures, and it is possible that a petrol motor of equivalent power output may be more suitable for future surveys; alternatively, power may be obtained from a take-off on one of the tractors.

Before the completion of the Henderson-Casey traverse the hydraulic system failed owing to leaking oil seals, and drilling was abandoned. During the winter months the drill was overhauled, but no suitable replacement oil seals were available for the hydraulic system, and the old worn ones had to be used again. At the commencement of the second regional traverse, the drill sledge tipped over at a melt water stream and fractured the feet of the hydraulic pump and control unit. It was returned to Mawson for welding, but after only two more holes had been drilled the vibration caused by the rough surface conditions, together with the low temperatures, caused the welds to fracture, and it became completely unserviceable. It was eventually returned to Melbourne and replaced by a different model for the subsequent expeditions to Wilkes. At the two holes that were drilled, the hydraulic oil was leaking badly and air was entering the system; this caused loss of power, which prevented drilling to a depth greater than 60 ft.

D.c. Generator Set

This unit operated almost continuously for over three months on the first regional traverse with no maintenance other than periodic oil-changes. It was found necessary to mask off the cooling vents near the commutator brushes, which would otherwise become packed with snow in heavy blowing snow conditions.

Before it was taken on the Henderson-Casey traverse there was no time for servicing, apart from a further oil change. There were consequently many stoppages, mainly due to broken wires on the control panel, which was eventually simplified and rewired. The commutator was badly distorted, which caused it to spark and get very dirty and icy, again causing stoppages. The whole unit was also subject to intense vibration, both during travel, because the sledge was not in good repair, and when in use, because it could not settle down firmly on hard blue ice.

On the second regional traverse, probably because of cold running, a fault in the fuel injector on the Lister diesel engine that drove the generator caused the engine to stop frequently. Injector replacement, followed by many attempts at pressure adjustment by trial and error proved to be wasted effort when it was found that a main bearing was unserviceable, thus putting the unit completely out of action. Following this failure, batteries were charged from the 6-volt generator of the Caterpillar D4 tractor.

Seismic Equipment

Operation of seismic recording equipment at low temperatures has been reported as producing many electrical and mechanical troubles, such as capacity loss in electrolytic condensers and cracking of optical systems. As might be expected, even more difficulties arise if the equipment is subjected to frequent temperature changes over wide ranges. For these reasons the seismic equipment used was transported and operated in a substantial thermally insulated cab fitted with thermostatically-controlled electrical heaters. Photographic processing tanks were fitted in the cab, together with radio equipment for use during refraction shooting. Rubber insulation was necessary on the seismic cables because the plastic insulation frequently used in geophysical prospecting becomes brittle at very low temperatures.

Amplifiers and control system. Apart from phase distortion in some filter units and noise due to the physical contact of some components, these units functioned satisfactorily, the only faults that could be attributed to extreme climatic conditions being the following:

(a) Amplifier noise due to operating in the cold after the d.c. generator, and therefore cab heating, had failed. This was probably due to components undergoing physical change as they warmed up after the equipment was switched on.

(b) Electrical noise due to low power-supply voltages brought about by increased voltage drop across the batteries at low temperature. Series-parallel combinations of all available batteries failed to rectify this noise completely.

Oscillograph camera. This functioned satisfactorily except for a few dry solder joints; also at one time a shortage of spare parts necessitated its operation without timing lines (timing of these records depended on the bleeper trace).

It was found necessary to fit the camera with a separate h.t. supply to enable it to be tested and the timing motor started without putting too heavy a drain on the main batteries.

Shooting boxes. With gloved hands, the SIE box was easier to use than the TIC box and was used preferentially on the first regional traverse. Later on, connexions were made through the seismic cab so that the TIC box could be operated from inside the cab by the observer. For the multiple air-shots, however, the higher-powered SIE box had to be used to cope with the increased detonator load, and this was operated outside the cab.

The cap-testing circuits were unreliable because of the effects of cold on the silver chloride cells.

Geophones. These operated satisfactorily.

Seismic cables. The rubber-covered cables were entirely satisfactory.

Explosives. Of the two types of explosives used, the RDX/TNT with CE primer was more convenient and easier to use. The Nobel 704 was extremely hard but crumbly once broken. In consequence it was very difficult to spike for insertion of the detonator, and often the paper split and the charge fell apart.

Seismic cab. It was not until after completion of the first regional traverse that it was realised that the ventilator of the cab had iced up. This may have resulted in high humidity, which was probably the cause of some cross-feed on the seismic equipment.

Before commencement of the second regional traverse some modifications were made to the layout of equipment in the cab to make it more accessible and to make more economical use of available space.

Barometers

Two of the three Askania microbarometers gave trouble with a tendency of their reading scales to stick at low temperatures. For the second year of the survey these two were replaced by two barometers of the same model lubricated with a special fine oil, but even these tended to stick. Because of this, two Fuess aneroid barometers were taken on the second regional traverse in addition to three of the Askania microbarometers. The microbarometers give reliable readings only for temperature changes of less than three Centigrade degrees per hour. In attempting to keep the instruments warm to prevent them from sticking, they were often subjected to more rapid temperature changes than this. The Fuess aneroid barometers, being temperature compensated, are less susceptible to changes in temperature. They operated satisfactorily, but the reading accuracy could have been better, one scale division being two millimetres of mercury.

Gravity Meter

The gravity meter functioned well throughout the first regional traverse. Drift rates as measured on returning to previously occupied stations were reasonable: for example, the total drift between leaving and returning to Mawson was only 2.2 milligals.

During the second year of the survey, a slight modification was made to provide power for the light source from an external battery. The normal batteries, being small, are very susceptible to cold and often become too weak to complete a reading even when carried in a pocket or in the hand between readings. The total gravity meter drift from Mawson back to Mawson over a period of 110 days on the second regional traverse was only 3.0 milligals.

Transport

The tractors generally were satisfactory apart from some mechanical troubles resulting from the operating conditions. The D4 tractor's electric starter motors, for example, suffered bad wear on the starter pinions, which caused them to jam frequently. In two years these starters had suffered more wear than is normal during the entire life of the tractors.

The Weasel similarly suffered faults due to the operating conditions. Owing to cold running when idling, the spark plugs became very dirty and required frequent cleaning. The springs and mounting bolts needed constant attention as a result of the very rough surface conditions.

Generally the speed was very low, being of the order of three or four miles per hour under good conditions or six miles per hour when running down hill on the latter part of the return journey. The surface conditions, of course, do not allow for a speed much greater than this, but some improvement could possibly be made by use of more powerful towing vehicles, or by reducing the weight of equipment to a minimum and using Weasels only. The latter, however, would be satisfactory only if air support was available to supply food and fuel. For regional operations proceeding beyond the range of available aircraft, the benefits of having well-protected equipment and ample supplies and spares outweigh the disadvantages of relatively slow travel.

APPENDIX D

DETERMINATION OF CORRECTIONS FOR DEPTH OF SHOT IN REFRACTION SHOOTING

The following assumptions are made:

(1) The seismic velocity in the ice is a continuously increasing scalar function of depth.

(2) There is no horizontal variation in the vertical velocity distribution.

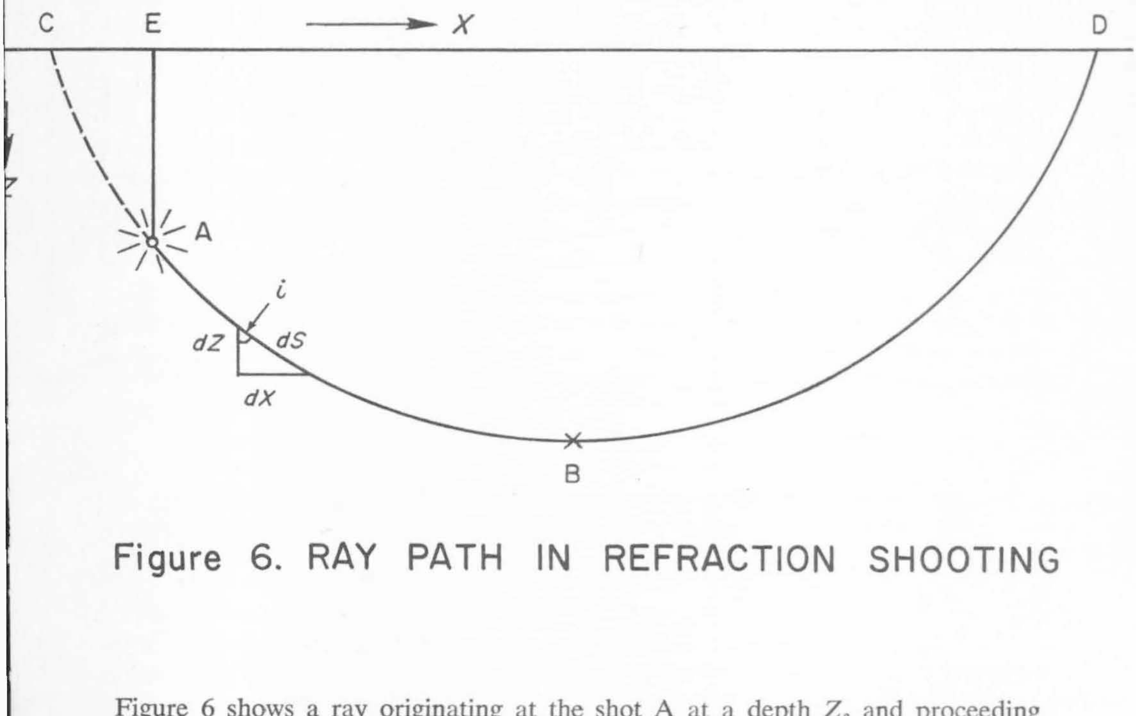


Figure 6. RAY PATH IN REFRACTION SHOOTING

Figure 6 shows a ray originating at the shot A at a depth Z_s and proceeding in a curved path to the geophone at D. From Snell's Law, the equation of the ray is $\sin i = V/V_m$ where V_m is the ray's maximum velocity at B and V is the velocity of the ray at any point where i is the inclination of the ray to the vertical. T is the time of travel of the ray from A to D. From the figure,

$$dX = \tan i.dZ$$

$$dT = dS/V = dZ/(V \cos i)$$

Expanding these,

$$dX = V(V_m^2 - V^2)^{-\frac{1}{2}}\, dZ$$

$$dT = V_m\, V^{-1}(V_m^2 - V^2)^{-\frac{1}{2}}\, dZ$$

The ray produced by the shot at A is equivalent to the ray that would be produced by a surface shot at C. Hence the corrections required are the distance CE (ΔX) and the time for the ray to travel from C to A (ΔT).

$$\Delta X = \int_0^{Z_s} dX = \int_0^{Z_s} V(V_m^2 - V^2)^{-\frac{1}{2}}\, dZ$$

$$\Delta T = \int_0^{Z_s} dT = V_m \int_0^{Z_s} V^{-1}(V_m^2 - V^2)^{-\frac{1}{2}}\, dZ$$

The evaluation of ΔX and ΔT is rather a laborious process, but can be made for four values of V_m (measured from the T/X plot) and the intermediate values can be found by interpolation. It necessitates a knowledge of the velocity distribution down to a depth $Z = Z_s$, which is found by shooting at the surface into geophone spreads relatively close to the shot-point. The problem is obviously simplified by maintaining a constant depth of shot. It can be simplified further if good results can be obtained at the farthest geophone spread by use of shallow depths of shot (about ten feet); in this case the corrections can be ignored completely.

