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AUSTRALIAN ICE THICKNESS MEASUREMENTS IN ANTARCTICA BY SEISMIC AND GRAVITY METHODS 1957-59

by

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PLATES.

ABSTRACT.

Ice thickness measurements carried out by field parties based on Mawson during 1957-59 consisted of:-

(i) regional traverses in the form of closed loops extending several hundred kilometres inland from Mawson;

(ii) semi-detailed traverses in the vicinity of a line of ice flow stakes about 25 Km. from Mawson.

The regional traverses showed that, beyond about 175 Km. inland, the area surveyed is influenced strongly by the Lambert Glacier - Amery Ice Shelf system situated some 200 Km. to the East. Preliminary contour plans of the ice and rock surfaces show fairly close correspondence. A sub-glacial extension of a range of mountains outcropping through the ice 80 Km. to the East of the traverses was found.

Work along the semi-detailed traverses close to Mawson detected sub-glacial extensions of the outcropping mountain ranges in the area. These extensions may explain the general direction of the coastline near Mawson.

1. INTRODUCTION.

During the period of the International Geophysical Year, 1957-58, the Australian National Antarctic Research Expeditions (A.N.A.R.E.) carried out a programme of ice thickness measurements on the Antarctic ice cap. Field parties for this work were based at Mawson station. One geophysicist of the Commonwealth Bureau of Mineral Resources was attached to A.N.A.R.E. during each of the two years covered by the I.G.Y. for the purpose of making these and other measurements.

The work carried out falls under three headings:-

(i) Regional traverse, 1957-58 field season;

(ii) Regional traverse, 1958-59 field season;

(iii) Semi-detailed traverses near Mawson.

2. REGIONAL TRAVERSE, 1957-58.

A preliminary report on the work carried out during the field season 1957-58 was presented at the Moscow meeting of C.S.A.G.I. in August, 1958. Reduction of the results has since been extended and includes additional altitude data obtained during the second Regional Traverse, 1958-59.

The traverse carried out was planned as a single line running due South along meridian 62°E for as great a distance as could be attained, so as to form the basis of closed loops to be surveyed later in selected areas of particular interest found during the traverse. Southerly progress was blocked by heavy crevassing at a distance of 576 Km. from Mawson and the party headed South-West from this point in the hope of clearing the outcropping nunataks and the crevassing associated with them, but was forced by impassable surfaces to turn back when a total distance of 642 Km. from Mawson had been covered. After another short run of 18 Km. from S.P.21 to S.P.23, the party returned to Mawson along the original route. Surplus fuel and explosives were left as a depot at a point 380 Km. from Mawson. The traverse is shown on Plate 2. This survey occupied a total of 100 days.

The techniques used may be summarised thus:-

(i) Seismic reflection stations were established at 32 Km. (20 mile) intervals in general, with stations closer together in areas where the rock surface level appeared to be changing rapidly;

(ii) Explosive charges averaging 450 gm. T.N.T. were detonated at the bottom of holes averaging 30 metres deep. These holes were drilled with a hydraulic flight auger;

(iii) 12-channel, wide-pass-band seismic recording equipment was used, transported in a thermally-insulated, electrically heated cab;

(iv) Small scale refraction methods were used at most reflection stations to determine the near-surface velocity distribution. Full scale refraction methods (unreversed) were used at two locations to measure wave velocities at depth in the ice;

(v) Altitudes were measured barometrically at each of the seismic stations and at points generally 8 Km. (5 miles) apart between them;

(vi) Gravity measurements were made at each point where an altitude measurement was made, using a Worden Geodetic gravity meter.

3. REGIONAL TRAVERSE 1958-59.

The plan for the second regional traverse was to proceed as rapidly as possible to the depot established during the first survey and from there to run traverses in the form of loops approximately 160 Km. square to the East and West. 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 contours 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.

Soon after leaving Mawson the party ran into difficulties with a belt of crevasses which led to a delay of 16 days while tractors were recovered from crevasses and repairs made to equipment. At the same time, the ice drill was so seriously damaged that only two further holes could be drilled after this incident. For the remainder of the seismic work air shooting techniques were used. During travel to the 380 Km. depot more fuel was consumed than had been anticipated and this fact, together with the loss of time experienced, led to the abandonment of the loop to the East.

