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by
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GLACIOLOGICAL OBSERVATIONS IN ENDERBY, KEMP, AND MAC.ROBERTSON LANDS, ANTARCTICA

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ABSTRACT

Glaciological observations made by geologists of the Australian National Antarctic Research Expeditions (ANARE) based at Mawson in 1958, 1959, and 1961 are described.

The main drainage unit in the sector 45°E to 80°E is Lambert Glacier; smaller important drainage basins are those of Robert and Wilma Glaciers, Beaver Glacier, and Thyer and Rayner Glaciers.

Reference is made to measurements of rate and volume of ice movement near Mawson, which are reported elsewhere.

The surface of the ice sheet in the ablation zone is predominantly bare ice, partly covered by névé in winter; remnants of this névé persist throughout the summer, and are converted into ice by partial melting of the snow crystals. Comparison of ablation measurements made in 1958 and 1959 with those made in earlier years shows that ablation rates during the autumn and winter were comparable in all years (about 0·07 cm per day). The rate increased markedly during December each year (to a maximum of over 1 cm per day in late December 1955 and early January 1956) except in 1958, when the rate increased only slightly, presumably because of the greatly decreased amount of sunshine in December 1958 and January 1959. Ablation rates during spring and early summer of 1958 at McLeod Nunataks and Leckie Range were 0·16 cm per day and 0·12 cm per day respectively, and at Beaver Lake, 0·26 cm per day. Some features of the accumulation zone are briefly described, and an account is given of localized ablation areas adjoining rock outcrops in the accumulation zone.

Snow and ice features, and topography of the ice sheet along two inland traverses are described, the traverses being from Amundsen Bay to Mawson, and Mawson to the southern Prince Charles Mountains and return. Ice flow distribution in the southern Prince Charles Mountains is also described. The flow is complex, with ice streams diverging from, as well as joining, the main stream, the Fisher Glacier.

Detailed observations on sea ice formation in 1958 and 1959, and break-out the following summers, are recounted. Unusual conditions, including a reversal of the normal deterioration, in January 1959 were probably the result of the unusually low amount of sunshine that summer. Sea ice conditions between Mawson and Edward VIII Gulf in August, September, and October 1961, and the distribution of pressure ice in Edward VIII Gulf at that time, are described. Regular measurements of sea ice thickness showed that the ice at Mawson reached maximum thicknesses of 168 cm in October 1958 and 160 cm in October 1959. At Davis, the maximum thickness in 1958 was 175 cm in late October.

I. INTRODUCTION

Mawson, the Australian National Antarctic Research Expeditions (ANARE) scientific station at 67°36′S, 62°52′E, was established in 1954. Since then, members of the expeditions have made measurements and observations on various aspects of glaciology. The author of this report was seconded to ANARE from the Bureau of Mineral Resources, Geology and Geophysics, of the Department of National Development, as geologist in the 1958 Mawson expedition. This party did not include a glaciologist, but, to maintain continuity of measurements, the author undertook a limited amount of glaciological work, mainly measurement of ablation and sea ice thickness in the vicinity of Mawson. When the opportunity offered, glaciological observations were also made during geological field work.

The report also includes observations by other members of the 1958 expeditions, notably measurements of sea ice thickness at Davis made by P. B. Turner. B. H. Stinear, of the Bureau of Mineral Resources, geologist in the 1959 Mawson expedition, continued measurements of ablation and sea ice thickness at Mawson, and kept note of the changes in sea ice conditions during formation and break-up. His observations are incorporated in this report. Observations by D. S. Trail, Bureau of Mineral Resources, geologist of the 1961 Mawson expedition, on the surface features of the ice-sheet between Mawson and the southern Prince Charles Mountains (650 kilometres south of Mawson, Fig. 1), and on sea ice conditions along the coast west of Mawson in late winter and spring, are also included.

As was the practice in previous years, all the measurements made during 1958 were in inches, mostly to the nearest quarter of an inch. Accordingly, all the tabulated measurements given in the report are in inches; where it is desirable for comparative purposes that the metric equivalent be given, this has been done.

II. PREVIOUS WORK

Glaciological observations were commenced by the ANARE party which established Mawson in 1954 (Stinear 1956; Loewe 1956). P. W. Crohn, geologist with the 1955 and 1956 Mawson expeditions, continued glaciological observations as opportunity allowed (Crohn 1959). His work included measurements of ablation, accumulation, ice movement, density, and temperature on the ice sheet, and measurements of sea ice thickness, and he also recorded many qualitative observations on the characteristics of the ice sheet and sea ice.

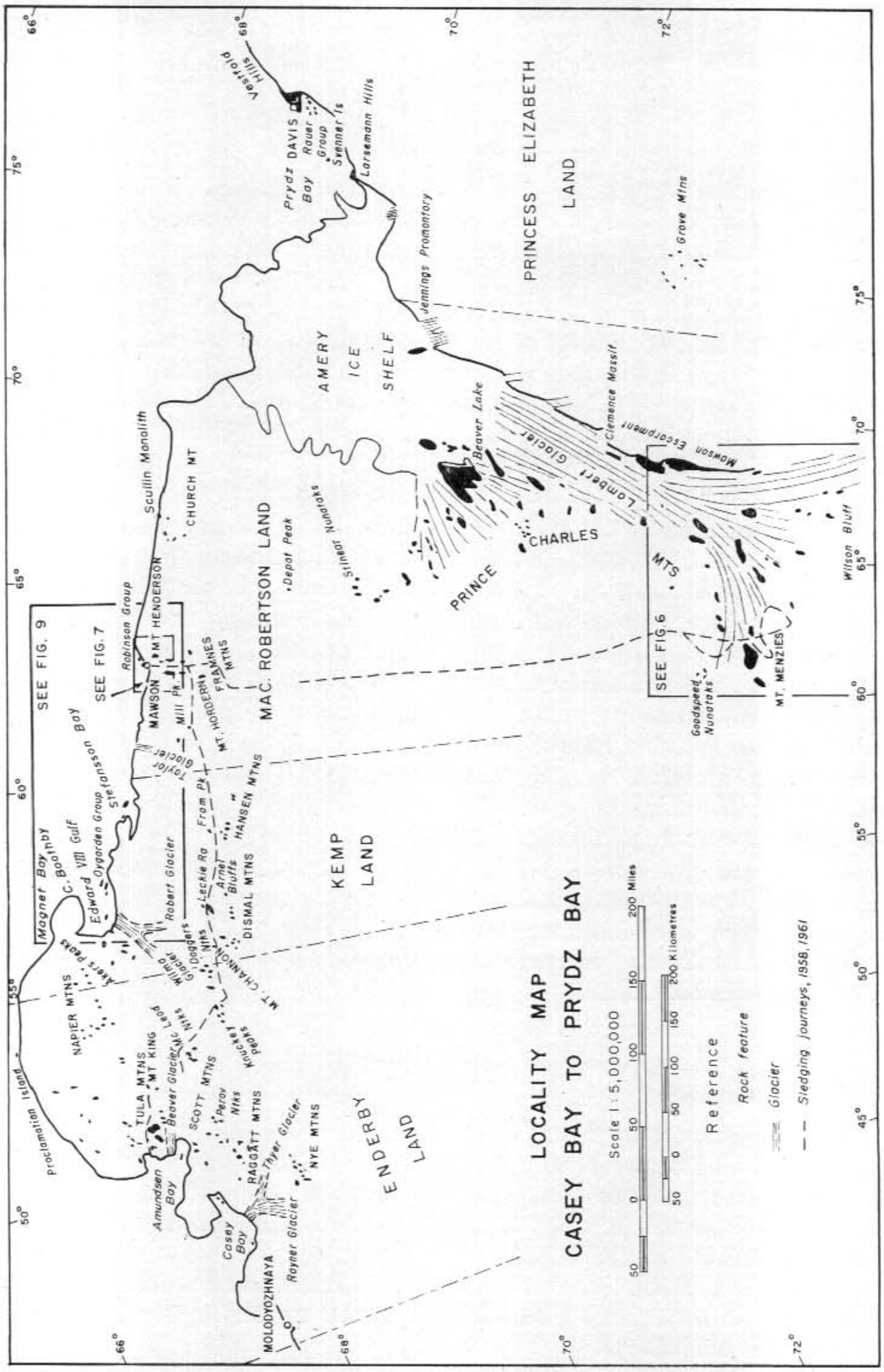

FIG. 1. Locality map, Casey Bay to Prydz Bay.

The 1957 Mawson expedition was the first to include a glaciologist, who enlarged on the previous work, as well as initiating new series of observations (Mellor 1958; 1959; 1960a; 1960b). In 1957, too, the thickness of the ice sheet south of Mawson was measured by seismic methods and this work was continued in 1958 (Goodspeed and Jesson 1959).

III. ICE SHEET DRAINAGE

Drainage of Enderby, Mac.Robertson and Kemp Lands is dominated by the vast Lambert Glacier system (Fig. 1). Together with its tributaries, and the glaciers flowing directly into the Amery Ice Shelf, Lambert Glacier drains a basin more than 800,000 square kilometres in area, extending inland to 80°S latitude. The western margin runs through latitude 68°S, longitude 65°E, south-west to about latitude 75°S, longitude 50°E. The eastern limit of the drainage basin is not known, but it is certainly beyond the Grove Mountains, because the ice sheet falls steeply to the west through this group.

The Lambert Glacier system so greatly facilitates the drainage of the inland ice to the sea that the surface of the ice sheet is considerably depressed throughout Mac.Robertson Land. Five hundred kilometres inland, the surface of Lambert Glacier is only 150 m above sea level. The height of the ice sheet at this distance from the coast is mostly about 2500 m.

The form of the ice sheet surface in Mac.Robertson Land suggests that the inland ice flows directly into the sea from north of the 70th parallel only. South of this parallel the ice flows towards Lambert Glacier and the southern Amery Ice Shelf. Broad valleys, occupied by Fisher Glacier and other huge ice streams trending east and north-east, supply ice to Lambert Glacier along its western side. The west-trending rock ridge referred to by Goodspeed and Jesson (1959) under the ice west of Stinear Nunataks (about latitude 69°40′S) partly dams the northward flow of the ice west of Prince Charles Mountains and diverts it towards Lambert Glacier. The ice sheet east of Lambert Glacier is to some extent cut off from it by the Mawson Escarpment, Clemence Massif, and rock exposures along the east side of the Amery Ice Shelf. Inflow on this side of the glacier seems to be less than it is on the west.

The high rock walls of many glacier valleys are partly exposed above the ice sheet as the Prince Charles Mountains (Fig. 1). Extensive, apparently thick, blankets of moraine on the plateau-like summits of many of the larger rock exposures indicate that the ice surface was once much higher than it is now (Trail 1964).

Another important drainage basin is that of Robert Glacier and Wilma Glacier, together with the much shorter Downer, Wilson, and Seaton Glaciers, all of which flow into Edward VIII Gulf. Ice flowing northwards into the peninsula of Enderby Land is diverted to the north-east by Robert and Wilma Glaciers. The other three glaciers, and Wilma Glacier in part, drain the interior of the Enderby Land peninsula. The northern and western margin of the basin extends from Edward VIII Gulf to the Napier Mountains, then south to near Knuckey Peaks. The eastern divide runs south from the south-eastern corner of Edward VIII Gulf. The direction of flow of the ice sheet is probably influenced by this drainage system south to about 69°S.

In the Tula Mountains, the ice flows south or south-west into the west-flowing Beaver Glacier, except in the north-western part of the mountains, where it flows directly into the north-east of Amundsen Bay. The Beaver Glacier, together with the nearby Auster Glacier, drains this region westwards of about longitude 54°E. The interior of the Enderby Land peninsula seems to be a semi-independent ice cap, cut off from the main ice sheet by the Beaver Glacier drainage system on the west and Wilma Glacier on the east.

The ice flow through Perov Nunataks is to the west, but there are no defined ice streams. South of Raggatt Mountains and Scott Mountains, the main drainage channels are Thyer Glacier and Rayner Glacier, which flow into Casey Bay. Elsewhere, the observed drainage was northwards towards the coast.

IV. ICE MOVEMENT

Ice movement between Fischer Nunatak (south of Mount Henderson) and Casey Range was measured in the autumn of 1958 by remeasuring movement of poles installed by Mellor the previous year (Fig. 7). At the same time, the thickness of the ice at the site of each pole was measured by seismic and gravity methods. By combining the data on ice movement and ice thickness, it was possible to estimate the amount of ice flowing across the line of the traverse each year. The line along which measurements of ice movement and ice thickness were made was 27·16 kilometres long, and about 12 kilometres inland from the coast. The average rate of flow across each metre of the line was found to be 68×10^5 kilograms per annum of water equivalent of ice. When ablation is taken into account, it can be calculated that an average 38×10^5 kilograms of water equivalent of ice reaches each metre of this part of the coastline annually. An account of this work is given elsewhere (McLeod and Jesson 1960).

V. OBSERVATIONS IN THE ABLATION ZONE

Most of the general features of the coastal ablation zone of the ice sheet in Mac.Robertson, Kemp, and Enderby Lands have already been described by Crohn (1959).

The surface in the ablation zone is commonly "blue" ice, hard, clear ice containing small air bubbles, and with a specific gravity of about 0·8 or more (E. E. Jesson found the average specific gravity of three samples from the lower part of the zone near Mawson to be 0·876). The ice surface commonly has the form of closely-spaced, triangular, cusp-like pyramids, with slightly curved, quite sharp edges and sharp apical points (Fig. 2). The pyramids may be up to 10 cm high, and 20 cm or so wide at the base. They commonly are elongated in the direction of the prevailing wind and have the shape of an asymmetric pyramid, with a sharp ridge running to windward of the apex and a steep triangular face on the leeward side. The formation of these cusps was observed on a frozen melt-water lake near Mawson in 1958. In April, the surface of the ice was glass smooth, but traversed by numerous cracks. By August, elongated shallow depressions 2 cm to 3 cm deep had formed along the northern side of these cracks; they had a vertical southern face, and a gently-sloping side on the north. During August, the depressions lengthened and broadened until adjacent ones almost met, leaving a sharp dividing ridge. Presumably the next stage would have been the development of the typical cusped pattern by deepening of the depressions and accentuation of the ridges under the influence of wind and radiation. Unfortunately, before this could occur, the surface was completely covered by snow.

ANARE photo I. R. McLeod.

FIG. 2. Cusped ice surface of ablation zone near Mawson, altitude about 500 m.

Near Mawson, large amounts of snow accumulate during the winter in parts of the ablation zone, even down to sea level. Drifts, which may reach considerable dimensions, form where the smooth flow of the wind is affected by obstructions or changes of slope of the ice sheet surface. This snow consists of hard, wind-packed névé, quite similar to the névé of the accumulation zone, the surface even being eroded into sastrugi.