An approximate set of corrections can be found by determining the average velocity down to Z_s from the results of the surface shots into close geophone spreads and using it in the following approximations:

$$\Delta X = Z_s \tan i'$$

$$\Delta T = Z_s/(V_a \cos i')$$

where V_a is the average velocity down to a depth Z_s and $\sin i' = V_a/V_m$.

These approximations are probably sufficiently accurate, as only the slope of the corrected T/X plot is involved in the final determination of the velocity distribution.

TABLE 1

FIRST REGIONAL TRAVERSE — RESULTS

Station	Latitude	Longitude	Ice Elevation, ft	Bouguer Anomaly B_1, mgal	Bouguer Anomaly B_2, mgal	Rock Elevation, ft	Ice Thickness, ft
Mawson	67°36.3′	62°52.3′	8	— 4.7	— 4.9	+ 8	0
GG 1		Unoccupied					
SP 1	67°43.8′	62°45.3′	1420	— 7.6	— 8.7	+ 49	1371
GG 2	67°46.9′	62°45.1′	1847	— 11.9	— 10.0	— 84	1931
GG 3	67°51.0′	62°40.0′	2458	— 5.5	— 11.6	+ 281	2177
SP 3	67°53.0′	62°30.0′	2873	+ 12.2	— 13.7	+1149	1724
GG 4	67°56.0′	62°22.0′	3159	+ 8.5	— 13.7	+ 985	2174
GG 5	67°59.8′	62°15.2′	3516	+ 4.6	— 16.1	+ 918	2598
GG 6	68°03.2′	62°10.6′	3742	— 35.3	— 22.0	— 591	4333
SP 4	68°06.7′	62°07.0′	4264	+ 0.5	— 24.8	+1122	3142
GG 7	68°10.3′	62°07.5′	4533	— 10.0	— 28.2	+ 808	3725
GG 8	68°13.9′	62°08.0′	4851	— 34.0	— 31.7	— 102	4953
GG 9	68°17.5′	62°08.5′	4918	— 36.9	— 35.7	— 53	4971
GG 10	68°21.1′	62°09.0′	5188	— 58.5	— 39.7	— 834	6022
SP 5	68°24.7′	62°09.7′	5373	— 43.2	— 43.0	— 7	5380
GG 11	68°27.6′	62°08.4′	5491	— 30.2	— 47.2	+ 755	4736
SP 6	68°32.7′	62°06.3′	5747	— 39.6	— 53.7	+ 627	5120
GG 12	68°37.0′	62°07.1′	5772	— 39.5	— 60.5	+ 932	4840
SP 7	68°41.3′	62°08.0′	5893	—111.3	— 66.3	—1997	7890
GG 13	68°43.5′	62°07.4′	5937	— 98.1	— 71.7	—1171	7108
GG 14	68°48.0′	62°06.7′	6002	— 97.6	— 82.2	— 684	6686
GG 15	68°52.4′	62°05.9′	6103	— 85.9	— 91.7	+ 257	5846
GG 16	68°54.6′	62°05.4′	6168	— 78.9	— 96.7	+ 790	5378
SP 8	68°59.1′	62°04.6′	6287	— 82.9	—107.1	+1077	5210
GG 17	69°03.4′	62°06.0′	6336	—113.1	—114.2	+ 49	6287
GG 18	69°07.7′	62°07.5′	6384	— 99.0	—121.2	+ 985	5399
SP 9	69°16.3′	62°10.2′	6495	— 90.8	—134.0	+1915	4580
SP 10	69°20.8′	62°10.2′	6658	— 81.0	—136.4	+2458	4200
GG 19	69°25.0′	62°10.1′	6824	— 91.8	—139.2	+2105	4719
GG 20	69°29.2′	62°10.0′	6884	— 71.2	—140.7	+3085	3799
GG 21	69°33.4′	62°09.9′	6956	— 71.8	—142.2	+3125	3831
SP 11	69°37.5′	62°09.8′	7120	— 97.7	—144.2	+2060	5060
GG 22	69°41.9′	62°08.1′	7115	—103.3	—140.7	+1659	5456
GG 23	69°46.3′	62°06.4′	7223	— 85.0	—137.7	+2340	4883
GG 24	69°50.7′	62°04.7′	7303	— 52.3	—134.2	+3635	3668
SP 12	69°55.1′	62°02.9′	7543	— 56.3	—131.3	+3333	4210
GG 25	69°59.7′	62°05.0′	7629	— 68.0	—127.7	+2650	4979
GG 26	70°04.3′	62°07.0′	7668	— 43.3	—123.7	+3565	4103
SP 13	70°13.4′	62°08.6′	7718	—106.7	—116.9	+ 453	7265

Station	Latitude	Longitude	Ice Elevation, ft	Bouguer Anomaly B_1, mgal	Bouguer Anomaly B_2, mgal	Rock Elevation, ft	Ice Thickness, ft
GG 27	70°17.9′	62°08.8′	7958	—107.0	—121.7	+ 653	7305
GG 28	70°22.4′	62°08.9′	7669	—133.0	—126.7	— 280	7389
GG 29	70°26.9′	62°09.1′	7487	—138.2	—132.2	— 266	7753
SP 14	70°31.3′	62°09.2′	7330	—164.2	—137.6	—1180	8510
GG 30	70°35.9′	62°08.9′	7457	—110.3	—125.2	+ 662	6795
GG 31	70°40.5′	62°08.6′	7556	— 54.5	—113.7	+2625	4931
GG 32	70°45.1′	62°08.3′	7505	— 71.3	—101.7	+1348	6157
SP 25	70°49.6′	62°08.0′	7483	— 85.6	— 90.9	+ 233	7250
GG 33	70°54.2′	62°07.7′	7357	—100.2	— 97.2	— 133	7490
GG 34	70°58.8′	62°07.4′	7166	— 99.9	—103.2	— 146	7312
GG 35	71°03.4′	62°07.1′	7231	—121.5	—109.7	— 524	7755
SP 15	71°08.1′	62°06.9′	7115	—133.1	—115.4	— 785	7900
GG 36	71°12.5′	62°07.0′	7050	—133.8	—113.7	— 893	7943
GG 37	71°17.0′	62°07.0′	6990	—114.0	—112.2	— 80	7070
SP 16	71°21.6′	62°07.0′	6890	—111.7	—111.0	— 30	6920
GG 38	71°26.0′	62°07.1′	6820	—111.6	—109.7	— 84	6904
GG 39	71°30.5′	62°07.2′	6751	—111.0	—108.2	— 124	6875
GG 40	71°34.9′	62°07.3′	6551	—100.0	—107.2	+ 320	6231
GG 41	71°39.4′	62°07.4′	6510	—116.6	—105.7	— 484	6994
GG 42	71°44.0′	62°07.5′	6351	—122.6	—104.7	— 795	7146
SP 17	71°45.8′	62°07.5′	6332	—123.0	—103.9	— 848	7180
GG 43	71°50.1′	62°07.5′	6454	— 86.6	— 92.2	+ 248	6206
GG 44	71°54.6′	62°07.6′	6429	— 99.6	— 80.2	— 862	7291
SP 24	71°59.2′	62°07.6′	6488	—106.7	— 67.6	—1732	8220
GG 45	72°03.5′	62°07.7′	6524	—102.3	— 67.7	—1535	8059
GG 46	72°08.0′	62°07.7′	6524	— 89.9	— 67.7	— 986	7510
SP 18	72°12.6′	62°07.8′	6446	— 74.4	— 67.8	— 294	6740
GG 47	72°17.0′	62°07.8′	6481	— 54.6	— 59.2	+ 204	6277
SP 19	72°21′6	62°07.8′	6441	— 49.2	— 49.2	0	6441
GG 48	72°26.2′	62°08.0′	6330	— 7.4	— 48.9	+1840	4490
GG 49	72°30.9′	62°08.1′	6343	— 38.2	— 48.7	+ 466	5877
SP 20	72°35.6′	62°08.3′	6217	— 38.8	— 48.4	+ 427	5790
GG 50	72°37.1′	61°54.3′	6224	+ 8.0	— 55.0	+2785	3439
GG 51	72°38.7′	61°40.2′	6403	+ 13.8	— 61.6	+3345	3058
GG 52	72°40.2′	61°26.2′	6506	— 27.2	— 68.3	+1820	4686
SP 21	72°41.8′	61°12.2′	6665	— 70.3	— 74.9	+ 204	6461
GG 53	72°44.3′	61°00.6′	6805	— 63.1	— 88.1	+1110	5695
GG 54	72°46.9′	60°49.0′	6870	— 88.8	—101.3	+ 555	6315
GG 55	72°49.4′	60°37.5′	7078	— 65.6	—114.5	+2170	4908
SP 22	72°52.0′	60°26.0′	7299	— 37.4	—127.7	+4004	3295
GG 56	72°47.6′	61°17.7′	6571	— 95.2	—107.7	+ 555	6016
SP 23	72°51.1′	61°21.0′	6584	— 74.7	—127.7	+2354	4230

TABLE 2

SECOND REGIONAL TRAVERSE — RESULTS

Station	Latitude	Longitude	Ice Elevation, ft	Bouguer Anomaly B_1, mgal	Bouguer Anomaly B_2, mgal	Rock Elevation, ft	Ice Thickness, ft
Mawson	67°36.3′	62°52.3′	8	— 4.7	— 4.9	+ 8	0
G 144	67°37.7′	62°52.3′	500	— 21.8	— 5.8	— 710	1210
G 143	67°38.1′	62°52.2′		Unoccupied			
G 142	67°38.9′	62°53.7′	714	— 22.9	— 6.3	— 737	1451
G 141	67°40.7′	62°51.8′	1057	— 17.6	— 7.1	— 466	1523
G 140	67°42.9′	62°48.7′	1371	— 24.7	— 8.1	— 737	2108
G 139	67°44.0′	62°49.0′	1496	— 20.8	— 9.5	— 502	1998
G 138	67°43.8′	62°47.2′	1444	— 17.1	— 9.5	— 337	1781
G 137	67°47.5′	62°45.3′	2019	— 9.8	— 10.5	+ 31	1988
G 136	67°50.3′	62°40.3′	2467	— 3.4	— 11.8	+ 373	2094
G 135	67°51.8′	62°34.6′	2712	— 4.8	— 12.8	+ 355	2357
G 134	67°52.4′	62°28.1′	2820	— 7.4	— 13.3	+ 262	2558
G 133	67°54.0′	62°22.3′	3002	+ 17.2	— 13.9	+1380	1622
G 132	67°56.6′	62°21.6′	3340	— 4.3	— 15.9	+ 471	2869
G 131	67°59.8′	62°22.5′	3580	— 1.8	— 16.8	+ 666	2914
G 130	68°02.5′	62°25.0′	3828	+ 4.0	— 17.4	+ 950	2878
G 129	68°04.8′	62°28.6′	3983	+ 11.2	— 17.9	+1291	2692
G 128	68°05.2′	62°27.0′		Unoccupied			
G 127	68°05.5′	62°30.7′	4071	+ 15.7	— 18.0	+1496	2575
G 126	68°07.8′	62°31.8′	4328	+ 12.5	— 18.6	+1380	2948
G 125	68°10.0′	62°35.0′	4471	+ 5.1	— 19.0	+1070	3401
G 124	68°12.2′	62°38.6′	4504	+ 7.7	— 19.7	+1217	3287
SP 40	68°14.5′	62°42.3′	4796	+ 4.4	— 20.5	+1106	3690
G 123	68°17.3′	62°47.3′	4938	+ 4.9	— 21.4	+1168	3770
G 122	68°18.2′	62°37.4′	5093	+ 5.0	— 27.1	+1425	3668
G 121	68°19.7′	62°31.9′	5186	— 15.1	— 30.3	+ 675	4511
G 120	68°20.9′	62°26.4′	5227	— 1.9	— 33.5	+1403	3824
G 119	68°22.2′	62°20.7′	5273	— 6.6	— 36.8	+1342	3931
G 118	68°23.5′	62°15.0′	5380	— 41.5	— 40.1	— 62	5442
SP 5	68°24.7′	62°09.7′	5373	— 43.2	— 43.0	— 7	5380
G 117	68°26.5′	62°09.3′	5438	— 40.5	— 45.6	+ 226	5212
G 116	68°28.9′	62°09.1′	5508	— 28.9	— 49.0	+ 895	4613
G 115	68°29.7′	62°13.3′	5509	— 35.1	— 50.1	+ 666	4843
G 114	68°32.3′	62°13.9′	5687	— 55.9	— 53.8	— 93	5780
G 113	68°35.7′	62°15.0′	5744	— 69.3	— 58.7	— 472	6216
G 112	68°37.9′	62°15.0′	5875	— 91.0	— 61.8	—1296	7171
G 111	68°40.9′	62°14.2′	5889	—109.5	— 66.1	—1928	7817
G 110	68°40.3′	62°05.9′	5962	— 99.2	— 65.3	—1506	7468
G 109	68°41.3′	62°01.8′	5999	— 92.9	— 66.8	—1160	7159