Measurements commenced when the party set off West from the depot, and, as had been expected, altitude in this direction was found to increase rapidly. After only 18 Km. had been covered the tractors, which were losing power due to the increase in altitude, became bogged down in soft snow. The party then turned North for 43 Km. when a slightly improved surface was found and the party again turned West. After a further 26 Km. progress the party turned North and ran parallel to the original traverse for 163 Km. and some 50 Km. West of it. Course was then altered to intersect the first traverse at a point 240 Km. North of the depot camp. The return to Mawson was made along a different route from that followed by the first party, producing two further small loops.

During this second survey, air shooting was used at each seismic reflection station except the first two, where the drill could still be used. For air shooting a square pattern of nine charges with 9 metres (30 feet) separation was used.

The charges were each 450 gm. T.N.T., suspended on bamboo poles 1.5 to 1.8 metres above the surface. A single linear spread of 12 geophones was used with 30.5 metres (100 feet) separation between them, and the pattern of charges was generally offset 610 metres (2000 feet) from the centre of the spread. Results from this method of air shooting were reasonably good, but generally inferior to those from shot holes.

Apart from the enforced use of air shooting, the equipment and techniques used in the seismic work were the same as had been used during the 1957-58 field season. No refraction measurements were made.

Gravity measurements were made in the same way as previously but the interval between gravity stations was reduced from 8 Km. to 4.8 Km. (3 miles). Differential altitude measurements were also made at 4.8 Km. intervals, using Fuess aneroid barometers.

The traverse carried out is shown on Plate 2, together with the 1957-58 traverse. The 1958-59 survey occupied a total of 110 days.

4. SEMI-DETAILED TRAVERSES NEAR MAWSON:

This project was carried out during the Autumn of 1958. Referring to Plate 5, it will be seen that some 25 Km. inland from Mawson the Framnes Mountains outcrop through the ice. There are four principle ranges, the Henderson, Masson, David and Casey Ranges, and, as they appear above the ice, they appear to be aligned roughly parallel to the presumed Northerly direction of ice flow.

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). Flow rate measurements are continuing.

To establish the sub-glacial rock profile across the line of stakes and to study its relation to the surface rate of flow, a seismic and gravimetric traverse was run along this line, supplemented by gravity measurements along two of the valleys, approximately perpendicular to the main traverse.

Shot holes were used for the seismic work on these traverses. Explosive charges ranging from 100 gm. to 450 gm. were shot at depths between 10m and 30m. Split linear geophone spreads were used in most cases, with the interval between geophones 17 metres and an offset of 61 metres from the shot hole to the nearest geophone on each side. Considerable interference from surface noise was experienced.

Levelling of seismic stations was carried out by theodolite, by observations of mountain peaks of known position and height. Gravity stations were levelled by the differential barometric method using the seismic stations as control points.

5. RESULTS FROM THE REGIONAL TRAVERSES.

Considerably more altitude information was obtained by the second field party to supplement and improve the results previously given for the first traverse. In particular, during a six day halt at the depot camp for maintenance and repairs on the transport equipment, detailed records were made of atmospheric pressure variations. These were found to correlate well with records kept at Mawson over the same period and these results, together with differential levelling carried out during the traverses, have been used to derive a revised value for the altitude of the depot camp. Other altitudes have been adjusted to fit this value and to eliminate misclosures around the loops.

The altitude results are presented in the form of a "Preliminary Ice Surface Contour Map" which is reproduced as Plate 3. In mapping the contours, altitude values obtained during journeys to the Prince Charles Mountains in earlier years were also used.

It will be seen that, close to the coast, the direction of greatest surface slope is to the North. Proceeding inland, the contours swing round as the direction of greatest slope acquires a progressively greater Easterly component. At a distance of 300 Km. from the coast the slope is to the East. The swing round towards the South continues approximately another 170 Km. At this distance the direction of greatest slope is approximately South-South-West. Towards the most Southerly point reached the contours indicate the direction of slope as approximately East-North-East. The highest part of the area covered is at Latitude 70°07' South, Longitude 60°50' East, 295 Km. from the coast and approximately 250 Km. West of the edge of the Amery Ice Shelf. The altitude here was 2570 metres and was increasing to the West.

These results show that the depression of the ice surface associated with the Lambert Glacier-Amery Ice Shelf system extends for at least 250 Km. and probably much more, to the West of the system.

