AUSTRALIAN GLACIOLOGICAL CONTRIBUTIONS IN ANTARCTICA

PRELIMINARY REPORT

By M. Mellor
(Glaciologist, Australian National Antarctic Research Expedition)

Abstract. The glaciological work of the Australian National Antarctic Research Expedition in 1957-58 is described, and some results are given in general terms.

Zusammenfassung. Die glaziologischen Arbeiten der australischen National Antarctic Research Expedition während 1957/58 werden beschrieben und einige der Ergebnisse angedeutet.

Introduction

In 1954 an Australian research station, Mawson, was established on the coast of MacRobertson Land, Antarctica, by the Australian National Antarctic Research Expeditions (A.N.A.R.E.). Since that time the base has been continuously occupied, but until 1957 no glaciologist was numbered amongst the party. Prior to 1957 some glaciological observations were made by the geologists, and these results now prove to be of great value. The scope of the investigations was widened considerably for the I.G.Y., and this programme will be maintained until January 1959.

I.G.Y. Programme

For a small expedition it is often difficult to decide whether the investigations of a particular discipline should be spread over a wide field or confined to intensive work on a specific problem. However, with a completely untouched field and the difficulty of collecting elaborate equipment in the time available, the decision to collect glaciological data on as many aspects as possible was easily arrived at. Shortage of manpower complicated all plans and glaciological work was made to dovetail into the work of other field parties as far as possible. Easy availability of light aircraft was a great help and the 100-day southern journey afforded an opportunity to observe the nature of the inland ice. In addition, glaciological observations were made by the men of the Davis station 400 miles (640 km.) east of Mawson. Some of the glaciological work done is outlined under various headings below.

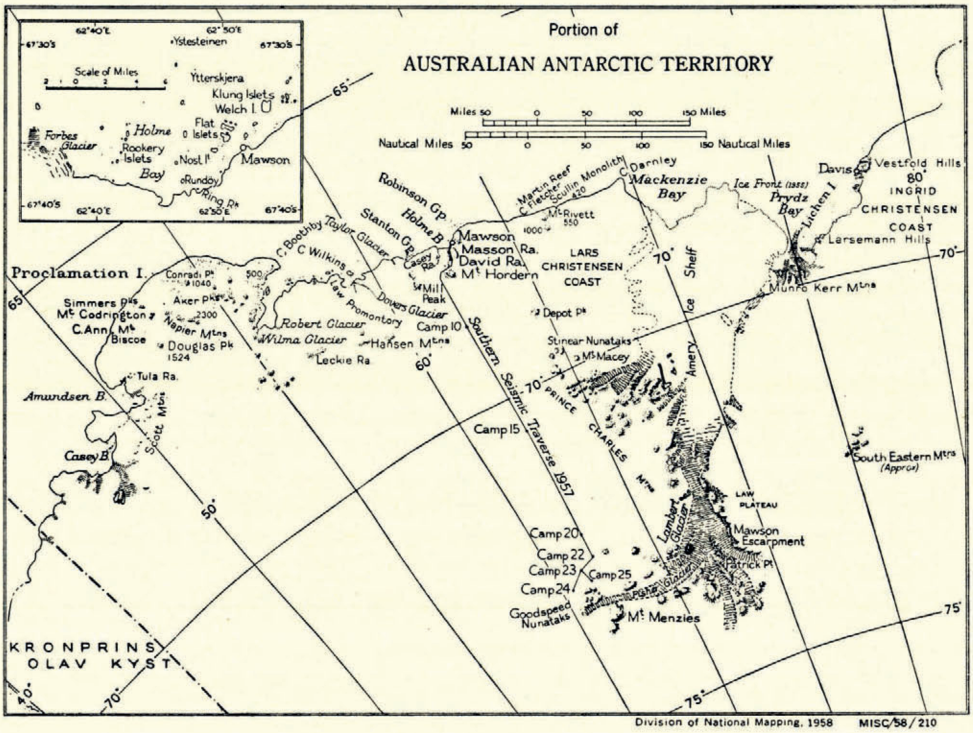
1. *General Observations*

Coastal and inland flights between long. 45° and 75° E. show that the plateau ice generally rises rapidly from a skerry-type coast, reaching an elevation of about 1500 m. 80 km. from the sea. Further inland the rises are more gradual and the maximum plateau heights recorded about 550 km. inland were around 3000 m. The elevation, thickness and movement of the ice appear to be strongly influenced by subglacial topography.