Station	Latitude	Longitude	Ice Elevation, ft	Bouguer Anomaly B_1, mgal	Bouguer Anomaly B_2, mgal	Rock Elevation, ft	Ice Thickness, ft
G 108	68°42.7′	61°55.5′	6090	—101.5	— 69.0	—1443	7533
G 107	68°44.1′	61°49.1′	6109	—102.0	— 71.3	—1363	7472
G 106	68°45.4′	61°43.3′	6156	— 97.6	— 73.4	—1075	7231
G 105	68°46.8′	61°37.1′	6190	— 99.3	— 75.6	—1052	7242
G 104	68°48.4′	61°30.5′	6255	— 87.3	— 77.9	— 418	7673
G 103	68°49.8′	61°24.1′	6313	— 80.8	— 80.2	— 27	6340
G 102	68°51.2′	61°17.9′	6330	— 80.9	— 82.5	+ 71	6259
G 101	68°52.7′	61°11.6′	6365	— 84.3	— 84.7	+ 18	6347
G 100	68°54.1′	61°05.7′	6412	— 85.3	— 86.4	+ 49	6363
G 99	68°55.6′	60°59.0′	6451	— 93.1	— 88.8	— 191	6642
G 98	68°57.0′	60°52.9′	6447	— 68.0	— 91.0	+1020	5427
G 97 } SP 39	68°58.6′	60°46.8′	6585	— 64.3	— 93.3	+1285	5300
G 96	69°01.3′	60°46.9′	6615	— 49.8	— 91.8	+1865	4750
G 95	69°03.9′	60°47.1′	6694	— 25.7	— 90.4	+2875	3819
G 94	69°06.5′	60°47.3′	6855	— 29.3	— 89.0	+2650	4205
G 93	69°09.0′	60°47.4′	7054	— 56.4	— 87.7	+1390	5664
G 92	69°11.6′	60°47.6′	7080	— 66.7	— 86.3	+ 870	6210
G 91	69°14.3′	60°47.7′	7136	— 55.2	— 84.9	+1320	5816
G 90 } SP 38	69°16.9′	60°47.8′	7164	— 28.3	— 83.5	+2454	4710
G 89	69°19.5′	60°47.9′	7347	— 39.8	— 85.5	+2030	5317
G 88	69°22.0′	60°48.0′	7342	— 31.1	— 87.4	+2500	4842
G 87	69°24.7′	60°48.2′	7482	— 24.4	— 89.5	+2890	4592
G 86	69°27.1′	60°48.3′	7570	— 54.3	— 91.4	+1646	5924
G 85	69°29.9′	60°48.4′	7593	— 51.7	— 93.6	+1860	5733
G 84	69°32.4′	60°48.4′	7683	— 44.2	— 95.5	+2275	5408
G 83	69°35.2′	60°48.5′	7761	— 34.0	— 97.7	+2825	4936
G 82	69°37.7′	60°48.6′	7853	— 61.4	— 99.6	+1695	6158
G 81	69°40.3′	60°48.7′	7890	— 55.7	—101.6	+2038	5852
G 80	69°43.0′	60°48.8′	7945	— 46.2	—103.7	+2550	5395
G 79	69°45.6′	60°48.9′	8006	— 37.7	—105.7	+3020	4986
G 78	69°48.1′	60°49.0′	8074	— 26.6	—107.6	+3695	4379
G 77	69°50.8′	60°49.0′	8153	— 30.8	—109.7	+3505	4648
G 76	69°53.4′	60°49.0′	8217	— 51.7	—111.7	+2662	5555
G 75 } SP 37	69°56.1′	60°49.2′	8260	— 45.8	—113.8	+3020	5240
G 74	69°57.3′	60°49.2′	8279	— 39.6	—113.4	+3275	5004
G 73	70°00.0′	60°49.3′	8318	— 32.7	—112.5	+3540	4778
G 72	70°02.7′	60°49.5′	8375	— 38.2	—111.6	+3257	5118
G 71	70°05.2′	60°49.6′	8417	— 66.6	—110.7	+1956	6461
G 70	70°07.8′	60°49.7′	8432	— 82.9	—109.8	+1193	7239
G 69	70°10.3′	60°49.8′	8420	— 88.5	—108.9	+ 905	7515

Station	Latitude	Longitude	Ice Elevation, ft	Bouguer Anomaly B_1, mgal	Bouguer Anomaly B_2, mgal	Rock Elevation, ft	Ice Thickness, ft
G 68	70°12.9′	60°49.9′	8403	— 93.7	—108.0	+ 635	7768
G 67	70°15.6′	60°50.0′	8409	— 94.0	—107.1	+ 572	7837
G 66	70°18.2′	60°50.1′	8396	— 92.0	—106.2	+ 631	7765
G 65	70°20.9′	60°50.3′	8341	— 94.9	—105.3	+ 462	7879
G 64	70°23.5′	60°50.4′	8333	— 96.0	—104.3	+ 368	7965
SP 36	70°26.1′	60°50.4′	8306	— 89.0	—103.3	+ 636	7670
G 63	70°26.1′	60°57.9′	8265	— 90.8	—103.1	+ 546	7719
G 62	70°26.2′	61°05.7′	8212	— 95.9	—102.8	+ 328	7884
G 61	70°26.3′	61°10.8′	8172	—102.8	—102.6	— 9	8181
G 60	70°26.3′	61°18.3′	8114	—105.2	—102.4	— 124	8238
G 59	70°26.4′	61°25.7′	8028	—102.4	—102.2	— 9	8037
G 58	70°26.5′	61°33.3′	8007	—101.4	—102.0	+ 27	7980
G 57	70°29.0′	61°33.5′	7981	—110.3	—101.7	— 382	8363
G 56	70°31.6′	61°33.7′	7936	—117.4	—101.4	— 711	8647
G 55	70°34.1′	61°34.0′	7915	—111.1	—101.1	— 44	7959
G 54	70°36.7′	61°34.1′	7862	— 98.6	—100.8	+ 98	7764
G 52 } SP 35 }	70°39.2′	61°33.6′	7804	— 94.8	—100.5	+ 254	7550
G 53	70°40.8′	61°33.7′	7818	— 95.1	—100.0	+ 218	7600
G 51	70°41.9′	61°33.7′	7824	— 97.3	— 99.7	+ 107	7717
G 50	70°44.4′	61°34.0′	7761	—104.7	— 98.9	— 258	8019
G 49	70°47.0′	61°34.2′	7648	—118.2	— 98.0	— 896	8544
G 48	70°49.7′	61°34.5′	7536	—136.3	— 97.2	—1735	9271
G 47 } G 45 }		Unoccupied					
G 46 } SP 34 }	70°49.7′	61°38.3′	7613	—129.7	— 96.5	—1477	9090
G 44	70°49.7′	61°42.8′	7619	—125.5	— 95.6	—1327	8946
G 43	70°49.6′	61°55.0′	7569	—102.1	— 93.2	— 395	7964
SP 25	70°49.5′	62°07.0′	7483	— 85.6	— 90.9	+ 233	7250

TABLE 3

HENDERSON-CASEY TRAVERSE — RESULTS

Station	Latitude	Longitude	Ice Elevation, ft	Bouguer Anomaly B_1, mgal	Bouguer Anomaly B_2, mgal	Rock Elevation, ft	Ice Thickness, ft
G 22	67°44.1′	62°24.2′	1746	— 0.2	+ 0.9	— 49	1795
SP 33	67°44.1′	62°25.5′	1630	— 1.2	0.0	— 53	1683
G 21	67°44.1′	62°26.8′	1613	— 2.5	— 0.7	— 80	1693
G 20	67°44.1′	62°27.9′	1598	— 5.3	— 1.5	— 169	1767
G 19	67°44.1′	62°29.2′	1632	— 4.4	— 2.0	— 106	1738
G 18	67°44.1′	62°30.3′	1598	— 3.8	— 2.7	— 49	1647
G 17	67°44.1′	62°31.5′	1564	— 5.4	— 3.4	— 89	1653
G 16	67°44.1′	62°32.7′	1407	— 14.8	— 4.0	— 479	1886
G 15	67°44.1′	62°33.9′	1413	— 14.1	— 4.7	— 416	1829
SP 32	67°44.1′	62°35.1′	1490	— 13.6	— 5.5	— 359	1849
G 14	67°44.1′	62°36.3′	1504	— 15.5	— 5.9	— 426	1930
G 13	67°44.1′	62°37.4′	1441	— 13.7	— 6.5	— 319	1760
G 12	67°44.1′	62°38.8′	1474	— 6.7	— 7.1	+ 18	1456
G 11	67°44.1′	62°39.9′	1496	— 5.9	— 7.7	+ 80	1416
G 10	67°44.1′	62°41.1′	1443	— 8.4	— 8.3	— 4	1447
G 9	67°44.0′	62°42.3′	1454	— 7.9	— 8.8	+ 40	1414
G 8	67°44.0′	62°43.4′	1424	— 7.7	— 9.5	+ 80	1364
SP 31	67°44.0′	62°44.7′	1468	— 7.5	— 10.0	+ 111	1357
G 1	67°44.0′	62°45.8′	1502	— 7.6	— 10.4	+ 124	1378
G 2	67°44.0′	62°47.0′	1478	— 14.5	— 10.6	— 173	1651
G 3	67°44.0′	62°48.2′	1486	— 18.4	— 10.8	— 337	1823
G 4	67°44.0′	62°49.5′	1472	— 20.6	— 10.9	— 431	1903
G 5	67°44.0′	62°55.6′	1497	— 21.9	— 11.3	— 470	1967
G 6	67°44.0′	62°51.9′	1530	— 22.1	— 11.5	— 470	2000
G 7	67°44.0′	62°53.1′	1591	— 20.3	— 11.7	— 382	1973
SP 30	67°43.9′	62°54.6′	1668	— 21.6	— 11.9	— 431	2099
SP 29	67°43.9′	62°56.7′	1644	— 15.6	— 12.4	— 142	1786
SP 28	67°43.9′	62°59.2′	1694	— 16.9	— 14.2	— 120	1814
SP 27	67°43.9′	63°01.3′	1734	— 8.5	— 15.7	+ 319	1415
SP 26	67°43.9′	63°01.9′	1765	— 6.5	— 16.5	+ 445	1320
G 25	67°45.5′	62°25.8′	1883	+ 2.6	— 0.6	+ 142	1741
G 24	67°45.0′	62°25.7′	1766	+ 1.4	— 0.4	+ 80	1686
G 23	67°44.6′	62°25.6′	1704	+ 0.6	— 0.2	+ 35	1669
SP 33	67°44.1′	62°25.5′	1630	— 1.1	0.0	— 49	1679
G 26	67°43.7′	62°25.5′	1527	— 8.3	+ 0.2	— 377	1904
G 27	67°43.2′	62°25.4′	1536	— 0.9	+ 0.4	— 58	1594