At the end of August 1958, névé formed a continuous cover in the corridor between Masson Range and David Range in the Framnes Mountains, south of a line joining Mount Parsons and Blair Peak. Parts of the surface were hard and slippery, with a very smooth, polished egg-shell-like texture. Even at this time, incipient melting was taking place at the very tips of sharp projections of sastrugi, giving a dark appearance to the snow. Between the beginning and end of October, a good deal of snow was stripped from the surface, but snow which had been compressed by vehicle tracks in early October was left standing in relief. By late January 1959, except for a large area of snow banked up against Mount Coates and some other parts of the David Range, and a few areas of "white"* ice and some small drifts, the corridor between the two ranges was clear of snow as far south as, and through, Hordern Gap.

In the ablation zone behind Mawson, especially above 300 m, extensive areas of snow persist throughout the year in the lee of steep slopes, where they are protected to some extent from the scouring and subliming effects of the wind. At the higher levels, these areas consist of névé with thin ice layers at various depths; at lower altitudes, the ice layers are more common, and the névé becomes granular during the summer. With time, the névé finally becomes "white" ice which grades into the "blue" ice of the ablation zone.

As Crohn (1959, p. 79) has pointed out, a film of melt-water forms during the day in summer on the surface of the ice sheet in the lower part of the ablation zone. This water collects to form ponds in depressions, or drains down valleys as melt-water streams. These streams are mostly small; as described below, streams draining from rock outcrops can be quite large.

During the early summer especially, melt-water from the smaller snowdrifts spreads as a film over the cusped surface of the ice underlying and adjacent to the drift, filling the hollows and producing zones of glass-smooth ice many square metres in extent; such smooth areas occur on slopes as great as 15°. In some cases, these smooth patches on the ice are the only remnant of a snow drift. In others, the drift is represented by a low mound, composed of almost opaque ice with a very high content of air bubbles; the ice is riddled with veins and blebs of clear ice, the result of percolation of

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* The term "white ice" is used by ANARE parties for a porous, more-or-less friable granular aggregate of ice crystals containing numerous layers and blebs of ice. It is transitional from névé to "blue" ice and, on the ice sheet, marks the transition from the accumulation zone to the ablation zone.

melt water into the snowdrift followed by re-freezing. Such "ice drifts" were common at Jennings Promontory, Beaver Lake, and Clemence Massif.

In places, especially on broad, flat stretches of ice, the regular cusped pattern is broken by areas in which the projections are lower and less angular. These areas of different surface texture may be the result of modification of the original cusped texture by meltwater, as described above; they could represent very smooth areas on which the cusped texture was redeveloping; or they could be areas which had been covered by snow and so protected from ablation, and then re-exposed as the snow was removed by wind.

Isolated ablation areas characteristically adjoin all the inland rock outcrops visited, even though they occur in the accumulation zone. The highest such area found was at Grove Mountains, where an extensive area of ice occurs at an elevation of 1800 m. The surface of the ablation areas is "blue" ice, which, except at Grove Mountains, has the characteristic cusped surface of the coastal ablation zone; at Grove Mountains, the ice surface was merely irregular, without sharp edged cusps. Cryoconite holes occur rarely close to the rock, but most morainal detritus remains exposed, lying either on the surface or in a shallow pit. In the latter case, a rudimentary pillar of ice may be formed under the boulder, and the larger boulders generally have a sharp-crested ridge of ice on their leeward side, even when it is the northern side, suggesting that the depression in which the boulder lies is as much, or more, the result of increased ablation because of wind turbulence, as it is of radiation due to solar heating of the rock.

Although the ice surface in most of the inland ablation areas was tending to exfoliate during spring and summer of 1958-59, columnar disintegration, such as occurs near the coast (Crohn 1959, p. 79, 80), was not seen.

All the ablation areas within the accumulation zone have a similar distribution relative to the rock exposure (Fig. 3). They occur on the leeward side of the rock exposure (in nearly all cases this is also the "downstream" side of ice movement) and are roughly triangular in shape, the edge of the rock forming the base of the triangle. Depending on the size of the rock outcrop, the "blue" ice may be many square kilometres in area, as at Leckie Range, and may extend for several kilometres from the rock; bare ice occurs 3 km north of Mill Peak, where the rock is only half a kilometre wide; it extends for 7 km north of Leckie Range. The surface of the ice area generally falls gently towards the rock, producing a depression, triangular in plan, which is emphasized by the steep ice slopes on either side near the rock exposure, where the ice begins to flow together again "downstream" of the obstruction. At the side of most of the rock exposures is a radiation moat which opens into the ablation area and, in the opposite direction, passes into a wind scour which, in turn, ends abruptly against a drift banked up on the windward side of the rock. The wind scour and radiation moat together form a trench between the surface of the ice sheet and each side of the rock exposure; one side of the trench is ice or névé, the other is formed by the steep side of the rock outcrop, or talus from it. The wind scour is distinguished from the radiation moat by having a side and floor of névé. The side is vertical or even overhanging, and is commonly topped by a cornice. The transition from side to floor is generally abrupt. The side and floor of the radiation moat are "blue" ice; the side is mostly very steep, but rarely vertical; in contrast to the wind scour, the transition from the surface of the ice sheet to the side of the moat, while well defined, is convex, and the transition from side to floor is concave. In most cases the floor is partly occupied by refrozen melt-water. The wind scour part of the trench is mostly narrower and deeper than the radiation moat, which becomes shallower and wider towards the opening to the ablation area. The dimensions of the trench depend on the size and shape of the rock outcrop. Depths of 15 m to 30 m and average widths up to 50 m are not uncommon for trenches around the larger outcrops. The Perov Nunataks and Fram Peak provide good examples of these features. The bare "blue" ice of these localized ablation zones passes into the névé through a transition zone of "white ice" which may be anything from 10 metres (as at Mill Peak) to 2 km (as at McLeod Nunataks) wide.

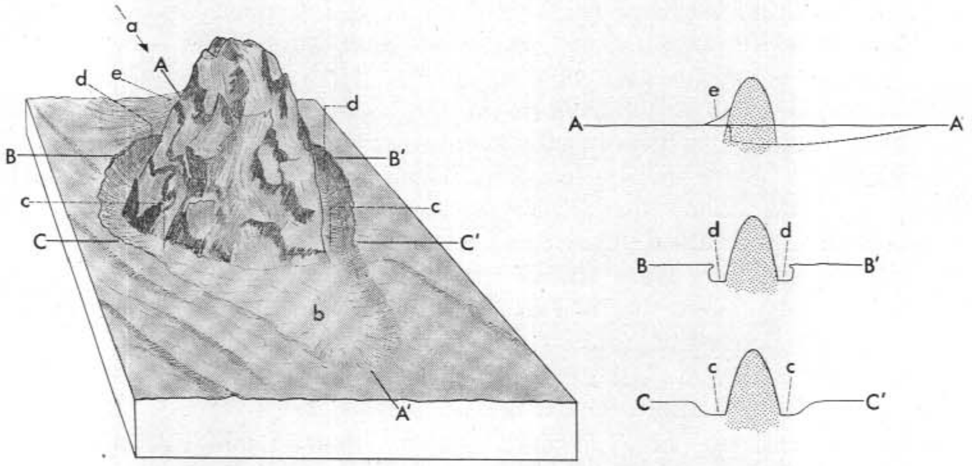


FIG. 3. Diagrammatic sketch of ablation area, wind scour, and radiation moat associated with nunatak in accumulation zone of ice sheet.

a. Prevailing wind direction.
b. Ablation area on leeward side of nunatak.
c. Radiation moat, with sloping side of ice.
d. Wind scour, with vertical side of névé topped by a cornice.
e. Drift banked up against windward side of nunatak.

The factors producing these local ablation areas within the accumulation zone are not fully understood. Schytt (1958) considers that evaporation is the dominant influence, but Swithinbank (1959) attributes an important role to wind erosion and turbulence, which keep the area clear of snow. Although turbulence may contribute towards the ablation (it must be the main agent in the production of areas of ablation on the windward side and top of domes in the ice sheet) it is difficult to see how it could be effective at distances of several kilometres from rock exposures, even if they are of large size. In some of these areas, wind-blown sand grains are common on the surface, and solar heating of these grains must assist ablation to some extent. Most of the ablation areas are on the northern side of the related rock outcrop, and another factor which may be effective in their formation or perpetuation is reflection or re-radiation of solar radiation by the rock surface.

During the summer, considerable amounts of water are produced on the larger inland rock exposures by melting of snow and ice on and near the rock. Extensive refrozen meltwater areas occur along the northern fronts of Leckie Range and McLeod Nunataks, and small pools of water were found in depressions in the moraine and the nearby ice. Where the topography of the ice sheet is such that the meltwater can drain away from the rock outcrop, a stream of considerable size may form. Crohn (1959, p. 79) refers to one such stream in the Prince Charles Mountains which had a channel almost 5 m deep.

Near rock exposures, isolated boulders of moraine generally are surrounded by a small pool of water on summer days. The pool acquires a thin surface layer of ice on overcast days.

Measurements of ablation in the Mawson area, initiated by Crohn (1959) and continued by Mellor (1959), were continued during 1958 and early 1959 by the author, and for the remainder of 1959 and early 1960 by B. H. Stinear. Stinear also made measurements of ablation in 1959 at 150 m altitude. The measurements are shown in Tables 1 and 2. Some of the sites used by Mellor could not be found, so that some of the measurements are not comparable with those of earlier years. The measurements at 45 m were made on three white-painted bamboo poles, and on seven unpainted steel poles, 3 inches in diameter, which had been set in the ice to carry radiation measuring equipment; the quoted figures for 1958 and January and February 1959 are the average of the measurements on all these poles. Later measurements were made only on the bamboo poles. The figures quoted for 100 m and 150 m are the average of measurements on three white-painted poles. The measurements at 175 m and 195 m were made on one pole at each site. Measurements at the 45 m site were discontinued after 15th August 1959, when the surface was covered by up to 30 cm of snow, which remained until the summer. The surface at all other sites was bare ice except on a few occasions, when it was covered by a thin layer of snow which was blown away within a few days.

The total ablation at the various sites is shown in Table 3.

A notable feature of the results is the considerable difference in ablation rates between the sites at 45 m and 75 m. The poles at 45 m were on the side of a steep north-facing slope, sheltered to some extent from the

TABLE 1

Ablation, Vicinity of Mawson, 1958 and 1959

(in inches of ice)*

Period ending	Altitude 45 m (beginning 20 March)	75 m (beginning 9 March)	Period ending	Altitude 45 m	75 m	150 m (beginning 22 April)
1958						
8 April	1		27 January	¾	¾	
26 April	0		2 February	¾	½	
2 May		2	9 February	¾	½	
5 May	¾		7 March	4¾		
19 May	0	½	1 April	¼	1⅞	
5 June	½	¾	8 April	⅜	⅛	
5 July	¼		15 April		½	
21 July	¼	1¾	22 April	⅛	¼	
28 July	¼	¼	29 April		¼	⅛
18 August	0	½	9 May	⅛	⅜	⅜
25 August	¼	0	24 May	¼	¾	⅜
9 September	0	½	7 June	⅛	⅜	¼
15 September	¼	0	20 June	¼	¼	¼
29 September	0	¼	2 July	0	⅛	⅛
7 October	¼	¼	23 July	¼	⅜	⅜
15 October	0	¼	3 August	¼	½	⅛
20 October	0	½	15 August	⅛	⅜	⅝
27 October	⅝	¼	24 September		¾	⅝
3 November	⅜	½	1 October		¼	⅛
10 November	¼	½	7 October		⅛	0
17 November	⅝	¾	17 October		⅞	⅜
24 November	⅜	½	23 October		0	¼
1 December	¾		6 November		1	¾
8 December	½	1	28 November		1¼	1
15 December	¼	1⅛	10 December		1⅝	1⅛
22 December	¼	⅞	18 December		1	½
30 December	1½	1	22 December		⅜	⅜
1959			1960			
5 January	¾	¾	3 January		3⅝	1¼
12 January	¾	½	12 January		1¾†	1⅛
19 January	1¼	1½	27 January			1⅝

† Two poles only.

* See Table 3 for summary in metric units.

TABLE 2

Ablation from the Ice-Sheet South of Mawson, 1958

(in inches of ice)*

Period ending	100 m (beginning 11 March)	175 m (beginning 26 February)	195 m (beginning 26 February)
11 March		½	1
26 April	2¼	2	1¼
21 July	2¼		
29 July	¼	2¾	2¾
17 October	¼	2	2¾
10 November	1½	1¼	1¼

* See Table 3 for summary in metric units.

TABLE 3

Total Ablation, Vicinity of Mawson, 1958 and 1959

Altitude metres	Total ablation inches of ice	Water equivalent*		Ablation rate cm/day
		inches	cm	
(a) *11 March 1958 to 10 November 1958 (244 days)*				
45†	5	4·4	11·1	0·04
75	8¾	7·6	19·3	0·08
100	8	7·0	17·7	0·07
175	8	7·0	17·7	0·07
195	8¼	7·2	18·2	0·07
(b) *10 November 1958 to 9 February 1959 (91 days)*				
45	9¼	8·0	20·4	0·23
75	10½	9·1	23·2	0·27
(c) *7 March 1959 to 6 November 1959 (244 days)*				
75	9⅛	7·9	20·2	0·08
150‡	4¾	4·1	10·5	0·04
(d) *6 November 1959 to 12 January 1960 (67 days)*				
75	9⅛	8·4	21·3	0·32
150‡	4¾	4·7	12·8	0·19

* Using a specific gravity of 0·87 for surface ice, the average of values found for three different points behind Mawson.

† From 20th March.

‡ From 22nd April.

prevailing south-south-east wind. The 75 m site was at the top of the slope and was exposed to the wind; the other sites were also exposed, and have ablation rates comparable to that at the 75 m site. The effect of the wind on the ablation rate is also shown by the comparatively large ablation for the winter period; from 19th May to 28th July, the ablation at 45 m was 1¼ inches (3 cm) of ice and at 75 m, 3¼ inches (8 cm); total sunshine in this period of 70 days was 30·1 hours.

The total ablation at 75 m from March 1958 to February 1959 was 19¼ inches of ice, much less than the amounts measured in previous years. For the period 16 March 1955 to 7 February 1956, Crohn (1959) recorded a loss of 32¼ inches (82 cm) of ice at a site 60 m above sea-level, and 23½ inches (59 cm) for the period 7 February 1956, to 1 January 1957 (which does not include the period of greatest ablation). Mellor (1959) found the ablation at the same altitude between February 1957 and February 1958 to be 53·5 cm of water, equal to about 24 inches of ice, also rather lower than the values for the previous two years. The ablation from early March 1959 to mid-January 1960, was 18¾ inches (47 cm) of ice.