The results of the ice thickness measurements made during the regional traverses are tabulated in Table 1. Reflection times have been corrected for delays due to low velocity layers near the surface. The velocities used are those derived from the refraction measurements viz.:-

SP4 - 3810 metres/sec.
SP5 - 3825 "
SP6 - 3840 "
SP7 and all points to the South - 3860 metres/sec.

Depths derived from gravity measurements were determined using measured Bouguer anomalies to interpolate between pairs of seismic reflection stations and still are subject to minor correction on revision.

Using values for the altitude of the rock surface under the ice, obtained from the ice thickness and altitude results, a "preliminary Rock surface contour map" has been drawn (plate 4). The rock surface is considerably more irregular than the ice surface and the contours as drawn through the observed points can do no more than show the broad trends.

The most prominent feature of this contour map is the submerged range at SP12. Unfortunately reflection quality here was poor (as might be expected from the convex surface presented by a rock altitude maximum) and some doubt exists as to the exact height of the rock surface here. However, if the seismic result from this station is ignored and gravity interpolation only is used between SP11 and SP13 a somewhat lower rock "high" still results. This almost certainly represents a sub-glacial extension of the spur of the Prince Charles Mountains which appears through the ice 80 Km. to the East at the "Riddell Nunataks", which have a maximum altitude of about 2300 metres.

It will be noted that over considerable areas of the map the rock surface appears below sea level; there is a tendency for the areas below sea level to occur predominantly on the Western side of the area traversed, but nevertheless it seems likely that to the East, in the area of the Lambert Glacier, most of the surface would fall below sea level to produce the "sink" into which the ice flows to form the Glacier. It is unfortunate that no measurements could be obtained in this area.

It will be noted that some of the trends exhibited by the ice surface contours appear to follow trends in the rock surface contours, although the rock surface contours are considerably more irregular. Both sets of contours run generally East-West near the coast. The ice surface contours commence to swing round towards a North-West to South-East direction some 90 Km. inland, at which point the rock surface is very irregular, with some areas more than 500 metres below sea level. A very prominent belt of ice domes and depressions running East-West was crossed here. Between this region and SP12, a distance of about 175 Km., both sets of contours have a pronounced North-West to South-East trend. South of SP12, as far as the depot camp at 380 Km. there appears to be little correlation between the rock and ice surface contours. Further South still, the information is too sketchy to attempt any comparison.

The general picture which emerges is that ice flow from the South is largely diverted to the West by the range of nunataks of which Mt. Menzies is the most prominent peak. To the North of this region the ice acquires an Easterly component of flow towards the Lambert Glacier system and tends to flow North-East, but further damming of ice flow occurs at the submerged range crossed near SP12 and part of the ice is diverted towards the South-East. North of this submerged range ice flow is broadly at right angles to the rock surface contours.

6. RESULTS FROM THE SEMI-DETAILED TRAVERSES:

The results are presented as profiles in Plate 6. Two rock valleys are indicated on the profile of Traverse A, one centred at Station SP32 the other at Station G6. These valleys reach a depth of 90 metres below sea level, and are separated by ridges rising some 60 metres above sea level. This relief is very gentle in comparison with the ranges appearing through the ice (which reach an altitude of over 1000 metres), but comparison with the station location diagram (plate 5) shows that the ridges and valleys do not occur where they would be expected to if the alignments of the ranges were produced on to traverse A. For example, the centre of the Easterly rock valley is due North of the tip of the David Range. It appears that the trends are in a roughly North East direction, so that for example the Southerly portion of the Masson Range and Mt. Henderson are connected by a sub-glacial ridge. A similar trend is seen in the islands lying close to the coast near Mawson, in the ice coastline itself and in the ice surface contours in the area between Mt. Henderson and Mawson. Thus it appears likely that ice flow in the region of the flow stake line is predominantly to the North-West and not approximately at right angles to the stake line as the mountain alignments would suggest. Flow rate measurements are presented in a paper by I. McLeod.

7. REFERENCES:

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TABLE I.

REGIONAL TRAVERSES. ICE THICKNESS MEASUREMENTS.