Station	Latitude	Longitude	Ice Elevation, ft	Bouguer Anomaly B_1, mgal	Bouguer Anomaly B_2, mgal	Rock Elevation ft	Ice Thickness, ft
G 28	67°42.8′	62°25.3′	1439	— 2.1	+ 0.6	— 120	1559
G 29	67°42.3′	62°25.3′	1294	— 6.6	— 0.8	— 328	1622
G 37	67°47.6′	62°44.9′	2033	— 4.9	— 11.6	+ 297	1736
G 36	67°47.2′	62°44.9′	1936	— 6.2	— 11.4	+ 231	1705
G 35	67°46.7′	62°44.8′	1819	— 9.1	— 11.2	+ 93	1726
G 34	67°46.3′	62°44.8′	1789	— 10.6	— 11.0	+ 18	1771
G 33	67°45.8′	62°44.8′	1731	— 9.2	— 10.8	+ 71	1660
G 32	67°45.4′	62°44.7′	1671	— 7.5	— 10.6	+ 138	1533
G 31	67°44.9′	62°44.7′	1591	— 7.6	— 10.4	+ 124	1467
G 30	67°44.5′	62°44.7′	1541	— 7.7	— 10.2	+ 111	1430
SP 31	67°44.0′	62°44.7′	1468	— 7.5	— 10.0	+ 111	1357
G 38	67°43.6′	62°44.6′	1377	— 7.7	— 9.8	+ 93	1284
G 39	67°43.1′	62°44.6′	1247	— 9.7	— 9.6	— 4	1251
G 40	67°42.7′	62°44.6′	1159	— 12.6	— 9.4	— 142	1301
G 41	67°42.2′	62°44.5′	1103	— 16.4	— 9.2	— 319	1422
G 42	67°41.8′	62°44.5′	1051	— 20.2	— 9.0	— 496	1547

TABLE 4

DIPS OF THE ICE/ROCK INTERFACE FROM SEISMIC REFLECTIONS

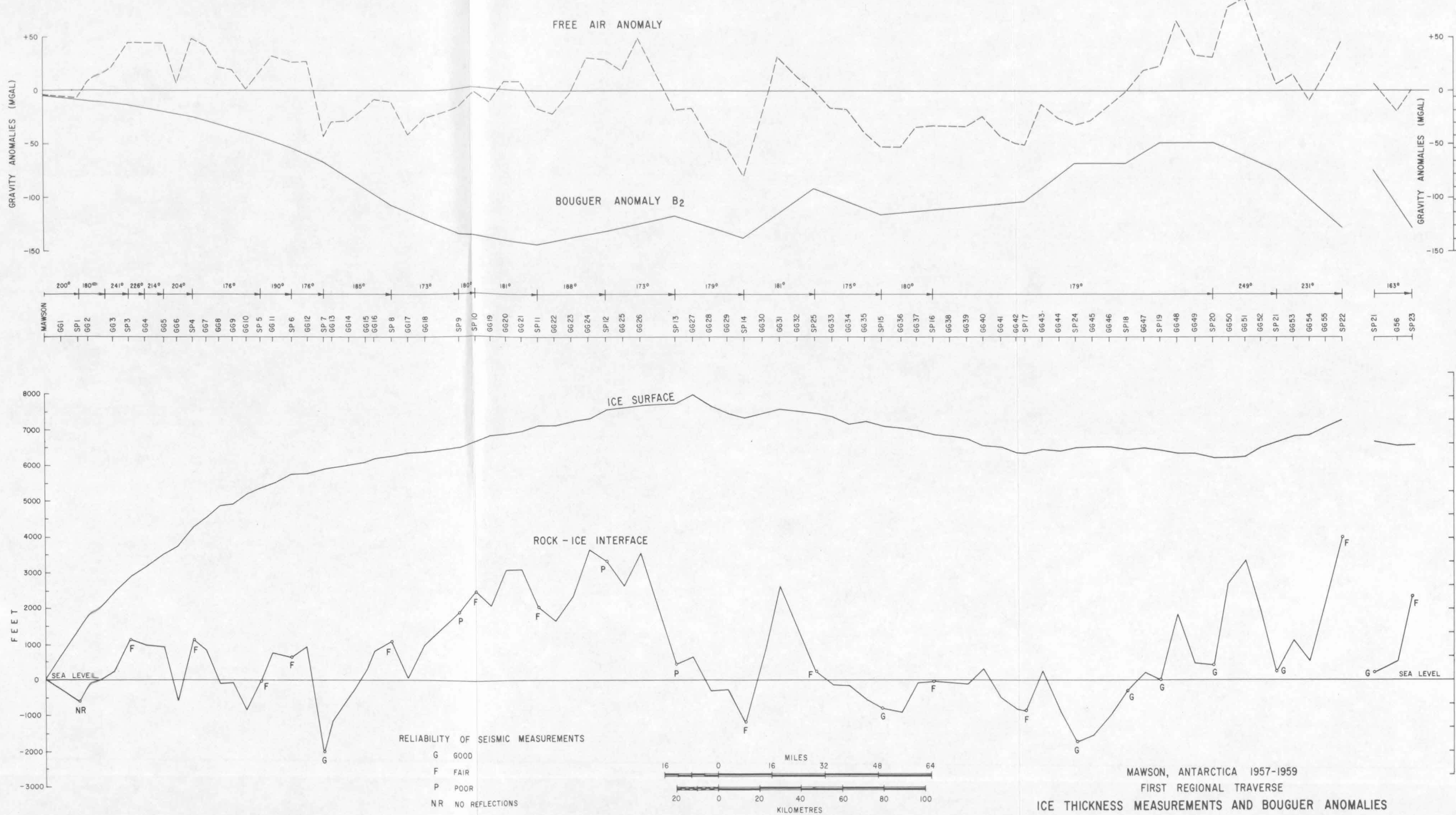
Shot-point	East/West Dip	North/South Dip
3	4°W	11°S
4	1°W	3°S
5	2°E	1°N
6	1°E	9°S
7	3°W	13°N
8	16°W	4°N
10	9°E	5°S
11	1°W	—
14	2°W	6°S
15	3°W	1°S
16	—	3°S
17	6°E	7°N
18	—	5°S
19	5°E	5°N
20	7°W	2°N
21	11°E	4°S
22	15°E	—
23	4°E	2°N
24	0°	0°
25	4°W	4°S
26	8°W	—
27	2°W	3°S
29	3°W	—
31	3°W	—
33	3°E	—
34	1°E	2°N
35	8°E	10°S
39	4°E	—
40	5°E	—

TABLE 5

DENSITY MEASUREMENTS ON OUTCROP SAMPLES

Location	Lithology	Dry Bulk Density g/cm^3	Apparent Grain Density g/cm^3	Porosity %	Bulk Density 100% saturated with water of 1.01 sp. gr. g/cm^3
Island 1½ miles north-east of Azimuth Island	Gneissic charnockite	2.77	2.77	0	2.77
Azimuth Island	Garnet gneiss	2.85	2.88	1	2.86
North end of North Masson Range, Framnes Mountains	Garnet-quartz-feldspar gneiss	2.64	2.64	0	2.64
Mt Parsons, David Range, Framnes Mountains	Recrystallised charnockite	2.71	2.79	3	2.74
Mt Parsons, David Range, Framnes Mountains	Pyroxene-scapolite gneiss	2.97	2.97	0	2.97
Summit of Mt Menzies, southern Prince Charles Mountains	Chloritoid quartzite	2.67	2.67	0	2.67
West end of Mt Bayliss, southern Prince Charles Mountains	Quartz-calcite-feldspar amphibolite	2.82	2.85	1	2.83
West end of Mt Bayliss, southern Prince Charles Mountains	Foliated granite	2.60	2.65	2	2.62
Beaver Lake, northern Prince Charles Mountains	Feldspathic sandstone	2.15	2.62	18	2.33
East end of Wilson Bluff, southern Prince Charles Mountains	Muscovite-quartz feldspar schist	2.68	2.68	0	2.68