When the figures for the different years are compared (Fig. 4), it is found that the rates in all years are comparable until the beginning of December. Thereafter, the rates for 1955, 1956, and 1959 show a sharp increase, while the rate for 1958 remains nearly constant. The rate for 1957 increased towards the end of the year, but the dates of measurement were too far apart to reveal whether or not the increase in the ablation rate was sudden, or when it occurred. Comparison of weather records for the five

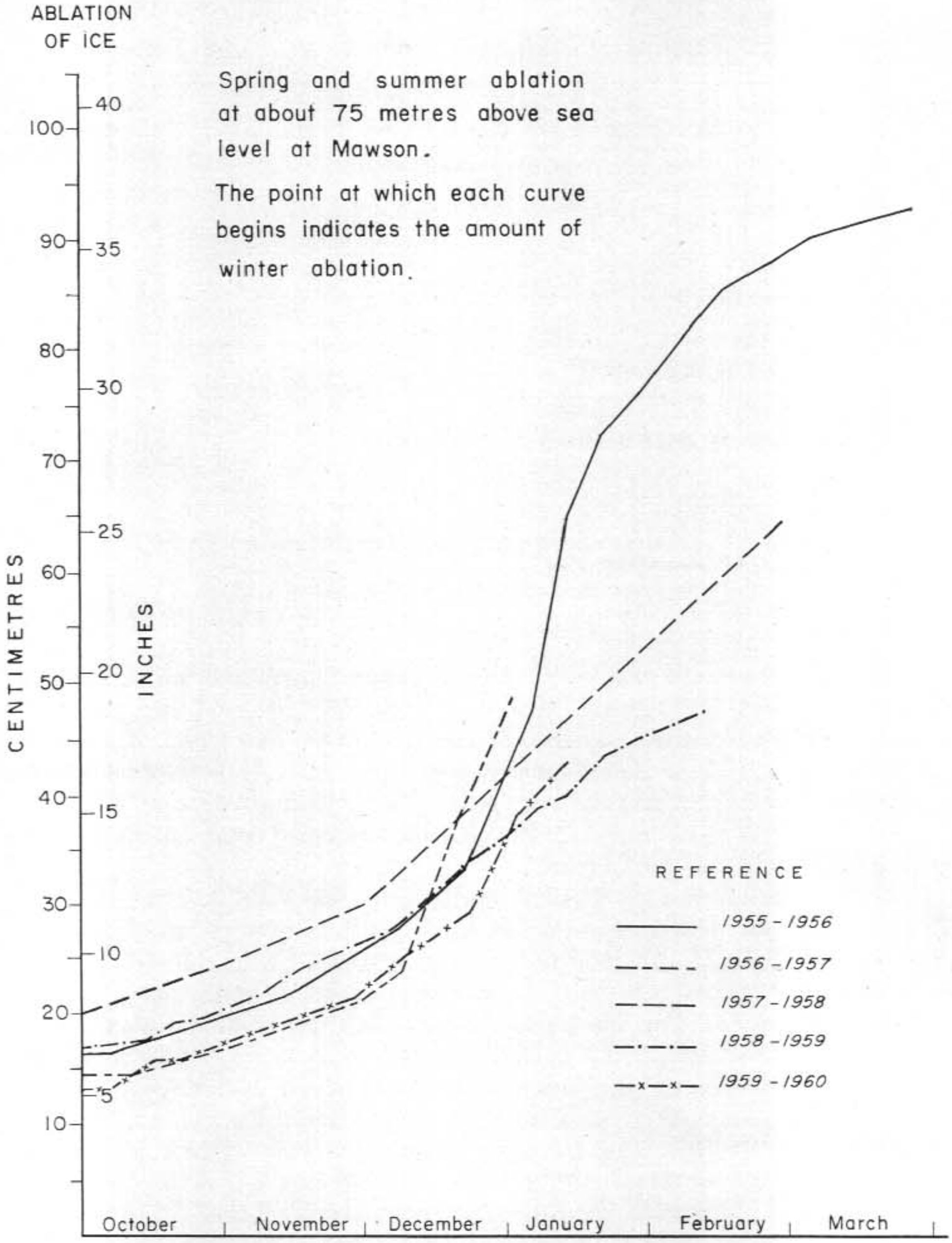


FIG. 4. Spring and summer ablation, Mawson.

January-February periods shows that wind-speeds and average temperatures were similar for each period, but that there was much less sunshine in December 1958 and January 1959 than in the same two months of the other years. The average daily hours of sunshine in December 1958 and January

1959 was 6·9; the figure for the other periods was: 1955-56, 11·7; 1956-57, 10·3; 1957-58, 9·8; 1959-60, 8·2. It seems likely that this greatly reduced amount of sunshine, with the corresponding increase in incoming radiation, was the cause of the low summer ablation, as well as of the abnormal sea ice conditions in the 1958-59 summer. The small ablation figure for 1959-60 may be explained partly by the fact that part of the summer period was not included, and partly by the lower amount of sunshine in this year, also.

TABLE 4

Ablation, Beaver Lake, September to November, 1958

Period	Ablation of ice	
	inches	cm
27 September to 21 October	2¾	7
21 October to 2 November	¾	2
2 November to 9 November	¾	2
Total (43 days)	4¼	11

Another effect of the reduced sunshine in 1958-59 was the much smaller extent to which columnar disintegration of the ice surface (Crohn 1959, p. 79, 80) occurred then. Incipient disintegration was first noticed in October 1958 along certain layers in the ice behind Mawson. However, by the end of January 1959, this had developed only in small localized areas. Most of the surface then consisted of short, asymmetric, east-west trending ridges up to 5 cm high, with a sharp crest, a steep or overhanging northern side, and a southern side sloping at about 45°.

During depoting operations for a sledging journey, ablation poles were installed at Leckie Range and McLeod Nunataks; these were later measured during the journey. At Leckie Range, the ablation loss at a point (altitude 1200 metres) a kilometre north of the range was 4¾ inches (12 cm) of ice between 21 September and 30 December 1958, a daily rate of 0·12 cm. At McLeod Nunataks (altitude 1100 metres), the average loss from four poles 200 m north of the main group (but only 20 m from large blocks of moraine lying on the ice) was ¾ inch between 25 September and 4 November, and 4 inches (10 cm) between 4 November and 11 December 1958, a rate of 0·16 cm per day for the whole period.

Ablation from the ice surface in the centre of Beaver Lake (70°50′S, 68°20′E), at an altitude just above sea level (average of two poles), is shown in Table 4.

The ablation of 4¼ inches (a daily rate of 0·26 cm) is much higher than the 2¼ inches at the 75 m site at Mawson between 29 September and 10 November, although Beaver Lake is 400 km south-east of Mawson; presumably the difference is due to the very high wind speeds characteristic of Beaver Lake.

Measurements of ablation on the sea ice at Mawson are described later, in the section of this report describing sea ice observations.

V. OBSERVATIONS IN THE ACCUMULATION ZONE

The only measurements of accumulation obtained during 1958 and 1959 were along the route of the southern seismic traverse. Accumulation for a ten-month period was measured by R. Blake and E. E. Jesson on poles installed by M. Mellor the previous season. The results have already been published by Mellor (1959). The accumulation (average of three poles) at the different sites ranged from a net loss of $\frac{3}{4}$ inch (2 cm) to a gain of 16 inches (41 cm).

The great range in the accumulation values, and the fact that in December 1958 the seismic party followed for several miles near latitude 70°S tracks made the previous January, show that snow does not accumulate on the ice sheet as a layer of more or less uniform thickness. The impression gained by both the seismic and sledging parties was that snow precipitated in high winds accumulates as long whale-back dunes, which may reach heights of over 3 m and extend downwind for several hundred metres.

Under conditions of moderate to strong winds without precipitation, these dunes are eroded into sastrugi. Because the fine weather katabatic winds usually come from a different direction from that of bad weather winds, the sastrugi trend in a different direction from that of the dunes, so that one flank of the dune is eroded to an almost vertical, deeply dissected face, while the other side is hardly affected. Such conditions were common a few kilometres east of Knuckey Peaks, where the sastrugi were about a metre high, and on parts of the seismic traverse, where the sastrugi reached heights of 2 m or more.

Under certain conditions (usually light to moderate winds with low drift) elongate accumulations form from drifting snow. In form, these often resemble sastrugi, but they are softer and less compact in appearance, and may partly bury sastrugi cut into the hard névé. They may trend in the same direction as the sastrugi, or have an orientation differing by up to 40° from the trend of the sastrugi. These accumulations (the author prefers not to call them sastrugi, restricting this term to features purely erosional in origin) are not stationary, but migrate down-wind, and increase in size or dissipate with varying wind conditions. Although there may be localized accumulations amongst the sastrugi, it is thought that drifting snow is not an important factor in the supply of material for nett accumulation at any particular locality.

Barchan dunes were seen at several places in 1958, both on the ground and from the air. The best developed dunes seen from the air were on the sea ice near Mawson—south-west of Flat Island in early August, and east of the Canopus Islands on 18 August. They were seen also on the ice sheet west of Church Mountain on 15 August. The first two groups did not display any regular arrangement; the dunes near Church Mountain were formed to all degrees of perfection, from those barely recognizable to those forming perfect crescents, approximately 3 m from tip to tip. The more perfect dunes were commonly arranged in lines trending downwind, with the apices of the individual dunes collinear; some of these lines extended for several hundred metres. In some cases parallel lines were quite close, only the width of a dune apart. On the ground, scattered barchan dunes were found by the author in the western Tula Mountains and 8 km west of Leckie Range.

These barchan dunes differed in shape from those figured by Moss (1938, p. 216). The "horns" were longer, each tapering off to a fairly sharp tip, and the dune consequently had a crescentic, almost semi-circular, plan, rather than the boomerang shape depicted by Moss. Each dune was about 3 m from tip to tip, and up to a metre high at the highest point of the apex.

During a six-day blizzard, three-quarters of a metre of soft snow was deposited on the ice sheet a few hundred metres south of Fram Peak, and a few indistinct barchans were formed on the smooth upper surface of this snow. At all three places where barchan dunes were examined on the ground, the snow of the dune was much softer than the surrounding surface, and had a characteristic slippery feel underfoot, a sensation akin to that experienced when walking on wet, greasy clay.

The southern seismic party recorded barchans at 69°52′S, 62°10′E (where they were 4 m from tip to tip, and 3 m high at the apex), at 70°23′S, 62°09′E (where they were the same height, but only 2 m from tip to tip), and near 69°10′S, 61°35′E. At all three places, only a few scattered dunes occurred. Those at the last locality were asymmetrical, with a western arm about 6 m long, and the eastern one about 4 m long.

The factors governing the formation of crescentic barchan dunes are not fully understood, but it is probable that the conditions postulated by Bagnold (1941) for the growth of sand barchans apply also to snow. Briefly, he considers that sand barchans form by the streaming of particles on either side of an obstruction caused by chance accumulation of particles on a flat surface, under conditions of nearly constant wind direction. A change of wind direction will rapidly destroy the crescentic shape.

In late November 1958, the sea ice in north-east Amundsen Bay was covered by snow, and extensive snow patches were common in the nearby Tula Mountains. The surface of the snow was smooth, with no sastrugi. The only relief was a series of transverse, sinuous dunes a quarter to half a metre high and up to 3 m wide. In places, on the sea ice especially, the snow had a "piecrust" surface, due to a hard crust a centimetre or so thick. These low, sinuous dunes may be the result of precipitation accompanied by light winds. The leeward flank of many dunes was rather steeper than the other, and it is likely that these transverse dunes are actually giant ripples, which migrate down-wind during or shortly after formation; the sinuosity would then be the result of varying rates of movement along the length of the dune. At the time of the visit, the dunes were immobilized by the harder crust.

A record of sastrugi directions was kept during flights across the ice sheet in 1958, and on the southern seismic, and sledging journeys. A study of these and the data obtained in previous years, in relation to the prevailing wind patterns, has been made by Mather and Goodspeed (1959) and Mather (1962).

Isolated ablation areas which occur within the accumulation zone have been described in the previous section.

VI. MORPHOLOGY AND SURFACE FEATURES OF THE ICE SHEET

General descriptions of the morphology and surface of the ice sheet in Enderby, Kemp and Mac.Robertson Lands have been given by Crohn (1959) and Mellor (1958). The section below, describing the features of the interior of Enderby and Kemp Lands, is the result of observations by the author during a sledging journey from Amundsen Bay to Mawson in late November and December 1958, and January 1959. The sections on the interior of Mac.Robertson Land and on the southern Prince Charles Mountains were prepared by D. S. Trail, from observations made during a sledging journey to the southern Prince Charles Mountains during December 1961 and January 1962 (Trail 1963).

(*a*) *Enderby Land and Kemp Land*

Rock exposures occur at intervals along the whole route followed during the sledging journey from Amundsen Bay to Mawson (Fig. 1); consequently, the area traversed cannot be regarded as typical of the interior of the ice sheet. The exposures range in size from the extensive ranges of the Tula Mountains to small, isolated nunataks such as Mill Peak.

In late November 1958, the sea ice in the north-eastern part of Amundsen Bay had an almost complete cover of snow. A party which landed near Pinn Island, in southern Casey Bay, in October 1957 found the sea ice there covered by half a metre or more of soft snow. Extensive patches of soft snow were common in the parts of the Tula Mountains traversed on the sledging journey.

The Tula Mountains region is evidently one of light prevailing winds. Over a nine day period of observations, the average wind speed at the camp at the north-east corner of Amundsen Bay was less than 5 knots. A few days of strong winds would strip most of the soft snow from the ice surface.

Despite the covering of soft snow at the time of the visit, it was evident that the Tula Mountains region is predominantly in the zone of ablation. This zone extends to an altitude of at least 1000 m. An extensive flat area of hard "blue" ice, with a cusped surface, was found west of Mount King at this altitude. Within this zone of ablation, local, possibly temporary, accumulation areas consist of hard névé like the surface of the ice sheet in the interior of the continent. More common are zones of "white ice", which occur usually on westward-facing lee slopes of the ice sheet.

The floors of the west-trending valleys through the Tula Mountains rise to the east either with a uniform gradient or as a series of terraces, with occasional depressions where gaps in the mountains allow the ice to drain south into Beaver Glacier. Crevassing is common; from the air, huge, straight transverse crevasses can be seen extending across parts of some of the valleys. Elsewhere, crevasses are generally concealed by a thin covering of soft snow, and their existence was revealed during the journey only when a man or dog broke through the hidden bridge.

Névé was encountered a kilometre south of Mount King at the south-east limit of the Tula Mountains, at an altitude of 1040 m. The surface between here and the Framnes Mountains is in the accumulation zone, except for the small areas of ablation, adjacent to the rock exposures, described in Section IV. Between Mount King and Knuckey Peaks, the surface is gently undulating, rising from 1040 m at Mount King to 1850 m at the southern end of Knuckey Peaks. About 13 km south of Mount King, the névé was cut by several long, quite straight cracks, a half to one kilometre apart, and only a centimetre wide, and running to the north-east and south-west as far as the eye could see; no other signs of crevassing were visible in the vicinity.