Station.	Latitude °S.	Longitude °E.	Ice Thickness Metres.	Method.
SP3	67°58'.0	62°30'.0	528	Seismic.
GG4	67°56'	62°22'	625	Gravity.
GG5	68°00'	62°18'	739	〃
GG6	68°03'	62°11'	1269	〃
SP4	68°06'.7	62°07'.0	943	Seismic.
GG7	68°10'	62°08'	1109	Gravity.
GG8	68°14'	62°09'	1005	〃
GG9	68°18'	62°09'	1476	〃
GG10	68°21'	62°09'	[illegible]	〃
SP5	68°24'.7	62°09'.7	1607	Seismic.
GG11	68°28'	62°08'	1409	Gravity.
SP6	68°32'.7	62°06'.3	1668	Seismic.
GG12	68°37'	62°07'	1516	Gravity.
SP7	68°41'.3	62°08'.0	2403	Seismic.
GG13	68°44'	62°07'	2181	Gravity.
GG14	68°48'	62°07'	2055	〃
GG15	68°52'	62°06'	1799	〃
GG16	68°55'	62°05'	1633	〃
SP8	68°59'.1	62°04'.6	1607	Seismic.
GG17	69°03'	62°06'	1905	Gravity.
GG18	69°08'	62°08'	1648	〃
SP9	69°16'.3	62°10'.2	1387	Seismic.
SP10	69°20'.8	62°10'.8	1284	〃
GG19	69°25'	62°10'	1450	Gravity.
GG20	69°29'	62°10'	1190	〃
GG21	69°33'	62°10'	1202	〃
SP11	69°37'.5	62°09'.8	1555	Seismic.
GG22	69°42'	62°08'	1398	Gravity.
GG23	69°46'	62°06'	974	〃
GG24	69°51'	62°05'	362	〃
SP12	69°55'	62°02'.9	256	Seismic.
GG25	70°00'	62°05'	752	Gravity.
GG26	70°04'	62°07'	779	〃
SP13	70°13'4	62°08'6	2237	Seismic.
GG27	70°18'	62°09'	2259	Gravity.
GG28	70°22'	62°09'	2460	〃
GG29	70°27'	62°09'	2425	〃
SP14	70°31'	62°09'.2	2655	Seismic.
[illegible]	70°36'	62°09'	2151	Gravity.
GG31	70°40'	62°09'	1614	〃
GG32	70°45'	62°08'	1942	〃
SP25	70°49'.6	62°08'.0	2244	Seismic.
GG33	70°54'	62°08'	2295	Gravity.
GG34	70°59'	62°08'	2164	〃
GG35	71°03'	62°07'	2372	〃
SP15	71°08'.1	62°06'.9	2401	Seismic.
GG36	71°12'	62°07'	2400	Gravity.
GG37	71°17'	62°07'	2145	〃
SP16	71°21'.6	62°07'.0	2095	Seismic.
GG38	71°26'	62°07'	2063	Gravity.
GG39	71°30'	62°07'	2091	〃
GG40	71°34'	62°07'.2	1916	〃
GG41	71°38'	62°07'.3	2134	〃
GG42	71°42'	62°07'.4	2184	〃