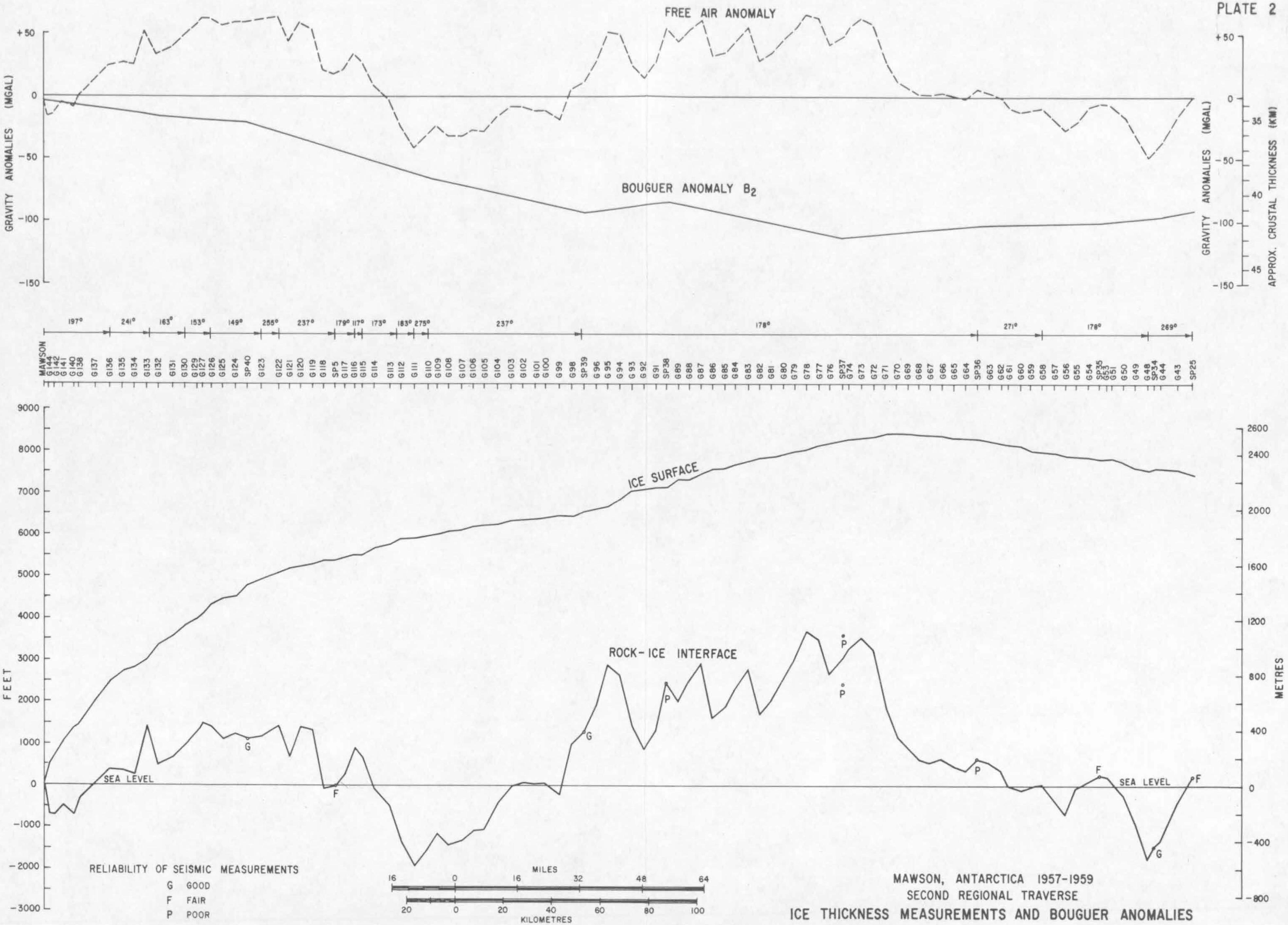
PLATE 1



MAWSON, ANTARCTICA 1957-1959
FIRST REGIONAL TRAVERSE
ICE THICKNESS MEASUREMENTS AND BOUGUER ANOMALIES

G158-53

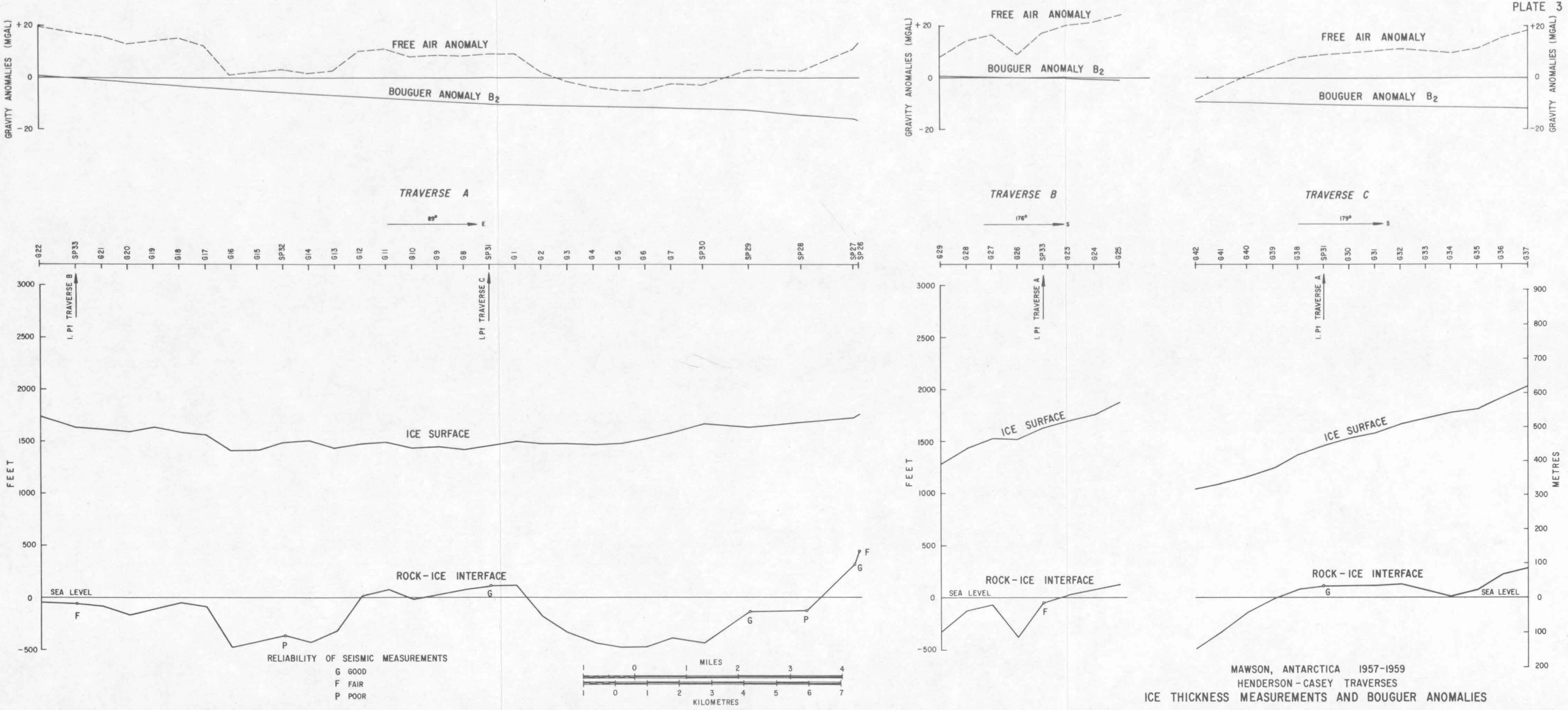
PLATE 2



MAWSON, ANTARCTICA 1957-1959
SECOND REGIONAL TRAVERSE
ICE THICKNESS MEASUREMENTS AND BOUGUER ANOMALIES

G158-56

PLATE 3



MAWSON, ANTARCTICA 1957-1959
HENDERSON - CASEY TRAVERSES
ICE THICKNESS MEASUREMENTS AND BOUGUER ANOMALIES

G158-57

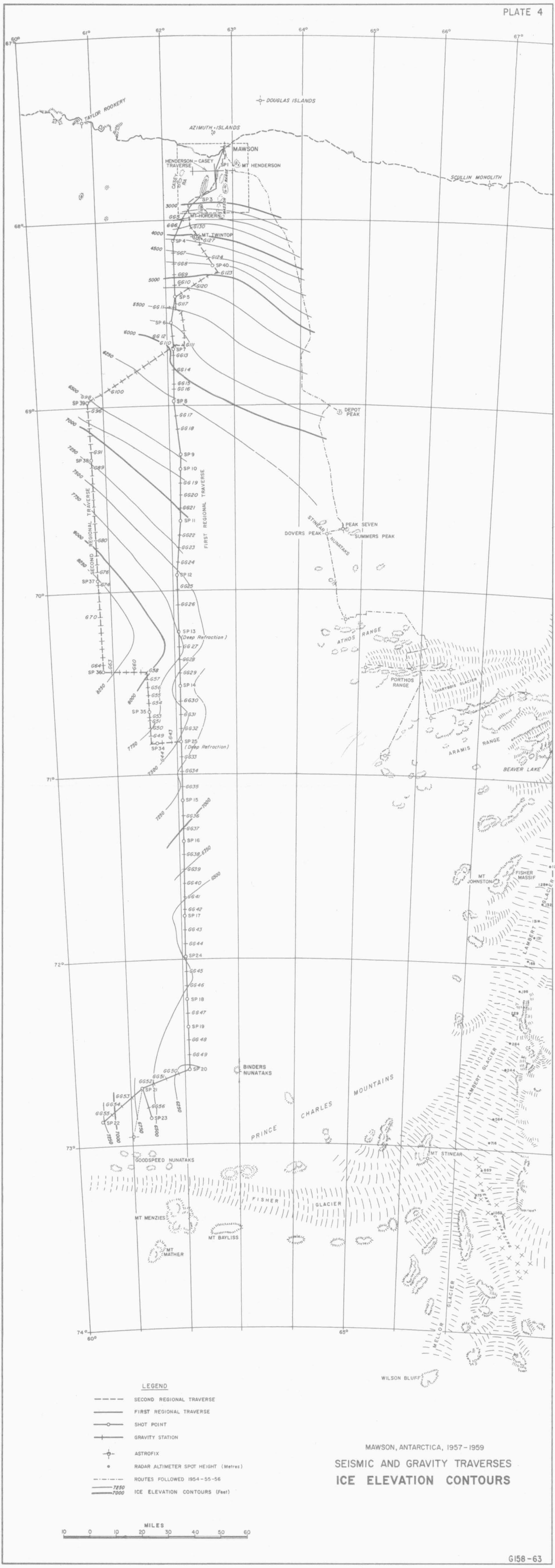
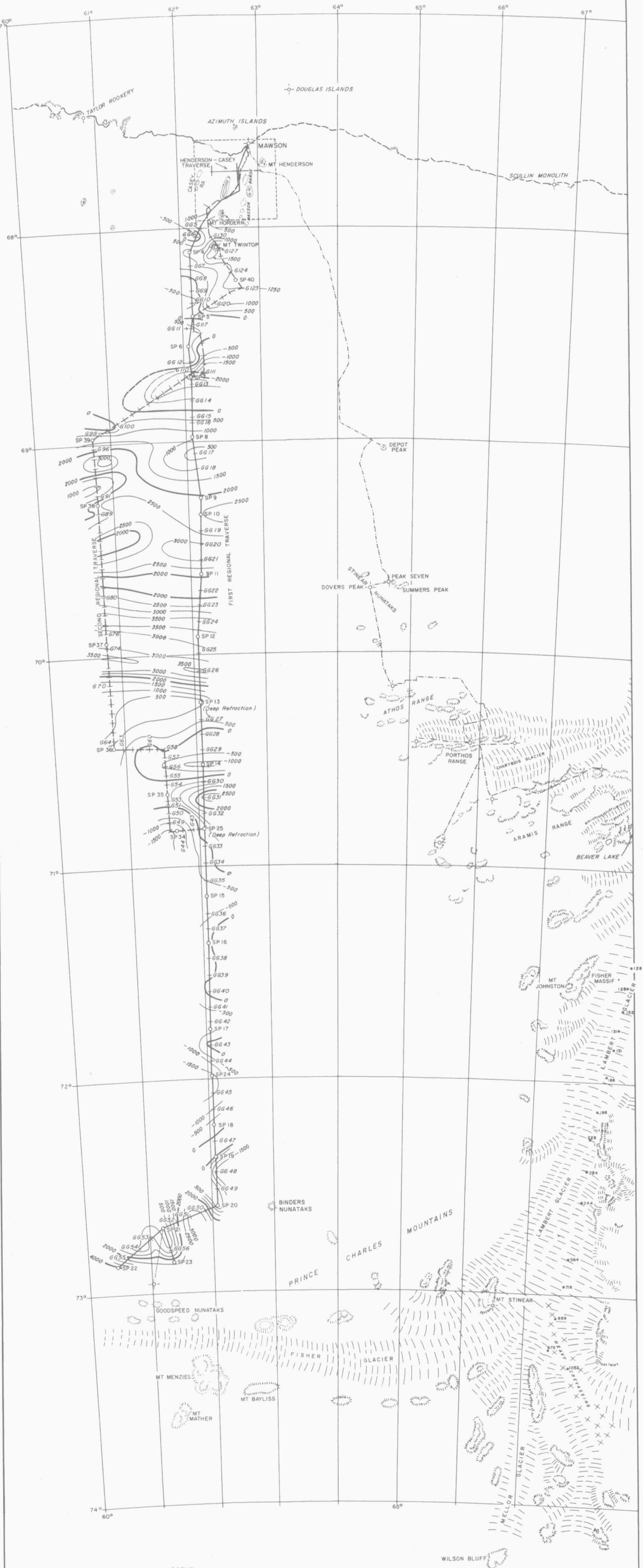


PLATE 4
DOUGLAS ISLANDS
TAYLOR ROOKERY
AZIMUTH ISLANDS
MAWSON
HENDERSON - CASEY TRAVERSE
MT HENDERSON
SCULLIN MONOLITH
MT HORDERN
MT TWINTOP
DEPOT PEAK
PEAK SEVEN
DOVERS PEAK
SUMMERS PEAK
STINEAR NUNATAKS
FIRST REGIONAL TRAVERSE
SECOND REGIONAL TRAVERSE
ATHOS RANGE
PORTHOS RANGE
ARAMIS RANGE
BEAVER LAKE
MT JOHNSTON
FISHER MASSIF
LAMBERT GLACIER
BINDERS NUNATAKS
PRINCE CHARLES MOUNTAINS
GOODSPEED NUNATAKS
MT STINEAR
FISHER GLACIER
MT MENZIES
MT BAYLISS
MT MATHER
MELLOR GLACIER
WILSON BLUFF
LEGEND
SECOND REGIONAL TRAVERSE
FIRST REGIONAL TRAVERSE
SHOT POINT
GRAVITY STATION
ASTROFIX
RADAR ALTIMETER SPOT HEIGHT (Metres)
ROUTES FOLLOWED 1954-55-56
ICE ELEVATION CONTOURS (Feet)
MILES
MAWSON, ANTARCTICA, 1957-1959
SEISMIC AND GRAVITY TRAVERSES
ICE ELEVATION CONTOURS
G158-63