The ice sheet rises to more than 2000 m between Knuckey Peaks and Mount Channon. This seems to be an area of high precipitation and low wind speeds, because the surface was soft, smooth snow into which men sank ankle-deep at each step, and there were no sastrugi whatsoever. The cloudbase commonly descended to ground level. The ice sheet between Knuckey Peaks and Mount Channon forms a broad, north-trending ridge. The katabatic wind is partly channelled to either side of this ridge, and wind-hardened névé characteristic of those parts of the accumulation zone affected by the katabatic wind does not form on the ridge. Mather and Goodspeed (1959) noted a diversion of the katabatic wind by a ridge 300 km south of Mawson. Soft snow patches were common on this ridge also.

Further east, where the surface falls toward Mount Channon, small areas of hard sastrugi show through the soft snow; these surface conditions extend almost to Leckie Range, and occur again on the high area west of Fram Peak.

Few rock exposures occur between Leckie Range and the Framnes Mountains, but the surface of the ice sheet shows considerable relief. Domes and valleys are quite marked and some of the former are heavily crevassed. The surface of the ice sheet falls steeply northwards through the Hansen Mountains and Arnel Bluffs, and a prominent north-facing scarp runs eastwards from Fram Peak. The surface of many of the domes, particularly the crest and eastern slopes, consists of crevassed "white ice". "White ice" was exposed 25 km east of Leckie Range, at an altitude of 1580 m. Twelve kilometres west of Mount Hordern (in the Framnes Mountains), "blue" ice occurs on top of a dome at 1070 m, close to the junction of the accumulation and coastal ablation zones, which was crossed about 8 km west of Mount Hordern at an altitude of 1040 m.

(*b*) *Mac.Robertson Land*

The 1961 geological party traversed the ice sheet between Mawson and the southern Prince Charles Mountains (lat. 74°S) along the 62nd meridian, following the route taken by geophysical parties in 1957 and 1958 and by the geological party in 1960.

Aspects of the surface of the ice sheet along this route have been briefly described by Mather and Goodspeed (1959) and by Mather (1962). Fig. 5, a profile of the ice sheet, is adapted from Mather and Goodspeed.

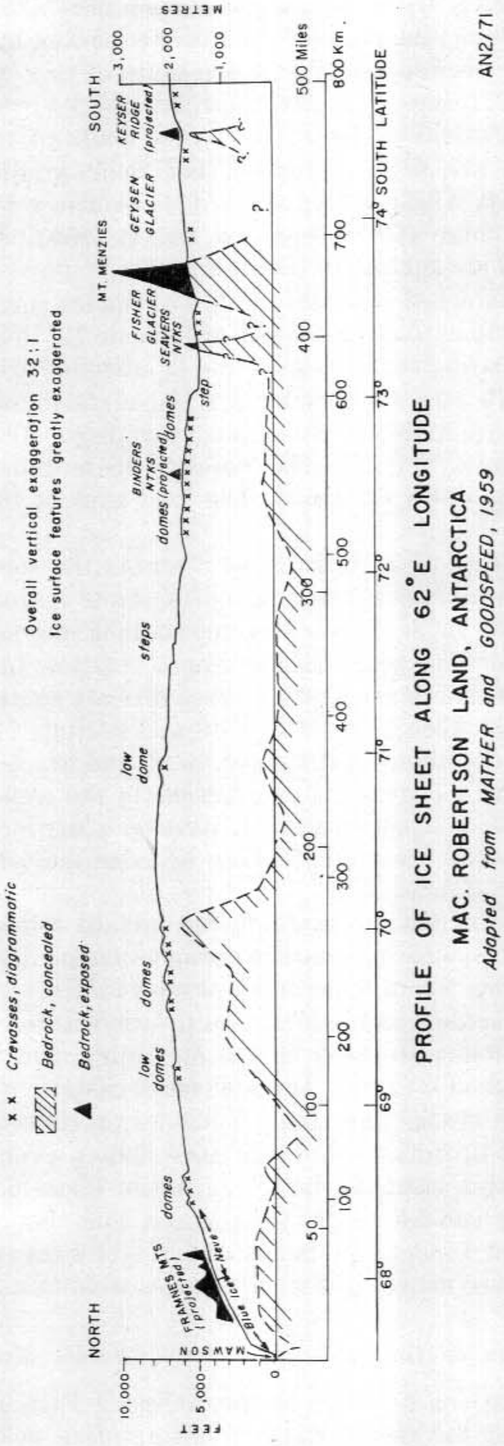
From the sea at Mawson, the "blue" ice surface of the ice sheet rises for 30 km to 50 km through the coastal ablation zone to an altitude of between 600 m and 1000 m, where ice passes under the cover of névé which forms the greater part of the surface in the accumulation zone.

The névé surface is almost everywhere cut by the wind into sastrugi, which range from 10 cm or so to about 1 m in height. Where the wind has eroded a mound or dune of compacted snow, the steep-sided ridges which remain may be 2 m or more high.

The trend of sastrugi changes from south-south-east near Mawson, through south, to south-west in the region of the southern Prince Charles Mountains. Mather (1962) attributes this systematic change to the diversion of the katabatic wind eastwards into the deep trough of the Lambert Glacier.

Between latitudes 69°S and 72°S, high and relatively soft sastrugi form patches several kilometres across, which alternate with equally wide patches of relatively smooth, hard névé carrying sastrugi less than 30 cm high. The broad patches of high sastrugi may correspond to the snow "waves", from 2 to 6 kilometres wide, described by Dolgushin (1960) between Mirny and Pioneerskaya.

From the altitude of 1200 m at the southernmost nunataks of the Framnes Mountains, 70 km south of Mawson, the névé surface of the ice sheet along the 62nd meridian rises gently with an overall gradient between 1 in 150 and 1 in 300 to reach an altitude of 2100 m at latitude 69°38′S, 250 km south of Mawson. For the greater part of this distance, the surface is a succession of ill-defined and very gentle undulations. The crests of the undulations are several kilometres apart and they rarely exceed 15 m in amplitude. About latitude 68°30′S, between 110 km and 130 km from Mawson, a group of névé ridges and domes forms a steep, north-facing step about 30 m high in the surface slope, which is about 1 in 100. The crests of the domes and ridges carry large crevasses up to 6 m wide. This zone of disturbed ice is located on the northern edge of a depression in the sub-ice rock surface, 900 m deep and 50 km wide (Goodspeed and Jesson 1959). The southern edge of the depression is marked at the surface by a 9 km-wide zone of low névé domes.



PROFILE OF ICE SHEET ALONG 62° E LONGITUDE
MAC. ROBERTSON LAND, ANTARCTICA
Adapted from MATHER and GOODSPEED, 1959

AN2/71

FIG. 5. Profile of ice sheet along 62° E longitude.

At latitude 69°38′S, the north face of a steep névé dome rises abruptly between 30 m and 60 m; the crest of the dome is broken by huge crevasses over 15 m wide. The névé surface for 55 km south of this dome is disturbed by steep domes and ridges with irregular hummocky surfaces and with large snow-filled crevasses on their crests. The floors of the broad valleys between the domes are little disturbed, but their gradients are locally steeper than 1 in 100. These domes and ridges overlie a high, steep-sided, west-trending rock ridge (Goodspeed and Jesson 1959), which rises 1000 m to within 300 m of the surface of the ice sheet.

South of this disturbed zone the surface of the ice sheet rises in gentle undulations from 2350 m to reach 2400 m at latitude 70°15′S, where it levels out as a gently undulating surface extending to latitude 70°30′S.

From latitude 70°30′S to latitude 71°S the surface gradually falls 150 m. The undulations are more clearly defined, forming a succession of broad hills and closed valleys. The hills rise between 15 m and 30 m, and have crests between 5 km and 8 km apart. The long axes of the closed valleys trend eastwards.

A small névé dome at latitude 70°54′S marks the southern edge of a 300 m rise in the sub-ice rock surface (Goodspeed and Jesson 1959).

South of latitude 71°S, the surface undulations increase in amplitude, exceeding 30 m, and their south-facing slopes steepen. Locally, gradients may exceed 1 in 100. There are at least three distinct south-facing steps in the ice cap surface between latitude 71°27′S and latitude 71°40′S. They are about 10 km apart; the highest falls about 60 m, and gradients on the steps approach 1 in 50. In this area, the undulations in the ice sheet surface, as Mather and Goodspeed (1959) observed, develop a distinct easterly slope, and the valleys between the swells visibly broaden and deepen eastwards towards the Lambert Glacier.

This markedly undulating, east-sloping surface continues to descend gently to latitude 72°S, where its nature changes sharply. Here a steep slope facing south-east drops about 50 m into a narrow valley, closed at its north-east end, which descends and widens south-westwards. From the slope above this valley, Mount Menzies, Mount McCauley, and Mount Scherger are clearly seen in good weather. The low south-eastern wall of the valley is a névé ridge with cracks and small crevasses on its crest. Southwards, this ridge rises and broadens into large névé domes, over 30 m high and more than 5 km broad, carrying large crevasses. These domes overlie the south-east trending sub-ice ridge (Goodspeed and Jesson 1959) which breaks the surface at Binders Nunataks and Mount Creswell, the northern outliers of the southern ranges of Prince Charles Mountains.

(c) *Glaciers of the southern Prince Charles Mountains*

Ground observations by Trail in the southern Prince Charles Mountains are augmented for this section by information collected by Ruker

(1963) and by airphoto interpretation. Fig. 6 shows the ice features of the southern Prince Charles Mountains.

From the western side of Binders Nunataks, a succession of high, steep, névé domes, with large crevasses, runs southwards for 25 km to merge with an elongated névé ridge extending for 40 km south-westwards to Goodspeed Nunataks. The south side of this ridge is about 60 m high, but the north side is considerably lower. The ridge has large crevasses on its crest and south side. South of the ridge, a broad basin of smooth snow, with a few small domes and patches of concealed crevasses, stretches 40 km to the north side of Fisher Glacier.

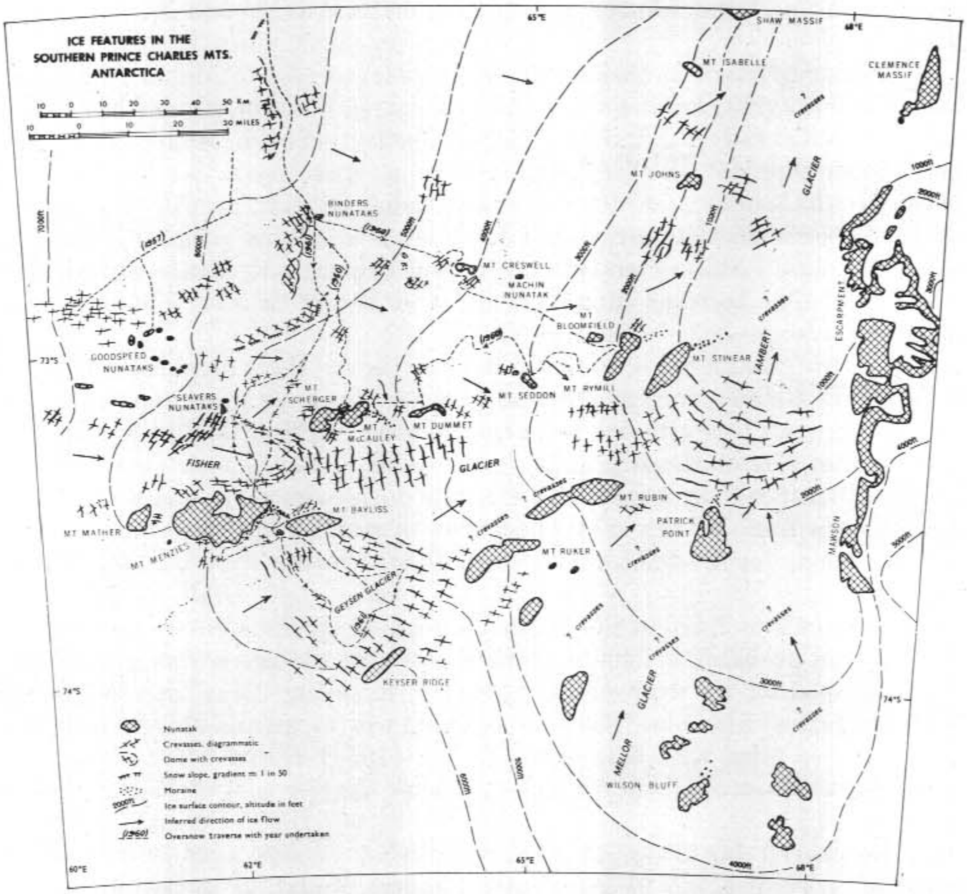


FIG. 6. Ice features in the southern Prince Charles Mountains, Antarctica.

Fisher Glacier, the most prominent and most clearly defined tributary of Lambert Glacier, has its source in the ice sheet west of longitude 60°E, over 2000 m above sea level. The glacier falls 1560 m in 200 km to its confluence with Lambert Glacier. Over most of its length Fisher Glacier is about 30 km broad; the glacier is constricted between Mount Menzies and Mount Scherger, and between Mount Rubin and Mounts Rymill and Stinear.

Between Binders Nunataks and Fisher Glacier, and along the north side of that glacier to its confluence with Lambert Glacier, the ice flow is complex.

A small glacier flows eastwards from Goodspeed Nunataks to merge with the disturbed ice flowing south-eastwards between Binders Nunataks and Goodspeed Nunataks and passing north of Mount Scherger and Mount McCauley. Fisher Glacier is constricted between Mount Menzies and Mount Scherger, and the distribution of crevasses around Mount Scherger, together with the trend of flow lines west of Mount Scherger, suggests that some ice from Fisher Glacier is diverted northwards around Mount Scherger.

The constriction in Fisher Glacier is relieved east of Mount McCauley and Mount Bayliss, and ice from the broad area between Mount McCauley and Mount Cresswell flows into Fisher Glacier between Mount McCauley and Mount Dummet, between Mount Dummet and Mount Seddon, and between Mount Seddon and Mount Rymill. Fisher Glacier, greatly augmented by these northern tributaries and by a large southern tributary, Geysen Glacier, is again constricted between Mount Stinear and Mount Rubin. The ice in the valley between Mount Rymill and Mount Stinear appears to be stagnant.

North of Mount Stinear, the surface of the ice sheet dips sharply down to Lambert Glacier, and an enormous quantity of ice must flow into the glacier along its western side from the ice sheet north of Mount Rymill.