Station.	Latitude °S.	Longitude °E.	Ice Thickness Metres.	Method
SP17	71°45'.8	62°07'.5	2190	Seismic
GG43	71°50'	62°07'.5	1926	Gravity
GG44	71°55'	62°07'.6	2237	"
SP24	71°59'.2	62°07'.6	2495	Seismic
GG45	72°04'	62°08'	2441	Gravity
GG46	72°08'	62°08'	2275	"
SP18	72°12'.6	62°07'.8	2045	Seismic
GG47	72°17'	62°08'	1935	Gravity
SP19	72°21'.6	62°07'.8	1983	Seismic
GG48	72°26'	62°08'	1417	Gravity
GG49	72°31'	62°08'	1798	"
SP20	72°35'.6	62°08'.3	1757	Seismic
GG50	72°37'	61°54'	1099	Gravity
GG51	72°39'	61°40'	1007	"
GG52	72°40'	61°26'	1477	"
SP21	72°41'.8	61°12'.2	1991	Seismic
GG53	72°44'	61°01'	1870	Gravity
GG54	72°47'	60°49'	2137	"
GG55	72°49'	60°38'	1834	"
SP22	72°52'.0	60°26'.0	1475	"
GG56	72°48'	61°17'	1899	"
SP23	72°51'.1	61°21'.0	1297	Seismic
G43	70°50'	61°55'	2436	Gravity
G44	70°50'	61°43'	2699	"
SP34	70°49.7'	61°38.3'	2732	Seismic
G48	70°50'	61°35'	2778	Gravity
G49	70°47'	61°34'	2565	"
G50	70°44'	61°34'	2414	"
G51	70°42'	61°34'	2322	"
G53	70°41'	61°34'	2287	"
SP35	70°39.2'	61°33.6'	2267	Seismic
G54	70°37'	61°34'	2315	Gravity
G55	70°34'	61°34'	2468	"
G56	70°32'	61°34'	2535	"
G57	70°29'	61°34'	2423	"
G58	70°26'	61°35'	2321	"
G59	70°26'	61°27'	2395	"
G60	70°26'	61°20'	2512	"
G61	70°26'	61°12'	2557	"
G62	70°26'	61°05'	2514	"
G63	70°26'	60°58'	2527	"
SP36	70°26'.5	60°50'.3	2572	Seismic
G64	70°24'	60°50'	2694	Gravity
G65	70°21'	60°50'	2712	"
G66	70°19'	60°50'	2718	"
G67	70°16'	60°50'	2775	"
G68	70°14'	60°50'	2793	"
G69	70°11'	60°50'	2759	"
G70	70°08'	60°50'	2721	"
G71	70°06'	60°50'	2539	"
G72	70°03'	60°50'	2196	"
G73	70°01'	60°50'	2135	"
G74	69°58'	60°50'	2240	"
SP37	69°55'.5	60°50'.3	2323	Seismic
G76	69°53'	60°50'	2365	Gravity
G77	69°50'	60°50'	2062	"
G78	69°48'	60°50'	1966	"
G79	69°45'	60°50'	2063	"
G80	69°42'	60°50'	2133	"
G81	69°40'	60°50'	2213	"

Station	Latitude	Longitude	Ice Thickness Metres.	Method
G82	69°37'	60°50'	2253	Gravity
G83	69°35'	60°50'	1860	"
G84	69°32'	60°50'	1941	"
G85	69°30'	60°50'	1988	"
G86	69°27'	60°50'	1994	"
G87	69°24'	60°50'	1572	"
G88	69°22'	60°50'	1592	"
G89	69°19'	60°50'	1679	"
SP38	69°16'.7	60°50'.3	1463	Seismic
G91	69°14'	60°50'	1769	Gravity
G92	69°12'	60°50'	1878	"
G93	69°09'	60°50'	1718	"
G94	69°06'	60°50'	1296	"
G95	69°04'	60°50'	1186	"
G96	69°01'	60°50'	1441	"
SP39	68°58'.6	60°50'.3	1591	Seismic
G98	68°57'	60°56'	1632	Gravity
G99	68°56'	61°02'	1955	"
G100	68°54'	61°08'	1902	"
G101	68°53'	61°14'	1909	"
G102	68°52'	61°20'	1888	"
G103	68°50'	61°26'	1916	"
G104	68°49'	61°32'	2003	"
G105	68°47'	61°38'	2179	"
G106	68°46'	61°44'	2179	"
G107	68°44'	61°50'	2253	"
G108	68°43'	61°56'	2273	"
G109	68°42'	62°02'	2171	"
G110	68°40'	62°08'	2265	"
G111	68°41'	62°15'	2405	"
G112	68°38'	62°15'	2204	"
G113	68°36'	62°14'	1919	"
G114	68°33'	62°14'	1769	"
G115	68°30'	62°13'	1486	"
G116	68°28'	62°12'	1425	"
G117	68°26'	62°11'	1575	"
G118	68°23'	62°16'	1624	"
G119	68°22'	62°22'	1191	"
G120	68°21'	62°28'	1168	"
G121	68°20'	62°34'	1351	"
G122	68°18'	62°40'	1109	"
G123	68°17'.1	62°46'.4	1118	"
SP40	68°14'.5	62°42'.5	1098	Seismic
G124	68°12'	62°39'	985	Gravity
G125	68°10'	62°36'	1019	"
G126	68°08'	62°33'	898	"
G127	68°06'	62°30'	793	"
G129	68°04'.2	62°27'.3	824	"
G130	68°02'	62°26'	886	"
G131	67°59'	62°24'	897	"
G132	67°56'	62°22'	873	"
G133	67°53'.6	62°20'.3	741	"