PLATE 5



LEGEND

- SECOND REGIONAL TRAVERSE
- FIRST REGIONAL TRAVERSE
- SHOT POINT
- GRAVITY STATION
- ASTROFIX
- RADAR ALTIMETER SPOT HEIGHT (Metres)
- ROUTES FOLLOWED 1954-55-56
- ROCK ELEVATION CONTOURS (Feet) 500 / 0 / -500

MILES

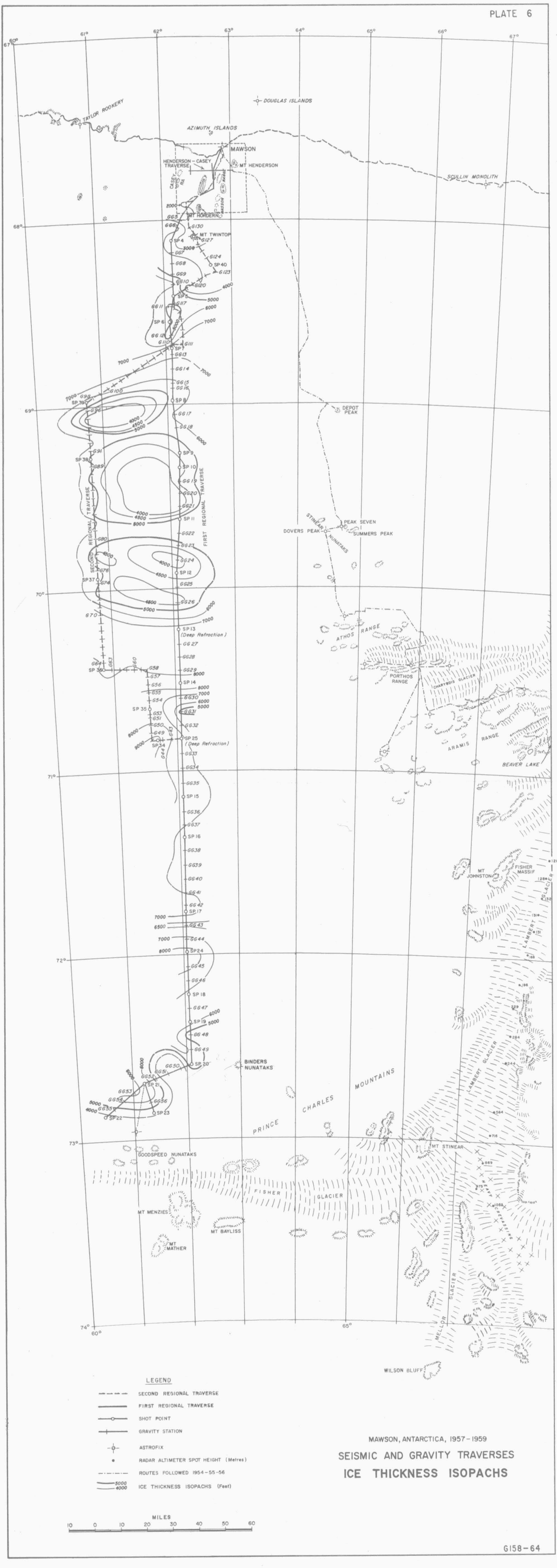
10 0 10 20 30 40 50 60

MAWSON, ANTARCTICA, 1957-1959

SEISMIC AND GRAVITY TRAVERSES

ROCK ELEVATION CONTOURS

G158-65



MAWSON, ANTARCTICA, 1957–1959

SEISMIC AND GRAVITY TRAVERSES

ICE THICKNESS ISOPACHS

G158-64

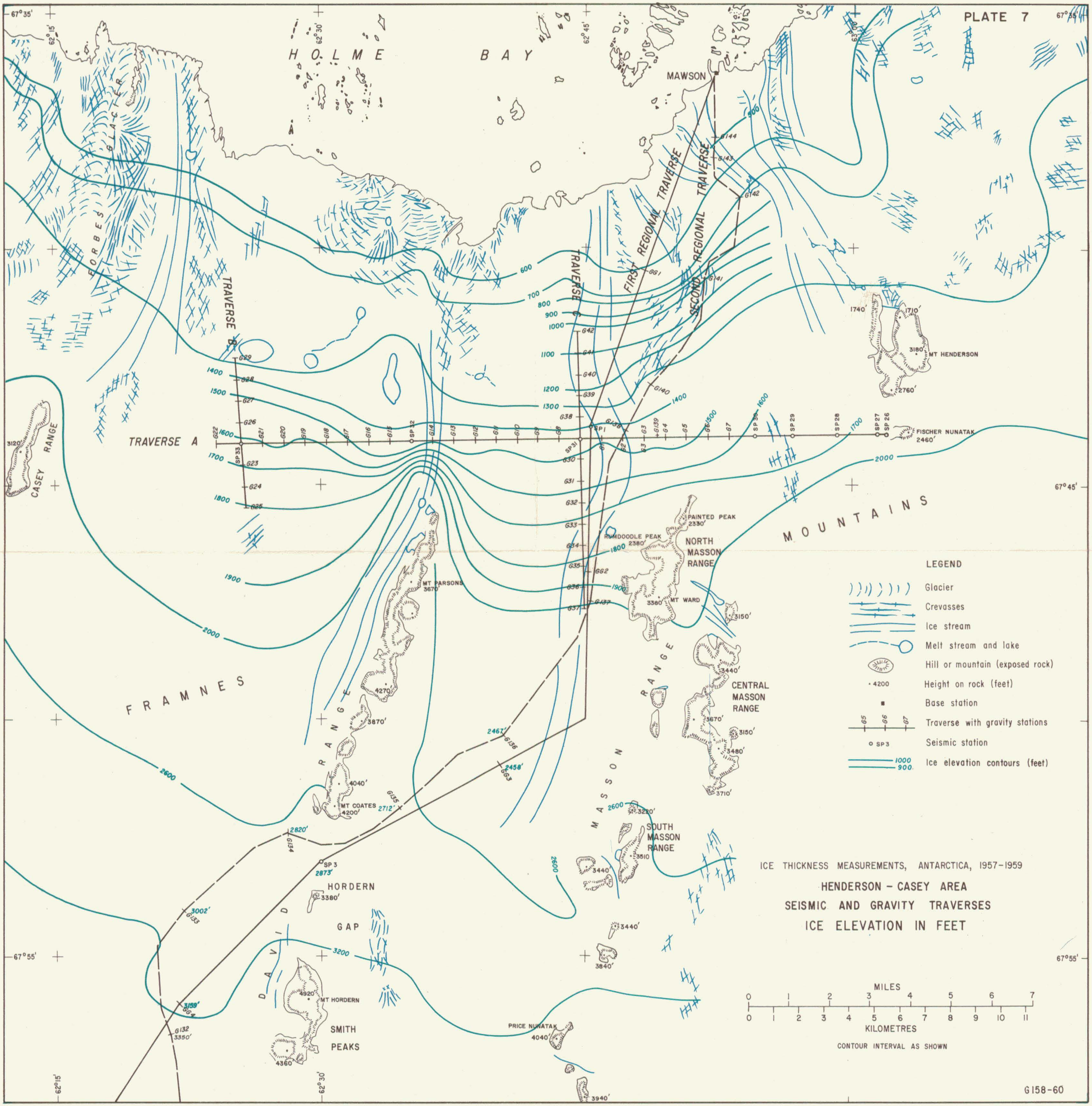
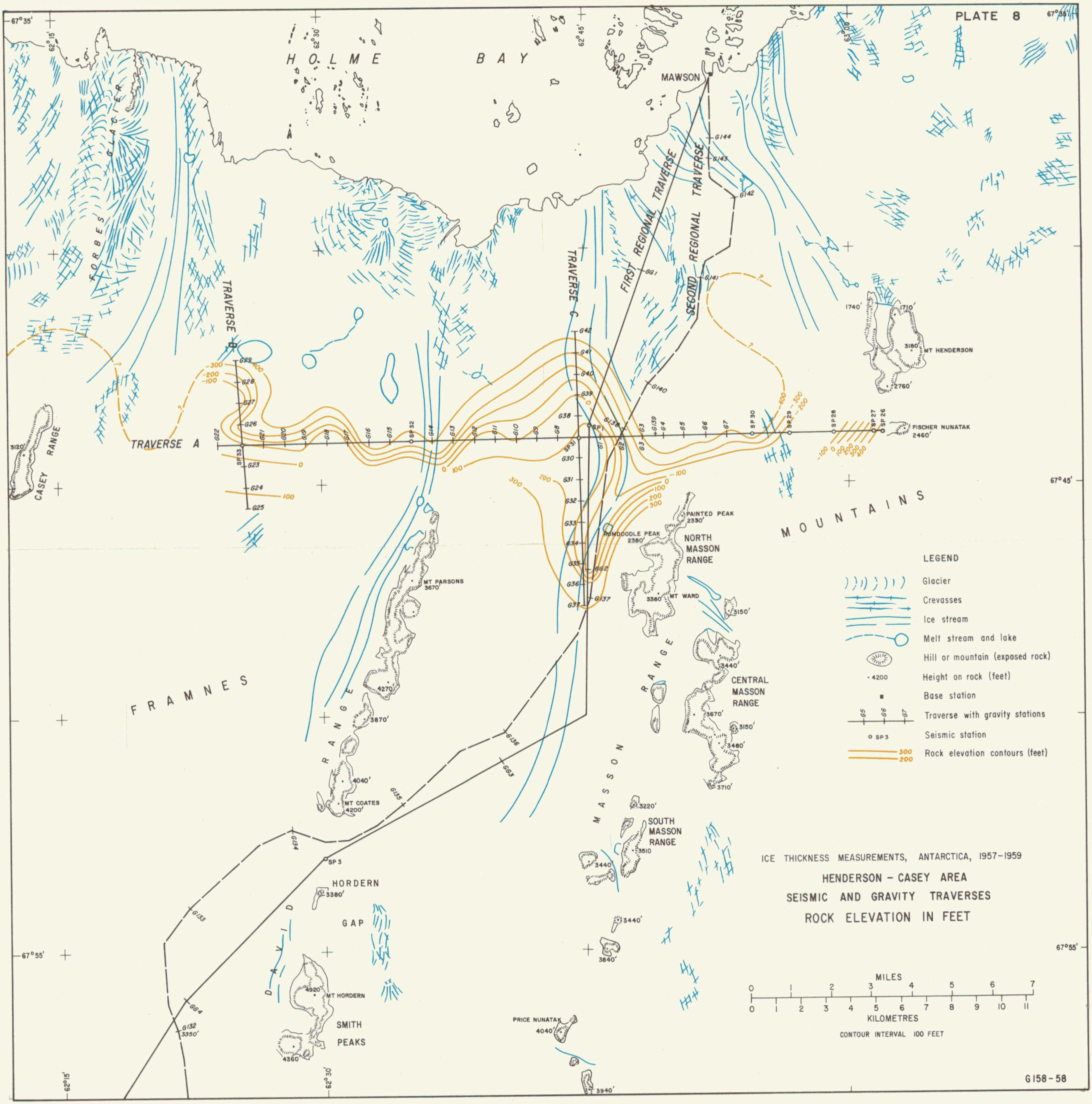