West of Mount Menzies, the upper part of Fisher Glacier carries large areas of disturbed ice, domes, and ice falls with huge crevasses and séracs. The eastern limit of this disturbed area is marked by the large ice fall which extends for several kilometres south-westwards from Seavers Nunataks.

Within about 7 km of the northern sides of Mount Menzies and Mount Bayliss, and probably of Mount Mather, the névé surface of the glacier has been stripped off by wind or by radiation, exposing "blue" ice. North of Mount Menzies this "blue" ice zone is broken by large and small longitudinal crevasses filled with soft snow. Ruker (1963) records that "blue" ice forms the surface of the north side of Fisher Glacier east of Mount Scherger.

The proved dog-sledge route across Fisher Glacier runs in a straight line from a point about 2½ km east of Seavers Nunataks to the north-east corner of Mount Menzies (Fig. 6). This route crosses small, well-bridged longitudinal crevasses within a few kilometres of Seavers Nunataks, and runs over several kilometres of smooth névé to the edge of the "blue" ice zone north of Mount Menzies. In this zone the route runs for 5 km or 6 km over narrow longitudinal crevasses and rough pot-holed "blue" ice, to south-sloping smooth "blue" ice within 2 km of the mountain.

A few kilometres east of this route, steep longitudinal ridges several metres high develop along the north side and the centre of the glacier, as the ice is constricted between Mount Menzies and Mount Scherger. Large longitudinal crevasses in these ridges increase in size and number eastwards. Some are 20 m wide; others have their lips contorted upwards as steep névé hummocks up to $2\frac{1}{2}$ m high.

Between Mount Bayliss and Mount Scherger, the longitudinal ridges unite in a mass of uplifted and intensely deformed ice several kilometres broad, rising 100 m and more above the margin of the glacier. The surface of the glacier is broken by lateral and diagonal crevasses over 30 m wide, and by high séracs. The area of disturbed ice ranges from 8 km to 15 km in breadth and occupies the centre of the glacier for at least 50 km, from Mount Scherger to Mount Dummet.

The surface of Fisher Glacier appears to be relatively little disturbed between Mount Rubin on the south and Mount Dummet and Mount Seddon on the north, and Ruker (1963) has suggested that the glacier may be crossed here. However, a zone of crevasses may exist along the north side of Mount Rubin.

Fisher Glacier, augmented by Geysen Glacier, is again constricted between Mount Rubin and Mount Rymill, and its surface is raised in two broad areas of crevasses and séracs which converge eastwards into the area of intensely deformed ice which occupies the confluence of Fisher, Lambert, and Mellor Glaciers.

Geysen Glacier has its source in the ice sheet south of Mount Mather at an altitude of over 2000 m. The surface of the glacier south of Mount Menzies is about 300 m higher than the surface of the Fisher Glacier north of Mount Menzies. As a result of its relatively steep gradient, the Geysen Glacier carries many extensive areas of disturbed ice.

West of Keyser Ridge, a succession of névé domes with large crevasses extends northwards towards Mount Mather. A continuous zone, 12 km wide, of large lateral crevasses extends along the north-west side of Keyser Ridge to the north-west side of Mount Ruker, where it broadens to merge with an area of large crevasses extending from the east end of Mount Bayliss. A broad névé dome with large crevasses is located about 5 km south of the west end of Mount Bayliss.

Between Mount Menzies and Mount Bayliss, a steep slope of undisturbed "blue" ice about 300 m high provides a safe route from Fisher Glacier to the south side of Mount Menzies. There are a few small crevasses and pot-holes in the ice at the top of the slope. Debris from the south-eastern cliffs of Mount Menzies accumulates as lateral moraine on this slope, and moves very slowly downhill to augment a broad area of moraine overlying almost stagnant ice at the north-east corner of the Mount Menzies massif. This area of moraine lies in an ice depression about 30 m lower than the southern margin of Fisher Glacier. Some of the moraine has been caught up by Fisher Glacier and has been drawn out across the foot of the slope as far as the broad area of stagnant moraine on the north side of Mount Bayliss.

Although the ice forming this slope is steep, it appears to move very slowly, and is probably cut off from the abundant supply of ice south of Mount Menzies by a submerged rock bar running between Mount Menzies and Mount Bayliss.

The stagnant ice occupying the outer part of the floor of the large abandoned cirque on the north side of Mount Menzies is also depressed about 30 m below the south margin of Fisher Glacier.

A snowfield, about 6 km long from east to west and 2 km broad, lies high on the south side of Mount Menzies close below the summit. This snowfield feeds two glaciers. One, 6 km wide, is a steep mountain glacier which flows a vertical distance of more than 1000 m down the southern cliffs of Mount Menzies, in a series of ice falls. It continues southwards from the foot of the mountain as a distinct up-raised ice stream with large crevasses for at least 3 km before it loses its identity in the great mass of ice flowing north-eastwards towards Mount Bayliss. The other glacier fed by the snowfield flows gently eastwards for 6 km along the broad east ridge of the mountain and terminates among the patterned moraine at the south end of the platform on the east side of the mountain.

The present accumulation rate of snow on the south side of Mount Menzies is evidently great enough to feed these glaciers, though one large and several small mountain glaciers previously occupying cirques on the north side of the mountain have been starved out of existence.

VII. SEA ICE OBSERVATIONS

Observations on the formation and distribution of sea ice, and measurements of ice thickness, were continued at both Mawson and Davis during 1958 and at Mawson in 1959. Crohn (1959) has given an account of sea ice observations at Mawson in 1955 and 1956, and Mellor (1960b) an account of sea ice thicknesses and general observations at Mawson and Davis from the establishment of these stations to early 1958. A diary of sea ice conditions at Mawson in 1958 and 1959, and observations made further afield in those years, are given in the Appendix.

No formal measurements of sea ice were made by the geologist in 1961 (D. S. Trail), but a journey he made by dog sledge to the Auster Rookery, 55 km east of Mawson, in July and August, and another to Kloa Point, 270 km west of Mawson (Fig. 7), in August to October, gave ample opportunity for casual observations and provoked a strong interest in the condition of the ice. The observations by Trail are recorded by him below, in section VII (c) and (d).

Localities in the vicinity of Mawson referred to in the following sections are shown in Fig. 7.

(*a*) *Mawson, 1958*

A detailed log was kept of sea ice conditions at Mawson through 1958 and early 1959. While the author was away in the field, a very full account of the formation of the ice was kept by the late Flight Lieutenant H. O. Wilson, and of part of the period of break-up by Wilson and R. Arnell. Their observations are summarized below.

In 1958, the harbour at Mawson was first completely covered by ice on 6 April, except for a small polynya in the south-east corner of the harbour. Thereafter, the sea ice in the vicinity of Mawson continued to thicken to a maximum in mid-October.

TABLE 5

Sea Ice Thickness, Mawson, April to October, 1958

Date		Harbour		West of West Arm	
		inches	cm	inches	cm
April	7	9½	24		
	10	12½	32		
	13	14¾	37		
	15	16¼	41		
	17	17¾	45		
	18	18¼	46		
	30	25½	65	27	69
May	7	27½	70	29½	75
	14	29	74	30½	77
	21	32¾	83	34	86
	28	34	86		
June	9	36½	93	38¼	97
	18	38¼	97	40	102
	25	40	102		
July	5	41	104	42¼	107
	9	41½	105	42½	108
	16	42¼	107	43¼	110
	23	43½	110	44½	113
	30	45½	116	46½	118
August	6	48	122	48¼	123
	13	50½	128	49½	126
	20	51½	131	50½	128
	29	54	137	52¾	134
September	3	55	140	54	137
	10	55¾	142	54	137
	19	57½	146	56¼	144
	24	58½	149	57	145
October	1	60¼	153	58	147
	8	61	155	58½	149
	15	62	157	59	150
	22	61¾	157	59	150

Thicknesses were measured in the centre of the harbour, and at a point 200 metres west of the tip of West Arm (Table 5; Fig. 8). Ablation of the sea ice also was measured at the site 200 metres west of West Arm by three bamboo poles. Until mid-October, the ice here was covered by snow for most of the time. The thickness of the snow layer changed irregularly as snow was deposited during blizzards or stripped from the surface by high winds.

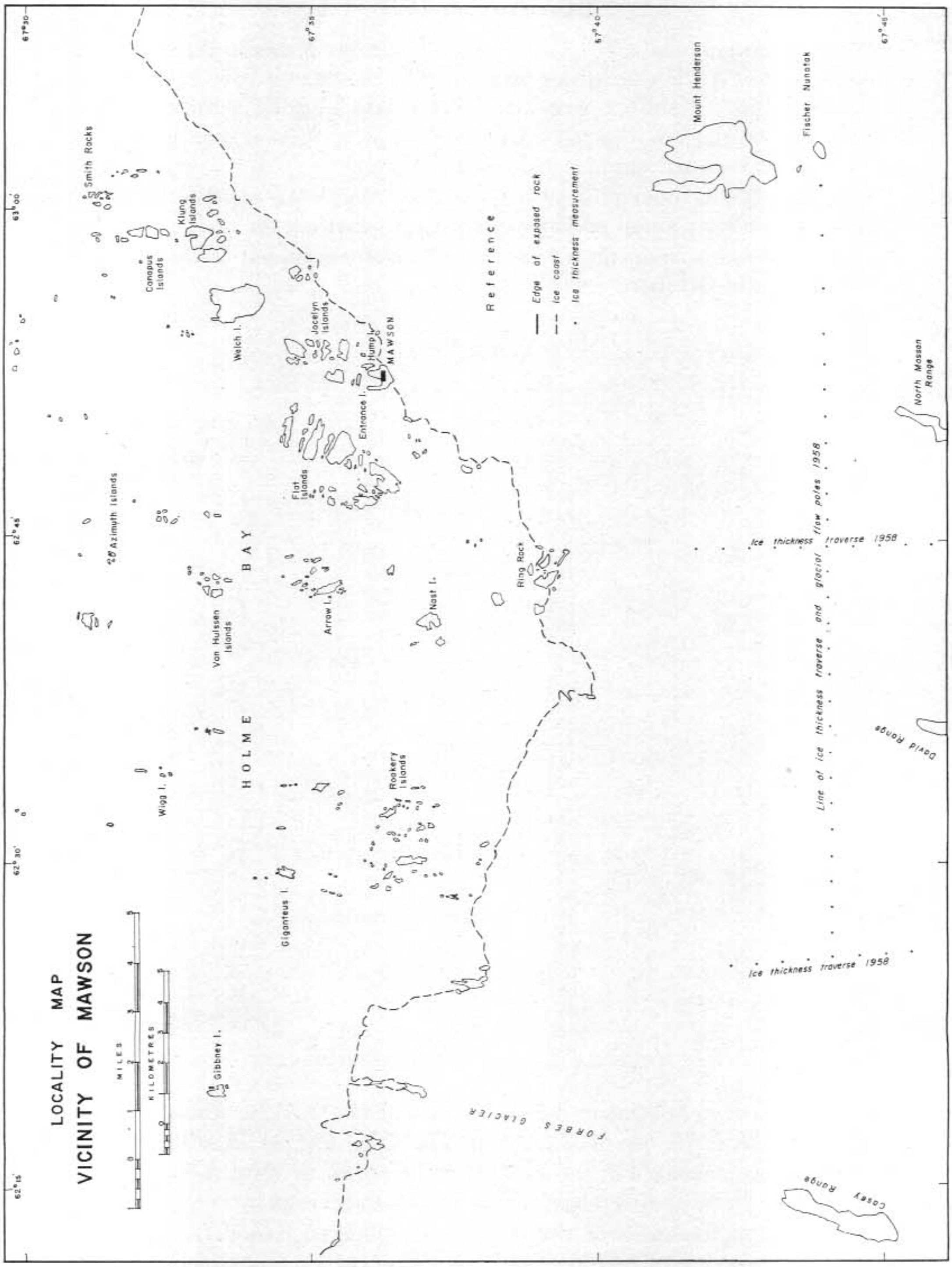


FIG. 7. Locality map, vicinity of Mawson.

Therefore, until mid-October, when the last of the snow disappeared from the ice at the site, pole height measurements are meaningless, and are not listed.

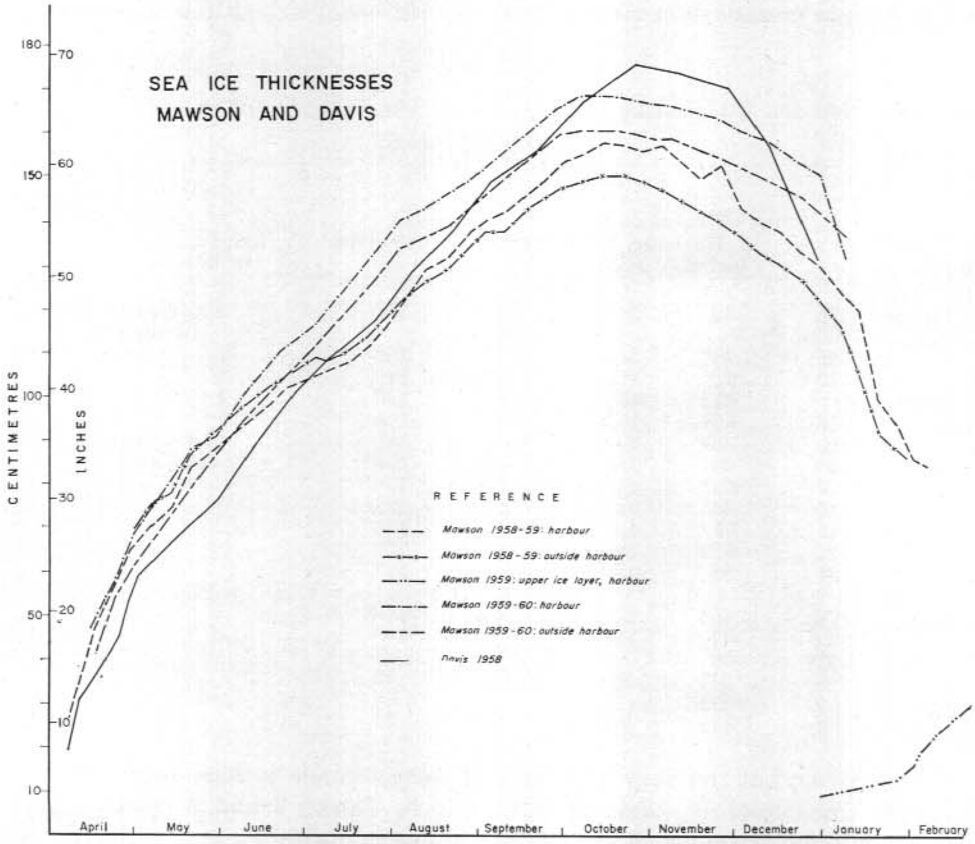


FIG. 8. Sea ice thicknesses, Mawson 1958-59 and 1959-60, and Davis 1958-59.