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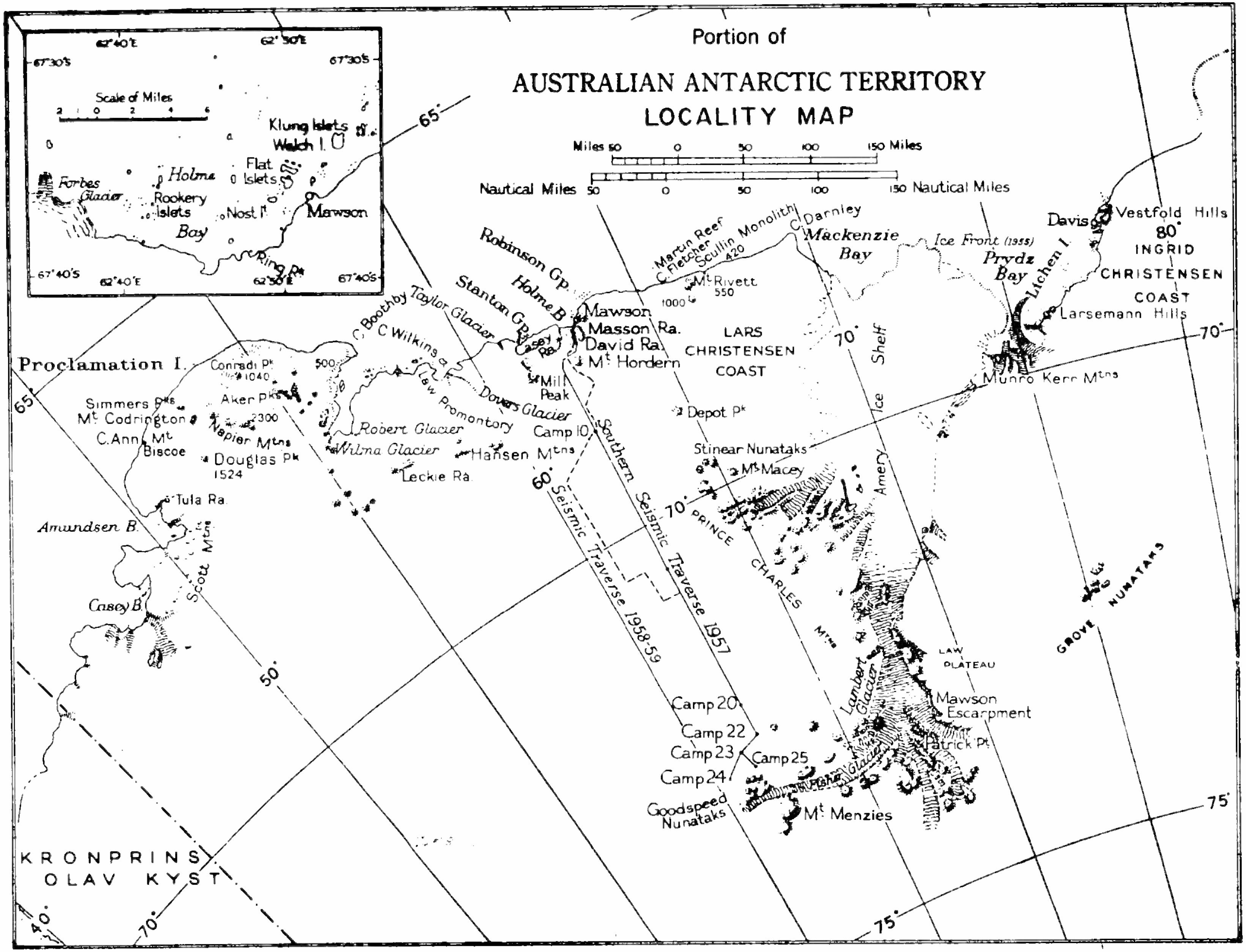
PLATE I



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ICE THICKNESS MEASUREMENTS, ANTARCTICA, 1958-59