PLATE 7
HOLME BAY
MAWSON
FORBES GLACIER
TRAVERSE A
TRAVERSE B
TRAVERSE C
FIRST REGIONAL TRAVERSE
SECOND REGIONAL TRAVERSE
CASEY RANGE
FRAMNES MOUNTAINS
MT HENDERSON
FISCHER NUNATAK
PAINTED PEAK
RUMDOODLE PEAK
NORTH MASSON RANGE
MT WARD
CENTRAL MASSON RANGE
SOUTH MASSON RANGE
MASSON RANGE
MT PARSONS
MT COATES
DAVID RANGE
HORDERN GAP
MT HORDERN
SMITH PEAKS
PRICE NUNATAK
LEGEND
Glacier
Crevasses
Ice stream
Melt stream and lake
Hill or mountain (exposed rock)
Height on rock (feet)
Base station
Traverse with gravity stations
Seismic station
Ice elevation contours (feet)
ICE THICKNESS MEASUREMENTS, ANTARCTICA, 1957-1959
HENDERSON - CASEY AREA
SEISMIC AND GRAVITY TRAVERSES
ICE ELEVATION IN FEET
MILES
KILOMETRES
CONTOUR INTERVAL AS SHOWN
G158-60



ICE THICKNESS MEASUREMENTS, ANTARCTICA, 1957-1959

HENDERSON - CASEY AREA
SEISMIC AND GRAVITY TRAVERSES
ROCK ELEVATION IN FEET

G158-58

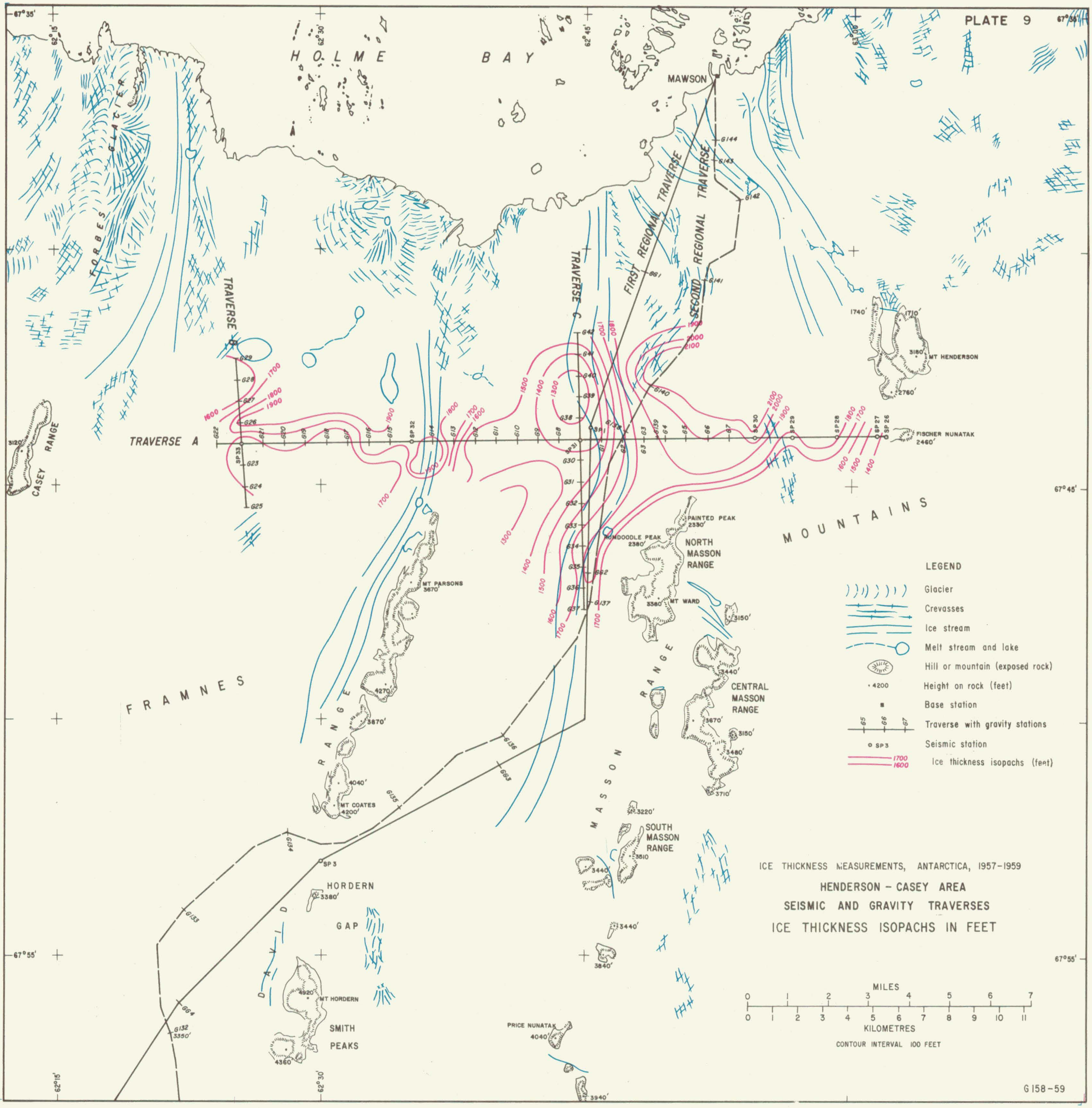


PLATE 9
HOLME BAY
MAWSON
FORBES GLACIER
TRAVERSE A
TRAVERSE B
TRAVERSE C
FIRST REGIONAL TRAVERSE
SECOND REGIONAL TRAVERSE
CASEY RANGE
3120'
MT HENDERSON
3180'
1740'
1710'
2760'
FISCHER NUNATAK
2460'
MOUNTAINS
PAINTED PEAK
2330'
NUNDOODLE PEAK
2380'
NORTH MASSON RANGE
MT WARD
3380'
MT PARSONS
3670'
FRAMNES
RANGE
MASSON RANGE
CENTRAL MASSON RANGE
SOUTH MASSON RANGE
MT COATES
4200'
HORDERN GAP
3380'
DAVID
MT HORDERN
4920
SMITH PEAKS
4360
PRICE NUNATAK
4040'
3940'
3840'
3440'
3220'
3510
G132
3350'
SP 3
67°35'
67°45'
67°55'
62°15'
62°30'
62°45'
63°00'
LEGEND
Glacier
Crevasses
Ice stream
Melt stream and lake
Hill or mountain (exposed rock)
Height on rock (feet)
Base station
Traverse with gravity stations
Seismic station
Ice thickness isopachs (feet)
ICE THICKNESS MEASUREMENTS, ANTARCTICA, 1957–1959
HENDERSON - CASEY AREA
SEISMIC AND GRAVITY TRAVERSES
ICE THICKNESS ISOPACHS IN FEET
MILES
KILOMETRES
CONTOUR INTERVAL 100 FEET
G 158-59

ANTARCTICA

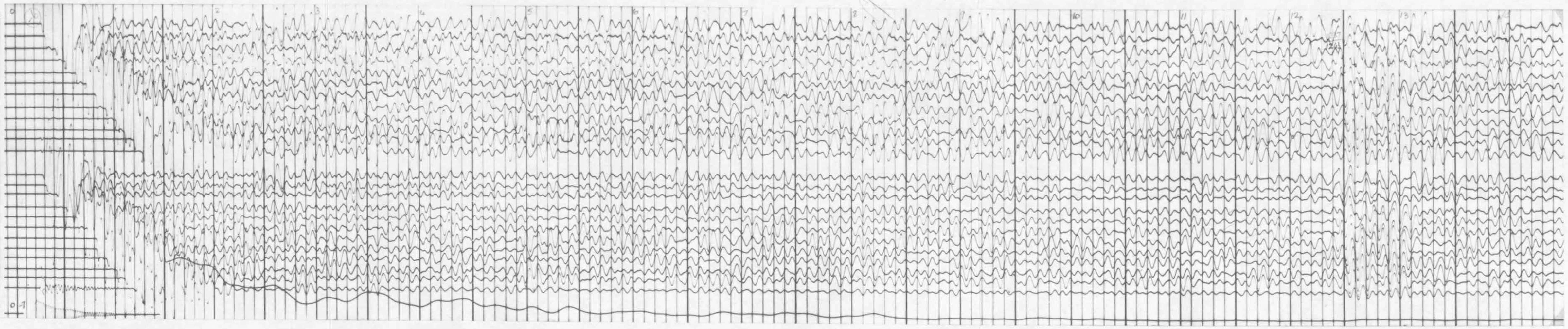
AREA MAWSON DATE 20·11·57
TRAVERSE First Regional
SHOT-POINT 7 SHOT B
DEPTH OF SHOT 90 ft
CHARGE 5 lb
SPREAD L Trace 1 to S, Trace 12 to W
SHOT-POINT OFFSET 600 ft
GEOPHONE SPACING 100 ft
FILTERS L 60 KK 120
GAINS Full A.G.C. Medium
MIXING 12S-12M PRESUPPRESSION 40%
GEOPHONES 20 c/s

REMARKS:

ANTARCTICA

AREA MAWSON DATE 26·12·57
TRAVERSE First Regional
SHOT-POINT 15 SHOT C
DEPTH OF SHOT 125 ft
CHARGE 1 lb
SPREAD R Trace 1 to N, Trace 12 to S
SHOT-POINT OFFSET 100 ft
GEOPHONE SPACING 100 ft
FILTERS K 70 KK 120
GAINS Full A.G.C. Medium
MIXING 12S-12M PRESUPPRESSION 40%
GEOPHONES 20 c/s

REMARKS:



ANTARCTICA

AREA MAWSON DATE 7·1·58
TRAVERSE First Regional
SHOT-POINT 20 SHOT C
DEPTH OF SHOT 92 ft
CHARGE 4 oz
SPREAD L Trace 1 to E, Trace 12 to S
SHOT-POINT OFFSET 600 ft
GEOPHONE SPACING 100 ft
FILTERS K 70 KK 120
GAINS Full A.G.C. Medium
MIXING 12S-12M PRESUPPRESSION 40%
GEOPHONES 20 c/s

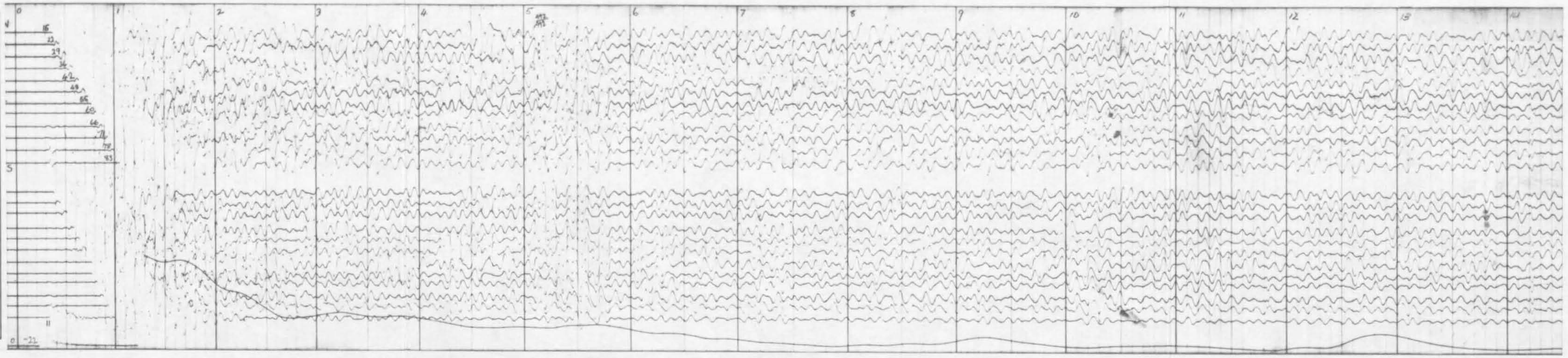
REMARKS:

EXAMPLES OF GOOD REFLECTIONS

ANTARCTICA

AREA MAWSON DATE 15·11·57
TRAVERSE First Regional
SHOT-POINT 4 SHOT E
DEPTH OF SHOT 85 ft
CHARGE 1 lb
SPREAD R Trace 1 to N, Trace 12 to S
SHOT-POINT OFFSET 85 ft
GEOPHONE SPACING 70 ft
FILTERS L 60 KK 120
GAINS Full A.G.C. Medium
MIXING 12S—12M PRESUPPRESSION 40%
GEOPHONES 20 c/s

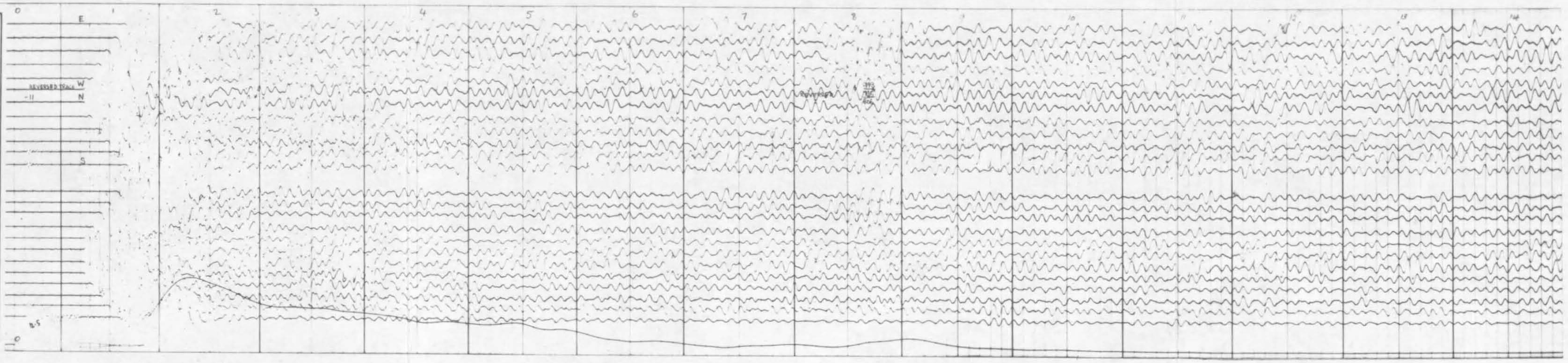
REMARKS:



ANTARCTICA

AREA MAWSON DATE 9·12·57
TRAVERSE First Regional
SHOT-POINT 11 SHOT D
DEPTH OF SHOT 95 ft
CHARGE 1 lb
SPREAD L Trace 1 to E, Trace 12 to S
SHOT-POINT OFFSET 600 ft
GEOPHONE SPACING 100 ft
FILTERS L 60 KK 120
GAINS Full A.G.C. Medium
MIXING 12S—12M PRESUPPRESSION 40%
GEOPHONES 20 c/s

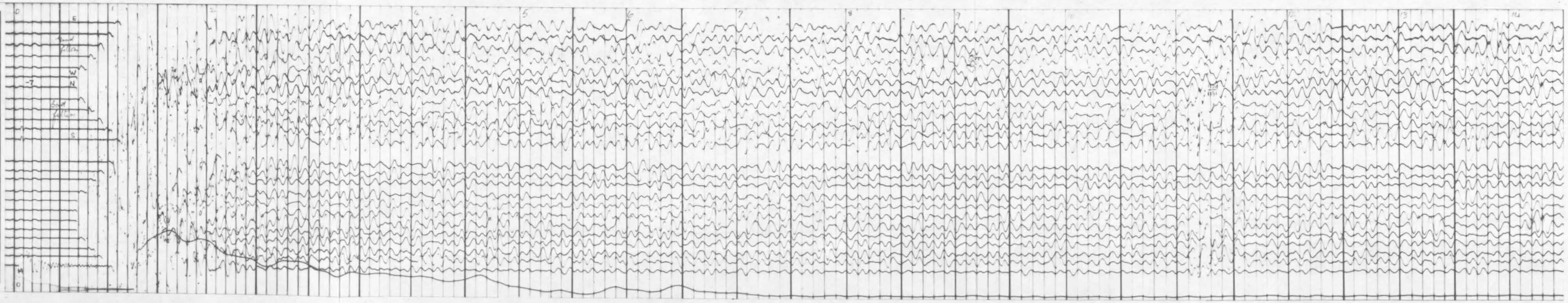
REMARKS:



ANTARCTICA

AREA MAWSON DATE 1·1·58
TRAVERSE First Regional
SHOT-POINT 17 SHOT D
DEPTH OF SHOT 95 ft
CHARGE 1 lb
SPREAD L Trace 1 to E, Trace 12 to S
SHOT-POINT OFFSET 600 ft
GEOPHONE SPACING 100 ft
FILTERS K 70 KK 120
GAINS Full A.G.C. Medium
MIXING 12S—12M PRESUPPRESSION 30%
GEOPHONES 20 c/s

REMARKS:



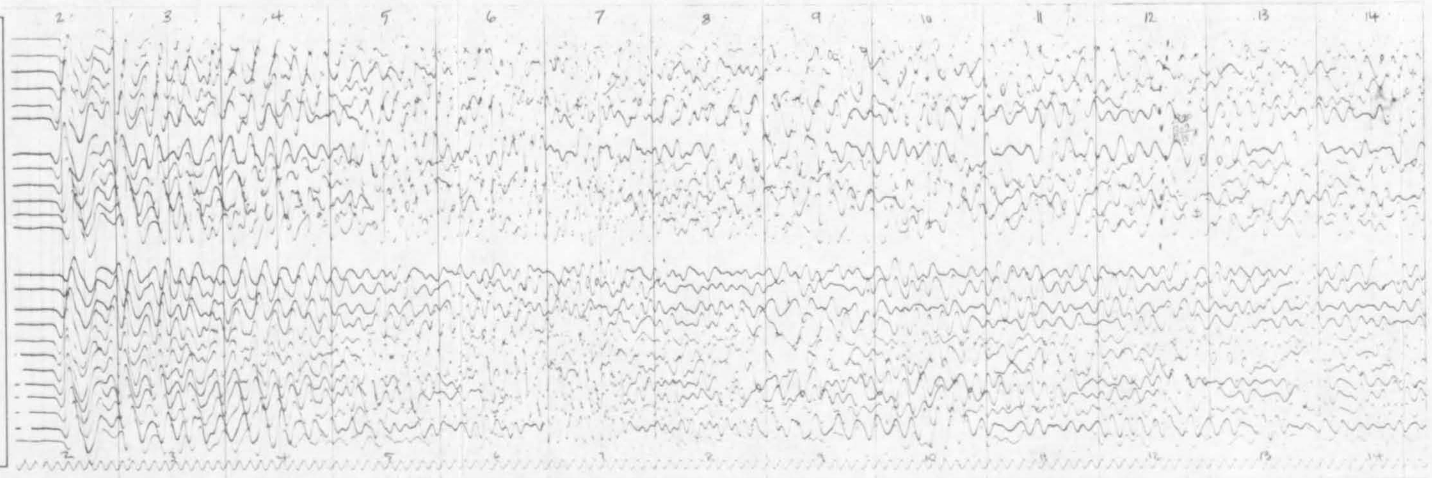
EXAMPLES OF FAIR REFLECTIONS

ANTARCTICA

AREA MAWSON DATE 24 12 58
TRAVERSE Second Regional
SHOT-POINT 36 SHOT 2B
DEPTH OF SHOT Air shot 6 ft above surface
CHARGE 9 x 1 lb
SPREAD S Trace 1 E, Trace 12 W
SHOT-POINT OFFSET 2000 ft N of centre of spread
GEOPHONE SPACING 100 ft, 400 ft between 6 and 7
FILTERS K 70 KK 120
GAINS U.S. - 20 A.G.C. Medium
MIXING 12 S - 12 M PRESUPPRESSION 50 %
GEOPHONES 20 c/s

REMARKS:

Square pattern shot, interval 30 ft



ANTARCTICA

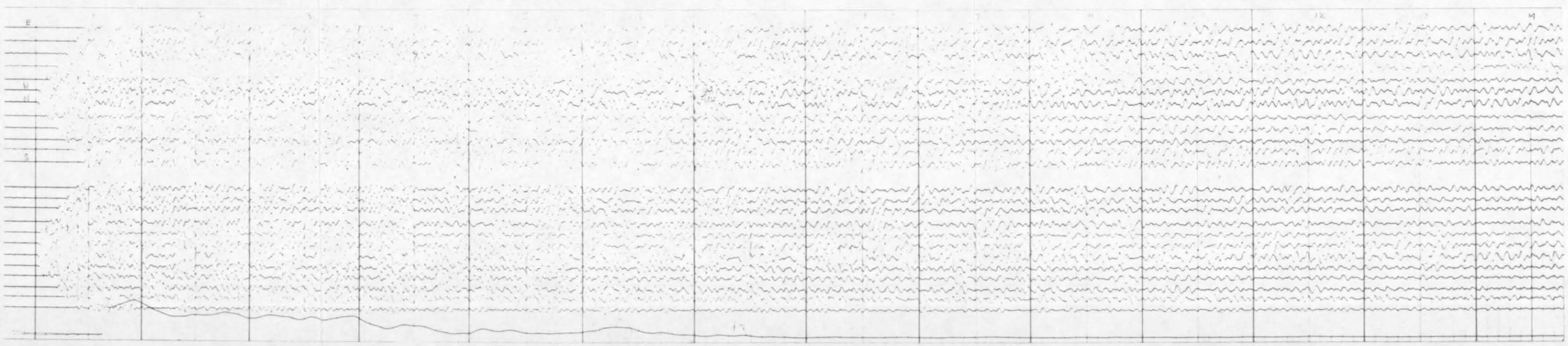
AREA MAWSON DATE 15 12 57
TRAVERSE First Regional
SHOT-POINT 13 SHOT C
DEPTH OF SHOT 100 ft
CHARGE 1 lb
SPREAD L Trace 1 to E, Trace 12 to S
SHOT-POINT OFFSET 600 ft
GEOPHONE SPACING 100 ft
FILTERS KK 70 K 120
GAINS U.S. - 10 A.G.C. Medium
MIXING 12 S - 12 M PRESUPPRESSION 40%
GEOPHONES 20 c/s

REMARKS:

ANTARCTICA

AREA MAWSON DATE 12 12 57
TRAVERSE First Regional
SHOT-POINT 12 SHOT A
DEPTH OF SHOT 87 ft
CHARGE 4 oz
SPREAD L Trace 1 to E, Trace 12 to S
SHOT-POINT OFFSET 600 ft
GEOPHONE SPACING 100 ft
FILTERS KK 90 KK 215
GAINS Full A.G.C. High
MIXING 12 S - 12 M PRESUPPRESSION 40%
GEOPHONES 20 c/s

REMARKS:



EXAMPLES OF POOR REFLECTIONS