Check measurements were made at times at various points outside the harbour; with one or two exceptions, the thickness was always within $\frac{1}{2}$ inch of that at the point 200 metres west of West Arm.

The sea ice began to deteriorate in mid-September, but its thickness continued to increase until mid-October. For three weeks in the second half of October and early November, the thickness remained almost constant, and then began to decrease steadily, as shown in Table 6 and Figure 8. For a time, the decrease in thickness was due to ablation from the upper surface rather than melting from below. From 22 October to 12 November, the ablation loss was $1\frac{3}{4}$ inches ($3\frac{1}{2}$ cm) and the nett decrease of thickness $2\frac{1}{4}$ inches ($5\frac{1}{2}$ cm). The total ablation loss was 2 inches (5 cm) between 1 October, when the ice was stripped of snow, and 12 November, when measurements became unreliable due to melting in of the poles.

In mid-November the ice near Mawson divided into three layers, an upper and lower layer of ice separated by water and sludge (see Appendix). The thicknesses of these layers inside and outside the harbour are shown in Tables 7 and 8 respectively. During the author's absence in the field, sea ice thickness measurements were made by different expedition members at various times, but the very soft base of the ice made precise measurement difficult. Consequently, some of the totals in Tables 7 and 8 do not agree with the thickness shown for the same date in Table 6.

TABLE 6

Sea Ice Thickness and Ablation, Mawson, October 1958 to February, 1959

Date		Thickness, Harbour		Thickness, West of West Arm		Ablation	Thickness change by addition to base
		inches	cm	inches	cm	inches	inches
1958							
October	15	62	157	59	150	¼ (from 8 October)	¾
	22	61¾	157	59	150	½	½
	29	61¼	156	58½	149	¼	—¼
November	5	61¾	157	57¾	147	¾	0
	12	60¼	153	56¾	144	⅛	—⅞
	19	58¾	149	55¾	142	(poles melted into ice)	
	26	60	152	54¾	139		
December	3	56¼	143	53½	136		
	10	55	140	52	132		
	17	54	137	51	130		
	24	52¼	133	49¾	126		
	31	51	130	47¾	121		
1959							
January	8	48½	123	45½	116		
	14	47	119	41¼	105		
	21	39	99	36	91		
	28	36½	93	34½	88		
February	2	33¾	86	33¼	84		
	6	33¼	84	32	81		

Deterioration of the ice continued, except for a reversal in late January and early February, 1959. Then, the ice, which had been so soft that it was unsafe to walk on, became hard, and easily able to support the weight of a man. The ice at the northern end of the harbour began to break up on 27 February, and the final breakout from the harbour occurred on the morning of 3 March.

(*b*) *Mawson, 1959*

The pattern in 1959 was not unlike that of the previous year. Ice cover was general by 8 April, except for a few small pools and leads, most of which had vanished by 15 April. As in 1958, the last parts of the sea to freeze were the small bays east and west of the station. Once again, the ice west of West Arm was initially slightly thicker than the ice in the harbour, but this year, it retained the margin throughout the year (Table 9; Fig. 8).

The thickness of the ice remained nearly constant through October. Softening of the ice was first noted on 13 October, below a depth of 2 feet. The division into three layers was not noted until 18 December in the harbour, and on 25 December off West Arm. In 1959-60, there was no major reversal of the deterioration, although periods of low temperature caused some hardening of the ice. M.V *Thala Dan* broke into the harbour through about 1 km of fast ice on 25 January, and moved around the harbour to break up the ice. That night the broken-up ice was blown out to sea by the katabatic wind, and the harbour was virtually clear of ice the next day.

Table 7

Thicknesses of Layers in Sea Ice inside Harbour, Mawson, December 1958 to February 1959

Date	Top inches	Middle inches	Bottom inches	Total inches	Total cm
1958					
December 30	3½	29	13½	46	117
1959					
January 28	5	7-9	22½-24½	36½	93
February 2	6	5-6	22-24½	33-34½	84-88
6	7¾	5¼-6¼	21-23½	35-36½	89-93
11	8½-9½	3-4½	17	29½-30½	75-77
24	11¾	?	?	?	?

Table 8

Thicknesses of Layers in Sea Ice outside Harbour, Mawson, November 1958 to February 1959

Date	Top inches	Middle inches	Bottom inches	Total inches	Total cm
1958					
November 19	24 (approx.)	24 (approx.)	12 (approx.)		
December 31	4	6	38	48	122
1959					
January 17	3	10	27½	40½	103
28	5	3-10	16-23½	29-35	74-89
February 2	6½	5-14½	16-23½	33¼	84
6	7¾	5¾-6¾	18-19	32	81
11	9-10	4¼-5	13¼-14½	28½	72

(c) *Observations in 1961*

In 1961 the sea ice near Mawson was strong enough to carry a dog sledge by the end of April, but all the ice north of Budd Island, 3 km north of Mawson, was broken up and driven out to sea by strong winds from time to time until mid-June, when the last break-out occurred.

By 28 July, firm ice with an almost continuous cover of névé extended more than 25 km north of the coastline between Mawson and Auster Rookery. As far as could be seen, this ice was broken only by a few small holes (1½ m maximum diameter) kept open by seals and emperor penguins, and located close to icebergs near Auster Rookery, or adjacent to various rock islands.

As the dog sledge party travelled westwards from Gibbney Island to Fold Island (Fig. 9), between 22 August and 2 September, the only gaps seen in the ice cover were a few small holes, up to 1½ m in diameter, within 3 km of Taylor Rookery and much used by fishing Emperor Penguins.

Three broad pools of open water, ranging from 100 metres to 1 km in length, were found among the small islands between Fold Island and the mainland, on 3 and 4 September. Night temperatures at this time fell below —20°C and day temperatures did not exceed —10°C.

TABLE 9

Sea Ice Thickness, Mawson, April 1959 to January 1960

Date		inches	cm	inches	cm
		Harbour		West of West Arm	
1959					
April	15	18	46	14¾	37
	23	22½	57	21	53
	30	27	69	24	61
May	20	34½	88		
	28	35½	90	34	86
June	8	40	102	37½	95
	19	43¼	110	40½	103
July	1	45½	116	43½	110
	23	52½	133	50	127
	30	55	140	52½	133
August	8	56	142	53½	136
	15	57½	146	54½	138
	22	58½	149	56	142
September	23	65	165	62½	159
October	1	66	168	63	160
	7	66	168	63	160
	13	66	168	63	160
	20	65¾	167	62¾	159
	27	65½	166	62¼	157
November	3	65¼	166	62¼	157
	21	64	163	60½	154
	28	63	160	59¾	152
December	6	62	157	58½	149
	18	60	152	57	145
	25	57¾	147	55½	141
1960					
January	3	51½	131	53½	136

The only significant gap seen in the ice from Fold Island to Kloa Point, traversed between 8 and 13 September, was a tide crack at Abrupt Island, about 230 km west of Mawson. The crack was about 30 cm wide, and sea water was surging in it.

During the return journey, on 29 September, after a two-day blizzard in which temperatures rose considerably (perhaps to —7°C), a zone, about 1½ m wide, of slushy snow overlying partly melted, mushy sea ice was found around a small iceberg at Broka Island.

On 1 October, after a second blizzard, dark, slushy snow formed many patches up to 30 metres in diameter in white, dry, poorly consolidated snow

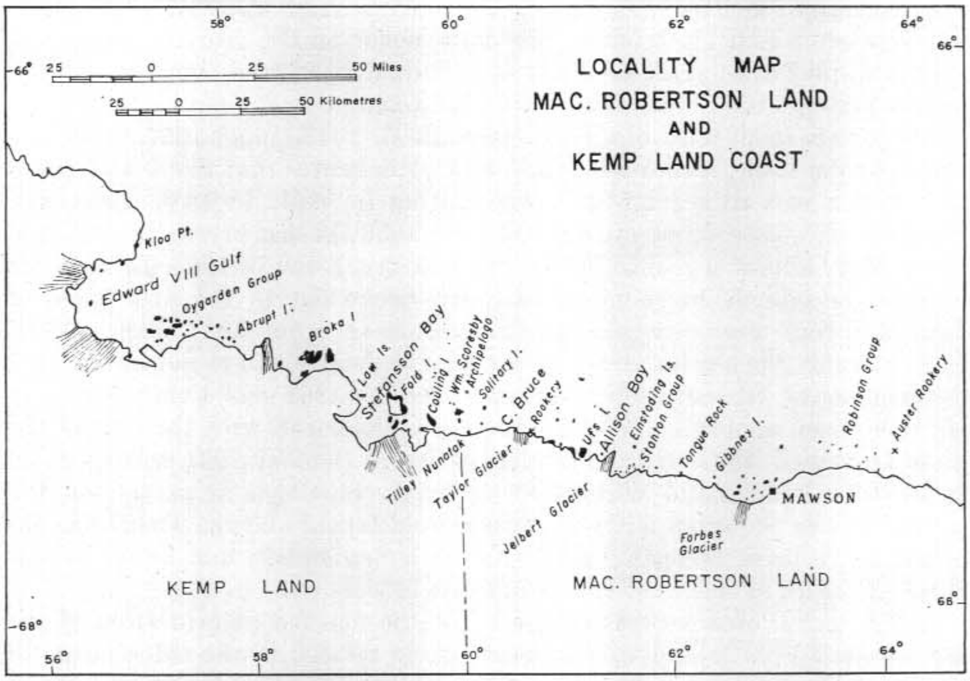


FIG. 9. Locality map, Mac.Robertson Land and Kemp Land coast.

overlying the sea ice across the 12 km breadth of Stefansson Bay. Similar slushy patches were common in thick snow on the sea ice among the small islands between Fold Island and the mainland on 4 October, after a third blizzard. These dark patches were thought to lie on firm ice until members of the party twice plunged through them into the sea; one of these unsound patches was at least 10 m long. Probing revealed that some slushy patches lay on relatively sound ice, but the darkest and largest were composed of 10 or 20 cm of slush lying on what was probably rotten ice.

The three pools of open water observed between Fold Island and the mainland on 3 and 4 September were larger on 4 October and were surrounded by zones of slush 20 metres or more wide. Several additional small pools of open water, up to 100 metres long, had formed.

On the following day, a number of slushy patches were seen in the cover of ½ to 1 m of soft snow between Fold Island and the William Scoresby Archipelago. A pool of open water about 100 metres across was found 2 km south of Couling Island.

The snow on the ice between the William Scoresby Archipelago and Campbell Head, 95 km west of Mawson, had a surface firm enough to support a walking man, and no sign of melting was seen. At Cape Bruce, a few leads up to 2½ m wide were found. The leads were covered by black ice less than 8 cm thick and the snow cover was slushy adjacent to the tide cracks here.

No sign of melting was seen on the journey from Cape Bruce to Mawson between 8 and 13 October. The snow cover on the sea ice diminished east of Cape Bruce, and bare ice was abundantly exposed over the 25 kilometres between the Forbes Glacier and Mawson.

A comparison with observations made in 1955, 1956, 1957, 1958 and 1959 (Crohn 1959; Mellor 1960; and above) indicates that the sea ice cover at Mawson was rather late in consolidating in 1961. In 1955, 1958, and 1959, the ice consolidated during April; in 1956 the last break-out occurred on 22 May, almost a month before the last break-out in 1961. In 1957 ice beyond the islands surrounding Mawson broke out in the first week of June, and four weeks elapsed before it reformed—even later than in 1961. In most years the sea ice at Mawson began to deteriorate in September and October, so the deterioration observed in October 1961 near Fold Island may not have been abnormal. Nevertheless, by comparison with the rest of the coast traversed, the condition of the sea ice in October 1961 was poor between Law Islands and William Scoresby Archipelago. In particular, the sea ice among the small islands between Fold Island and the mainland contained large pools of open water even on 3 September, and by 4 October much of the ice at this locality was not safe to walk on.

The casual observations suggest that the marked deterioration of the sea ice near Fold Island was at least partly related to the thick cover of unconsolidated snow. Remarkably, the thick bay ice noted by Crohn (1959) in several places between Fold Island and the mainland was also prominent in 1961, and one patch of it was less than 200 metres from a broad pool of open water noted in September and October 1961.

(*d*) *Pressure ice*

Pressure ice is composed of ridges and hummocks of flakes and blocks of sea ice thrust above the general level of the sea ice sheet. It may form a formidable obstacle to travellers.

In 1961, pressure ice was prominent at four localities (Fig. 9): near Auster Rookery, off the tongue of Jelbart Glacier, in and around William Scoresby Archipelago, and in Edward VIII Gulf.

The Auster Emperor Penguin rookery is 15 km offshore among a mass of large icebergs covering an area about 15 km long and 8 km wide. In 1961 the approach to the rookery from the west was over pressure ice composed of irregular masses of blocks and slabs of ice, forming ridges and hummocks mostly from 15 cm to 1 m high; a few reached a maximum height of 1½ m. The pressure ice extended about 5 km west and south-west of the rookery and appeared to be highest adjacent to the almost unbroken, north-trending line of large icebergs (up to 400 m long) about 5 km west of the rookery. No pressure ice was seen west of this line of icebergs and it is inferred that the pressure ice here is produced by the prevailing south-east wind pressing and fracturing ice floes against the line of presumably grounded icebergs.

A small area of pressure ice noted in 1956 by Crohn (1959) north-east of Tongue Rock was also seen in 1961.

Crohn (1959) records pressure ice in 1956 extending from about 3 km east of Einstoding Islands to the mainland in the south and to the Jelbart Glacier tongue in the west. Pressure ice in 1961 occupied a significantly different area: from a point about 2 km west of Einstoding Islands, the southern boundary of the pressure ice ran for 8 km south-westwards to within a few hundred metres of the snout of Jelbart Glacier. The southern boundary continued westwards from Jelbart Glacier for 12 km towards the north end of Ufs Island, where the ridges and hummocks died out. The northern limit of the pressure ice was not observed.

In 1961 the pressure ridges and hummocks in this area were formed by small flakes and blocks of ice and had a maximum height of about 1 m. W. R. Wyers (glaciologist at Mawson in 1961) noted a continuous smooth-floored channel about 3 m wide and ½ m to 1 m deep, which followed an almost straight course through the pressure ice for more than 2 km northwards from Jelbart Glacier tongue. Wyers interpreted this as a shear in the ice cover caused by the thrust of Jelbart Glacier.

A comparison with maps made from airphotos taken in 1956 showed that a promontory of the ice coast between Ufs Island and Allison Bay had disappeared by 1961. The promontory, which had the form of an equilateral triangle with sides of about 3 km, had broken up to form a group of icebergs, some over 400 m long. It appeared likely that the northward drift of these icebergs under the influence of the wind had at least partly caused the deformation of the large area of sea ice between Einstoding Islands and Ufs Island, but the existence of a lane of smooth ice several hundred metres wide between the icebergs and the pressure ice seemed to contradict this theory.