SEISMIC AND GRAVITY TRAVERSES

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G 158-28

PLATE 2

PLATE 3

SEISMIC AND GRAVIMETRIC TRAVERSE 1957-59

PRELIMINARY ICE SURFACE CONTOURS

PLATE 3

G 158-34

PLATE 4

SEISMIC AND GRAVIMETRIC TRAVERSE 1957-59

PRELIMINARY ROCK SURFACE CONTOURS

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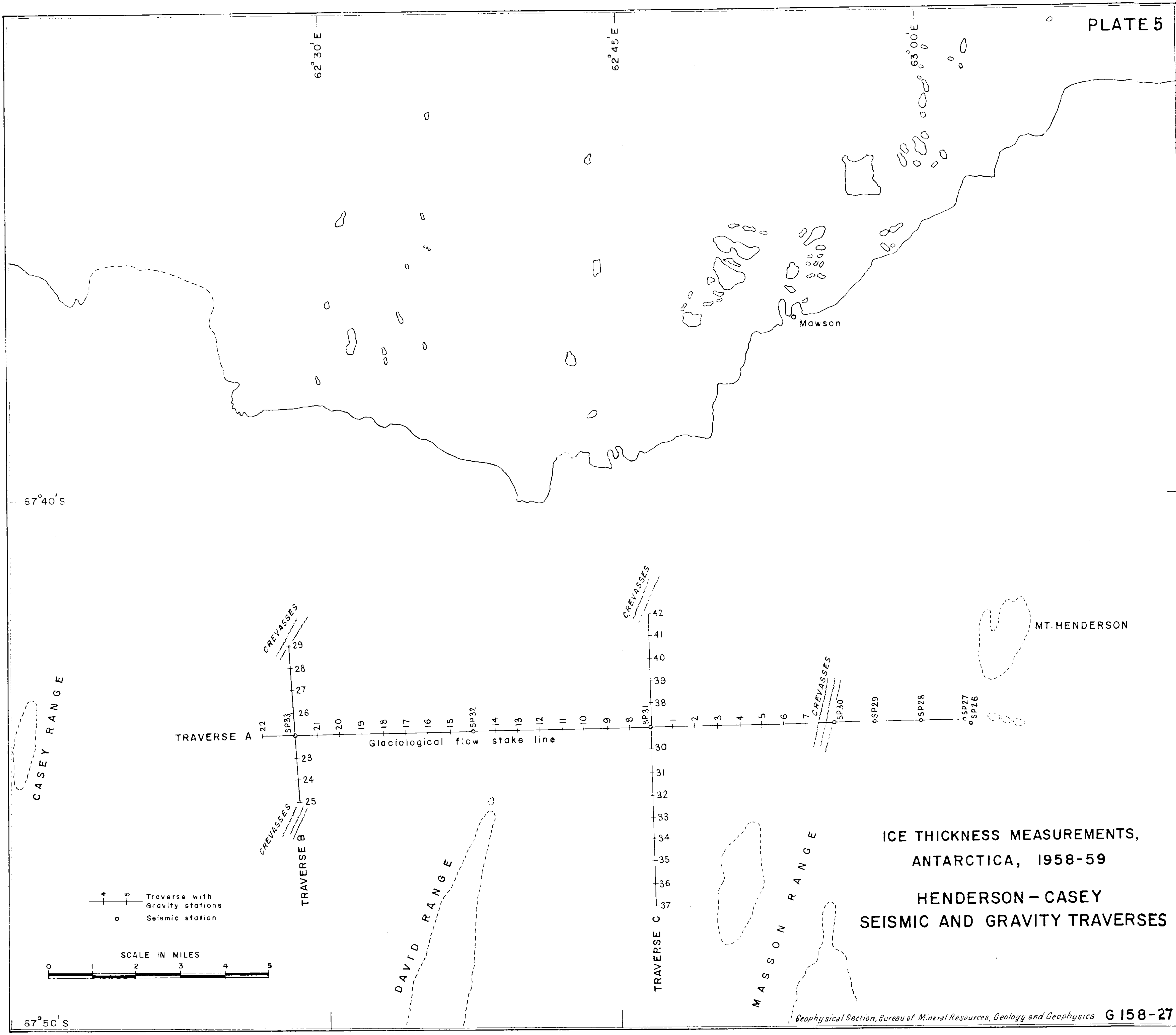

ICE THICKNESS MEASUREMENTS, ANTARCTICA, 1958-59

HENDERSON – CASEY SEISMIC AND GRAVITY TRAVERSES

Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics G 158-27

To Accompany Records 1959, No 74