In 1961, pressure ice extended from Solitary Island west for 8 km to William Scoresby Archipelago and 5 km south to the coast at Tilley Nunatak. The northward limit of the pressure ice was not observed. This pressure ice was composed principally of west-trending ridges of ice blocks and slabs, up to 1 m high, though many ridges ran at various angles to this trend.

Several small areas of pressure ice less than ½ m high were observed in 1961 between William Scoresby Archipelago and Couling Island.

R. A. Ruker and S. Kirkby (personal communications) reported severe pressure ice along the north side of Edward VIII Gulf in April and June 1960. The party crossing the mouth of this gulf in September 1961 found pressure ice in two westward-trending zones, each about 6 km broad (Fig. 10). The northern zone was adjacent to the north shore of the Gulf, the southern zone to the Oygarden Group. Both zones broadened westwards and appeared to converge towards the head of the Gulf.

The southern zone in 1961 was composed of ridges aligned approximately parallel to the south shore of the Gulf. The ridges were commonly

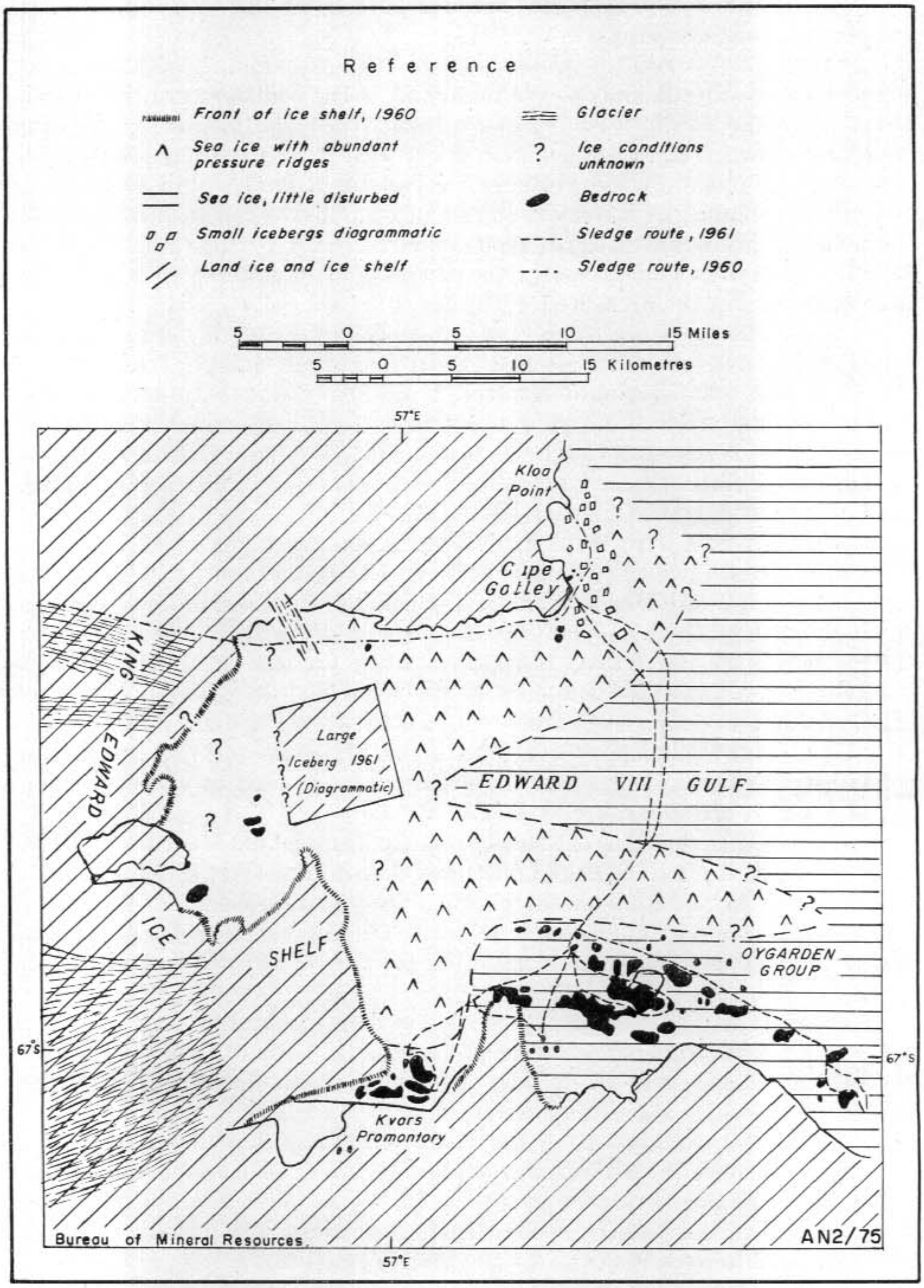


FIG. 10. Diagram of ice conditions in Edward VIII Gulf, September 1961.

1½ m high and had a maximum height of about 2½ m. They ranged up to 30 m in width. The ridges were composed of large slabs and blocks of ice with gently sloping to vertical attitudes. The spaces between the blocks were filled with unconsolidated snow or were scoured out by the wind. Slabs 1½ m long and ¼ or ½ m thick were common; a few slabs probably exceeded 3 m in length.

The northern zone along the route taken by the 1961 party was basically a group of ridges similar to those in the southern zone. They were aligned parallel to the shore, but other ridges intersected them, producing peaks estimated at between 4 m and 5 m high, separated by saddles 2 m high. The hollows among the intersecting ridges were commonly floored by tilted blocks and slabs rather than by level sea ice.

The zones were 13 km apart at the line of the 1961 traverse. Between them were some isolated pressure ridges, hundreds of metres apart, and mostly less than ½ m high, separated by wide fields of level sea ice.

The deformed ice on either side of Edward VIII Gulf may be a result of the seaward movement of the ice in the centre of the Gulf, impelled by the King Edward Ice Shelf past the ice held fast by the islands and small glacier tongues which line the north and south shores of the Gulf. Alternatively, the prevailing south-east wind may force sea ice into Edward VIII Gulf and produce pressure ridges around the edges of the Gulf.

Mellor (1960) observed that ice at the west end of the Oygarden Group persisted for at least 18 months (winter, 1956 to December 1957) and he suggested that bay ice could persist over the whole of Edward VIII Gulf.

In February 1960, Styles (1964) observed that Edward VIII Gulf was choked with ice, and the presence of floes, 3 to 4 m thick, recorded by Styles off the mouth of the Gulf suggests that at least some bay ice exists in it.

Possibly pressure ice may recur in approximately the same locations, year after year, on this coast, and a periodic survey of the pressure ice would assist in determining its origin.

(*e*) *Davis, 1958*

An account of sea ice conditions and thickness in 1958 and early 1959 was kept by P. B. Turner, who supplied the following information.

On 9 March 1958, the bay in front of the station was ice-free, but to the south, Heidemann Bay was completely ice-covered and ice was forming to the north of the station. By 12 March, ice extended to the horizon, with the exception of a few isolated areas, and by 17 March, the ice cover was complete, and was 4 inches (10 cm) thick.

Two days later a number of breaks appeared and after three days, open water was visible 2 km from the station. On 25 March, there was open sea 2 km from the station; the remaining ice was 7 inches (19 cm) thick. On 29 March, the ice broke up rapidly under blizzard conditions, and the

TABLE 10

Sea Ice Thickness, Davis, April 1958 to December 1958

Date		Thickness	
		inches	cm
April	7	7–8	18–20
	11	12	30
	18	14½	37
	22	16	41
	25	17½	44
	29	21	53
May	2	23	58
	16	26½	67
	30	30	76
June	13	35	89
	27	39½	100
July	11	43	109
	26	46	117
August	8	50½	128
	22	54	137
September	5	58½	149
	20	61	155
October	7	65½	166
	27	69	175
November	15	68	173
	28	67	170
December	13	61½	156
	31	51	130

following day, open water extended from the shore in front of the station to the south-west horizon.

Ice was reforming by 3 April, and by 7 April, the cover was again complete. The new ice was 7 to 8 inches (18 to 20 cm) thick, and remnants of the old ice were 12 inches (30 cm) thick. Thereafter, the ice near the station thickened steadily to a maximum in late October (Table 10; Fig. 8).

In the period from 11 April to 15 November, the nett surface loss by ablation was ¾ inch. Although the ice remained fast near the station, open water could be seen outside the nearby islands after blizzards. From the air, a lead several kilometres wide could usually be seen about 7 km offshore from Davis, extending past Rauer Islands to near Svenner Islands. The ice cover in Prydz Bay and MacKenzie Bay was generally thin, and great expanses of open water were seen from the air on several occasions. A strip of fast ice many kilometres wide remained along the western edge of MacKenzie Bay from near Cape Darnley to the junction of the Amery Ice Shelf with the ice sheet.

On 20 January 1959, the edge of the fast ice was along the seaward edge of the islands west of the station, and extended north-east from Magnetic Island. The ice towards the shore was very rotten. The average thickness broken by M.V. *Thala Dan* increased from 33 inches (84 cm) near Turner Island to 45 inches (114 cm) near Bluff Island. In places, it was 60 inches (152 cm) thick. The seaward part of the fast ice was quite hard; towards the coast, it became more rotten. On 27 January, after high winds on the previous two days, the only ice remaining was between the coast and Trigwell, Flutter, and Lake Islands.

VIII. ACKNOWLEDGMENTS

The author acknowledges with pleasure the assistance given on many occasions by his fellow expedition members. Appreciation is due especially to the surveyor, Mr. G. A. Knuckey, who made the surveys associated with the glaciological work, and assisted in many other ways; the pilots of the RAAF Antarctic Flight, Squadron Leader I. Grove and the late Flight Lieutenant H. O. Wilson, for observations related to various aspects of the work; and Mr. I. L. Adams, the officer-in-charge at Mawson in 1958, who took an interest in the work at all times. While the author was absent in the field during part of the periods of sea ice formation and deterioration, a very detailed account of sea ice conditions was kept by Flight Lieutenant Wilson, and Messrs R. A. Borland and R. Arnel continued routine glaciological observations. B. H. Stinear and D. S. Trail, of the Bureau of Mineral Resources, kindly made available the observations they made in 1959 and 1961 respectively.

During the preparation of the report, the author was assisted by discussions with Dr. U. Radok, of the Meteorology Department, University of Melbourne, who gave much helpful advice on glaciological matters; Dr. Radok, and Mr. W. Budd, also of the Meteorology Department, kindly read the manuscript. All conclusions remain, however, the author's responsibility.

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APPENDIX

DIARY OF SEA ICE CONDITIONS, 1958 AND 1959

Mawson and environs, 1958

A considerable amount of spray ice had formed on the rocks around the harbour at Mawson by the end of February 1958, and pancake ice and sludge covered the surface of the sheltered inlet at the foot of Gauss Gully (which is on the south-eastern side of the rock outcrop on which the station is built). Frazil ice was first seen on the harbour on 2 March, but was dissipated by wind within a few hours. This pattern of frazil ice formation and subsequent dispersion re-occurred almost every day in the succeeding three weeks, and sludge also formed on several occasions. Pancake ice formed in the sheltered south-east corner of the harbour, near the aircraft hangar, on 18 March.

On 21 March, frazil ice and sludge covered most of the harbour at Mawson, and during the night of 22-23 March, ice formed to windward of the nearby islands. A strip of shore ice formed along the western side of the harbour; this was 30 m to 45 m wide along most of the length of West Arm, then narrowed to 1 to 5 m, and extended in an arc from the tip of West Arm to the western end of Entrance Island. By the evening of 23 March, wind had broken up the strip between West Arm and Entrance Island. Most of the remaining ice in the harbour was broken up by wind and swell the next day, and on 25 March, the final portion, which had attained a thickness of 8 inches (20 cm), was also blown out to sea. The ice between the islands east and north-east of the harbour continued to spread; on 25 March, its thickness ranged from 3 to 11 inches (7½ to 28 cm); by 27 March, the thickness had increased by an average of 3 inches (7½ cm). With the exception of the strip between Hump Island and East Arm, this ice was all blown out to sea by a blizzard on 29 March.

Meanwhile, members of the seismic party, then working near Mount Henderson, observed on 22 March that a ⅞th ice cover, with long north-south leads, extended seaward from Van Hulssen Island to the horizon. On 24 March, this had decreased to a ⅜th cover, and the shore lead had widened considerably, although the Flat Islands were all joined by ice. The ice had increased again to a ⅞th cover by the next day.

On the afternoon of 31 March, new ice formed on the eastern side of West Arm, and by 2 April, had covered two-thirds of the harbour; four days later, the harbour was covered, with the exception of a small area near the hangar. The advancing front of this ice was 1 to 1½ inches (2½ to 4½ cm) thick. A distinct line remained on the surface where the advance stopped for some hours on 3 April. Next day, the thickness was 6½ inches (16½ cm) on one side of the line, and 3½ inches (9 cm) on the other. The following day, the thickness at ten points in the harbour averaged 7½ inches (19 cm) with extreme values of 6 and 9 inches (15 and 22½ cm).

During the first two days of April, the ice advanced south-eastwards from the Flat Islands to the northern tips of West Arm and Entrance Island. The freeze-up was rather slower east of Mawson, but by 4 April, ice cover was general and the only patches of open water were a small coastal polynya along the west coast, two polynyas against the ice cliffs east of Mawson, and one extending from south-west of Welch Island to the coast of the continent. At various times, other polynyas (including a large one north of Flat Islands) were formed by strong winds but, by 10 April, as far as could be seen from a height of 75 m behind Mawson, the ice cover was complete. The last parts to freeze over were those where the wind was channelled down small valleys in the ice sheet; these were presumably prevented from freezing by the stronger winds coming from these valleys. H. O. Wilson has suggested the name "wind ponds" for such small polynyas.

The thickness of the ice increased steadily during the late autumn, winter, and early spring. During this period, the ice was mostly covered by snow, especially away from the coast, where sastrugi a metre or more high were commonly seen. Between Mawson and Taylor Glacier, much of the ice within a kilometre or two of the coast was kept bare by wind turbulence near the edge of the ice sheet. Around Mawson, part of the snow cover was permeated by seawater, so that patches of snow, some of them 5 cm thick, were in effect "welded" permanently to the sea ice.

The first signs of deterioration of the ice appeared in September, when seaweed and dark rubbish on the ice began to melt into it. About the same time, the lower part of the ice became porous, so that seawater quickly filled a hole drilled to within 45 cm of the base of the ice.

By November, pieces of debris lay in water-filled pot-holes half a metre deep. Pools of water several centimetres deep formed even under patches of oil on the ice. The snow cover was stripped from the ice and the surface became dimpled by small pits which spread and deepened, so that in places it became cusped like the ablation zone of the ice-sheet. The ice was crazed by thin cracks, and the water which welled up through the tide cracks around the shoreline in ever greater amounts did not re-freeze; this upwelling was most marked in front of the hangar where the aircraft was moved onto the ice, and caused the termination of flying operations.

In mid-November, the bottom half-metre of the ice became soft and mushy, and shortly after, the ice divided into three layers. The upper layer was hard, the middle one contained water or sludge, and the lower one was at first moderately hard, and later, soft, porous, somewhat columnar ice. In general, the hard crust was of roughly the same thickness from place to place, whilst the middle and bottom layers showed considerable variation, especially in the early stages of the division. Large, platy ice crystals projected down from the base of the top layer, or lay on the upper surface of the lowest layer. This partitioning was at first patchy and marked by a dark surface colour, so that it was possible for a ski-equipped Soviet LI2 aircraft (similar to a DC-3) to land north-west of the harbour as late as 18 December. In a few places there was only a hard upper layer, 2 to 5 cm thick, with nothing but water beneath.

By 12 December, the sea ice surface was covered by a white crystalline crust, and on 27 December the ice assumed a bluish-grey colour, giving the appearance of being completely waterlogged. On 13 January 1959, a pool formed in the south-east corner of the harbour; although frazil ice and pancake ice formed on this at times, and its size varied, it remained unfrozen for some time.

Towards the end of January, there was a reversal in the general deterioration of the sea ice. On 18 January, the frazil ice which formed overnight on a pool below the camp did not dissipate, and thereafter, although the pool increased slightly in size, frazil ice covered at least part of the surface. Pancake ice formed on it on 27 January and during a blizzard from 27 to 29 January, the surface of this pool and the one below the aircraft hangar were completely covered by snow, under which ice formed; by 6 February, this ice was 8 inches (20 cm) thick.

M.V. *Thala Dan* broke into the harbour on the morning of 4 February. New ice immediately began forming in the broken-up area behind the ship. Forty-eight hours later, this ice ranged from 2¾ inches (7 cm) to 3¼ inches (9 cm) in thickness; on 11 February, it was 4½ inches (11 cm) thick, and on the 24 February, 10 inches (25 cm).

The first signs of breakout of the sea ice in the Mawson area were reported by the returning seismic party who, on 15 January 1959, saw two leads extending north-west and north-east from a point about 15 km north of Mawson. By 21 January, these had increased to a large Y-shaped lead, one arm extending north-east for 15 km, the other broadening to the north-west horizon. By 24 January, the western arm had widened considerably, and was partly filled by pack ice, and the eastern arm also extended to the horizon; the southern end of the open water was near Gibbney Island.

Three days later, after high winds, open water extended from 12 km north of Mawson in an arc from the north-west to the north-east horizon, and there was a polynya near Welch Island.

On 1 February, after a blizzard, the edge of the remaining fast ice extended from the coast west of Rookery Islands, thence 10 km north of Mawson to beyond the Robinson Group. On 9 February, the seaward edge ran from Welch Island to the northern Flat Islands, thence to Arrow Island and Rookery Islands; two days later, when M.V. *Thala Dan* sailed, the edge of the remaining ice ran from the coast near Canopus Islands along the seaward edges of this group, to Welch Island, Jocelyn Islands, Flat Islands, Arrow Island and Nost Island, and thence to the coast. The ice edge was deeply embayed where it was not protected by the islands.

B. H. Stinear reported that, by 21 February, open water extended westwards along the coast west of Mawson. The ice at the northern end of the harbour at Mawson started to break up on 27 February, and final break-out from the harbour took place on the morning of 3 March.

Other observations, 1958

During 1958, open water along the coast was reported on several occasions:

13 April. A shore lead, about 5 km wide, extended along the part of the coast of western Holme Bay which was visible from near the north end of Masson Range, with several parallel leads to seaward. These were completely re-frozen by 22 April.

16 April. Numerous leads and cracks occurred among the icebergs near Auster Rookery. All were re-frozen by 14 May, and no open water was visible on the 29 May.

15 May. Open water was present in the vicinity of Scullin Monolith. Open water occurred in this area every time it was seen during the year, the greatest extent being from near Stephens Island to the east of Cape Darnley, on 3 August. On most occasions the sea surface was whipped to foam by strong winds. When ice was seen in this vicinity, it always appeared thin, and was usuallly gone a few days later. The persistent open water, and the experiences of the aircraft party which force-landed in the vicinity in August 1958, and of Dovers' party in 1954, show that this is an area of violent prevailing winds.

17 July. Open water extended to the horizon from north of Gibbney Island to the Stanton Group. Water sky was seen to the north-north-west of Mawson on 17 May, and the effect was very strong after 19 June. This area was completely re-frozen by 21 July.

25 September. Fifty kilometres north of the Stanton Group, water with a thin ice cover extended 50 km from east to west and 25 km from north to south. Open water was seen here on several later occasions, reaching to within 50 km of Mawson. Water sky was seen from Mawson from 23 July onwards, in this direction.

9 November. A pool of open water was present in the south-east corner of William Scoresby Bay.

10 November. Extensive break-out had occurred, leaving the ice edge about 50 km offshore, from near Cape Boothby to north of Gibbney Island; a salient penetrated to within 30 km of the coast, from the south-east corner of the area which had broken out.

9 December. From a height of 10,000 feet above the Robinson Group, the eastern edge of the sea ice was seen to run north from the coast at about 65½°E, then to curve around to the west at about 67°S to meet the eastern edge of the break-out noted on 10 November. Pack-ice could be seen a few kilometres north of this fast ice.

During the year, ice thicknesses were measured at several places along the coastline. The results are shown in Table A.

TABLE A

Sea Ice Thicknesses other than at Mawson and Davis, 1958

Date		Thickness	
		inches	cm
May			
30	Islands used as camp south-west of Auster Rookery, north-east Robinson Group	31	79
August			
3	1½ km north-north-east of Wigg Island	42½	108
3	2¼ km south-east of Wigg Island	44½	113
3	2¼ km east of Arrow Island	46	117
September			
13	Depot in Oygarden Group	59½	151
October			
16	Half-way between West Arm and Flat Island	54¼	138
16	Half-way between Flat Island and Jocelyn Islands	55¼	140
November			
22	Amundsen Bay, off north-west corner of Mount Oldfield	56	142

Mawson and environs, 1959

Sea ice began to form at about the same time in 1959 as in 1958. On 7 March, light frazil ice extended out from the coast for about 15 km, with open water beyond. Ice commenced forming on the harbour on 21 March, but open water remained to the east, north, and west until 8 April, when a general freeze-up occurred. The only open water then remaining was in the small bay west of Mawson, along the ice cliffs about a kilometre east of the station, and a lead extending from the tips of each of West Arm and East

Arm. The sea was completely frozen by 15 April, except for a few short leads off the end of West Arm, and possibly a lead off Welch Island. The ice thickness at six points north and north-west of the tip of West Arm, about 120 m apart, ranged from 13 to 15 inches ($32\frac{1}{2}$ to $37\frac{1}{2}$ cm). The ice in the harbour the same day was 18 inches (45 cm) thick.

The thickness of the ice continued to increase steadily, both in the harbour and west of the tip of West Arm, until late September. The thickness at both places remained almost constant throughout October, with a slight decrease in the latter part of the month. For most of the winter and early spring, the ice was covered by patchy snow, which was rarely more than 5 cm thick.

On 13 October, the ice off West Arm was wet and mushy downwards of 60 cm below the surface. The ice in the harbour was also wetter than it had been, but not to the degree of the ice off West Arm. This state, of a hard upper layer and a soft, mushy, lower layer, persisted. On 21 November, the lower layer was very wet below 45 cm and water came into the hole about 75 cm below the surface, while on 28 November, the ice was very wet, and water came into the hole about 30 cm below the surface. On 18 December, water entered the test hole in the harbour when it was 30 cm deep. There was a layer of soft ice from 12 to 13 inches (30 to $32\frac{1}{2}$ cm) below the surface, with firm ice below this. The same division into three layers was noted off West Arm on 25 December: an upper layer of ice 7 to 8 inches (18 to 20 cm) thick, below which was 2 to 3 inches (5 to $7\frac{1}{2}$ cm) of water, then soft, waterlogged ice. The upper layer of ice in the harbour on the same day was 8 inches (20 cm) thick, with 4 inches (10 cm) of water then soft ice, with some hard layers, below it. The sequence in the harbour on 3 January was: 8 inches (20 cm) of honeycombed and weathered ice at the top, then 10 to 12 inches (25 to 30 cm) of waterlogged ice and water, with the ice hard in places and soft in others; the layer below this was fairly uniform in character, firm but not hard. The layers in the ice off West Arm were similar to those in the harbour; the thicknesses of the upper two layers were 12 inches (30 cm) and 8 to 10 inches (20 to 25 cm).

On 2 December, the sea ice in the harbour had a grey, sodden appearance, and the surface was becoming very cusped. The ice in front of the hangar was covered by 20 cm of water; that night, water flooded through the tide-cracks to a depth of $\frac{1}{4}$ metre and more. There was obvious deterioration of the ice on 7 and 8 December, two days of above-freezing air temperatures; but the ice was still solid on 18 December, except where dark material on the surface had caused partial melting. Melting was particularly noticeable north of the tip of West Arm, where seaweed was common on the ice, and a lead $1\frac{1}{2}$ m wide extended seawards. On 22 December, the tide crack around the harbour was impassable and the leads outside the harbour were opening up, and on 30 December, the sea ice surface in the harbour was very rough and soft, with several holes and short leads, which increased in number over the next few days.

From then on, the ice continued to deteriorate, with occasional slight reversals because of low air temperatures. The ice in the harbour was broken up by M.V. *Thala Dan* on 25 January 1960, and was blown out to sea that night. The ice moved out of the small bay west of Mawson on 31 January, and this bay and the one east of Mawson were clear of ice by 2 February.

Open water was observed north of Mawson from the air on 14 August. It was again noted on 4 November. It was then less extensive; the northern edge of the fast ice was 75 km north of Mawson, and pack ice with narrow open leads extended from the fast ice to the horizon. An aerial reconnaissance on 1 December revealed that the edge of fast ice extended east and south-west from the north-west end of Mawson Corridor (a lane of open water through a mass of grounded icebergs, extending for about 40 km north-north-eastwards from a point about 50 km north of Mawson). To the north and north-east, the cover of pack was complete to the horizon, except for a few small pools and leads. To the north-west, the pack was broken, with many wide, open leads extending into a large area of open water west of Mawson Corridor. The east edge of the open water bore south-west to a point 50 km north-west of Mawson, thence west-north-west. The extent of open water from east to west was 40 to 50 km; beyond this was a $\frac{7}{8}$ cover of pack, with many leads and pools. Similar conditions existed on 11 December.

On 19 December, the south-east corner of the open water was 15 km north of Tongue Rock, that is, 15 km south of its position on the 11 December. Two days later, open water had reached the coast 2 km east of Tongue Rock; the outer edge of the pack ice was within 10 km of Rookery Islands, and the sea ice between Rookery Islands and the coast was breaking up. Two leads extended south-eastwards through fairly dense pack to within 12 km of Welch Island. An open pool was observed about 12 km north of Welch Island the following day.

Further aerial reconnaissance on 24 December showed that the skerries north-west of Rookery Islands were in open water, which extended northwards to the horizon. The water's edge was along the west side of the line of icebergs on the west side of Mawson Corridor, that is, in much the same position as it had been on 1 December. Ice still existed around Rookery Islands, and between them and the coast, but it was breaking up and contained many small pools. The ice around Gibbney Island was also breaking up, and open water was within 5 km of the north and west of the island.

On 30 December, from the hill behind Mawson station, open water was seen to extend from the west to the north-north-west, about 12 km distant; no open water could be seen to the east and north. On 1 January 1960, conditions to the west around to the north-north-west were much the same, but to the north and north-north-east, open water was continuous from the horizon to within 20 km of the station.

Two days later, open water had reached the coast south of Rookery Islands. From there, the edge of the remaining fast ice trended north and north-east at about 11 km radius from Mawson. Van Hulssen Island was still ice-bound; Canopus Islands were at the edge of the ice. Open water extended as far as could be seen to the east. On 12 January, the edge of the fast-ice extended from the coast south of Rookery Islands to the north end of the Arrow Island group, thence to the north side of Van Hulssen Island, east to the north-west corner of Welch Island, and farther east to the middle of Canopus Islands. By 16 January the ice to within 3 km of Mawson had broken out. The ice was still breaking up slowly on 19 January. It began to break up in West Bay on 23 January, and by 2 February, the coast on either side of Mawson was free of ice.

Other observations, 1959

Sea ice thickness at Taylor was measured on two occasions during the year; it was 38½ inches (98 cm) on 11 June, and 55 inches (140 cm), with a covering of 4 to 6 inches of hard snow, on 4 August.

Observations on sea ice conditions to the east and west of Mawson were made during some aircraft flights. As in earlier years, open water was often sighted in the vicinity of Scullin Monolith.

15 August. Open water came to 25 km north of Scullin Monolith and reached the coast between Point Williams and Cape Darnley.

23 August. The western edge of the open water met the coast between Scullin Monolith and Murray Monolith. MacKenzie Bay was ice-free; open water was 8 km off Larsemann Hills, and extended to Svenner Islands and northern Rauer Islands, and to within 300 metres of Sörsdal Glacier, south of Vestfold Hills.

20 September. Open water had encroached to Mule Island, off the south-west of Vestfold Hills, and to the tip of Sörsdal Glacier. The pattern to the west was much the same as on 23 August, except that there were patches of thin ice over the south end of MacKenzie Bay.

11 December. The western edge of open water along the coast was about 8 km west of Scullin Monolith; west of this, an embayment penetrated southwards from the horizon to within 8 km of the coast north of Mount Rivett. Off Davis, water came to the western shores of the inner islands.

17 December. MacKenzie Bay was again clear of ice. The edge of ice bounding the open water on the north extended from the cape on the north-east side of the bay westwards to meet the west side of the bay 40 km north of its head. The north edge of this ice met the coast 8 km south of Cape Darnley, and from Cape Darnley to Cape Rouse, open water stretched from the coast northwards to the horizon. Open water came to within 3 km of the coast from 25 to 40 km west of Scullin Monolith.

19 December. Open water west of Mawson came to within 15 km of Tongue Rock (see preceding section). The edge of fast ice was 15 to 20 km off the coast at Mule Point. From Mule Point, the ice edge swung north-west past Edward VIII Gulf and appeared to swing into the coast again about 15 km west of Wheeler Bay.

21 December. Open water had reached the coast between Tongue Rock and just east of Stanton Group. The edge of the pack ice then trended north-west to the west edge of Stanton Group. West of this, conditions were similar to those of 19 December.

24 December. The ice edge between Mawson and Edward VIII Gulf was much the same, although the ice had deteriorated noticeably.