Heavy summer melting occurs below 900 m. and well-developed surface drainage systems exist. On the Lambert Glacier melt characteristics were observed 450 km. from the sea and at an elevation of 950 m. However, in favoured locations and on ice shelves there is a surplus of deposited snow at the end of summer and blue ice bands, which are such a characteristic feature of many Arctic ice caps, are formed.

The winds have an overwhelming influence on the distribution and deposition of snow in this sector and most of the coastal plateau slopes are kept free of lying snow throughout the winter, owing to the action of the incessant katabatic winds. In spite of this, anomalies in the wind direction along certain stretches of coast lead to a reduction of the katabatic effect and domed ice caps are formed by turbulent deposition of snow on the many islands and skerries which lie only a few kilometres from the frontal ice cliffs of the continent. These "ice islands" have an annual surplus of snow, exhibit blue banding and ice calves from their cliffs.

Inland from the ablation zones the lying snow and firn are cut into *sastrugi* and "blizzard dunes". The sharp-edged *sastrugi* are oriented parallel to the direction of the prevailing winds, which are predominantly katabatic. These wind directions vary from place to place. The "blizzard dunes" are smoother and generally larger than the *sastrugi*, and lie along the direction of the blizzard winds, which carry heavy precipitation.



Division of National Mapping, 1958 MISC/58/210

One of the most interesting features of this area is the Amery Ice Shelf, which was found to extend considerably further south than previously expected. The ice shelf is fed by an enormous glacier (now named the Lambert Glacier) which begins its ascent at lat. 71° 50′ and continues as a single stream down to lat. 73° 20′. At this point a great tributary joins it from the west, but the main glacier continues much further south. The width is about 65 km. and the glacier is flanked by mountains on both sides. It is believed to be larger than the Beardmore Glacier and must certainly be one of Antarctica's biggest glaciers. The glacier was mapped and profiled by radar altimeter, but no flow measurements were possible this year.

In the mountains of Enderby Land a small valley glacier viewed from the air showed bands bearing a superficial resemblance to the ogives so common on the outflow glaciers of Vatnajökull. However, the author was unable to land to make detailed comparisons.

2. *Accumulation*

Stake measurements were made along a route from Mawson to the Prince Charles Mountains between January 1955 and February 1957 and the mean annual accumulation quantities resulting from this work are shown below.

Region (km. south of Mawson)	*Annual net Accumulation* (mm. of water)
26 to 80	50
80 to 192	100
192 to 256	170
256 to 320	200

A new course of accumulation stakes has been laid and results should shortly be forthcoming. It is hoped that accumulation quantities will be deducible from pit sections secured during the main southern journey.

3. *Ablation*

There is an ablation zone some 20 km. wide in the Mawson region and the firn limit has a maximum height of about 950 m. Above this height, melting is negligible, although sublimation and wind erosion occur. Below 650 m. the hard bubbly ice is kept clear of snow throughout the year by strong winds. In mid-winter, when ice loss was by sublimation only, the ablation rates remained constant with changes of altitude (at about 0·76 mm. of ice per day) but local anomalies in the wind speed affected the rate. In midsummer, when heavy melting occurred, ablation rates decreased with increasing altitude. During the summer, the ice surface of the plateau slopes up to about 150 m. disintegrated into columnar granules, 0·5 to 2·5 cm. across, polygonal in cross section, and with a vertical length of 2 to 6 cm. A rapid check on these indicated that each column represented a single crystal.

The total ice loss between February 1957 and February 1958 is given below.

Altitude (metres)	*Total Ablation* (mm. of water)
60	535
150	495
180	490
305	260
335	230
365	220
425	235 (point measurement)

White-painted bamboo stakes were found to be satisfactory for measuring purposes as long as a set of 2 to 3 m. was maintained for a projecting length not exceeding 0·5 m.

4. *Ice Movement*

Flow measurements were carried out in a number of localities and an appreciable volume of data on surface movement of the ice is now available.

Measurements along a 45 kilometre line of stakes placed parallel to the coast on the plateau slopes 14 km. from the sea gave an average rate of flow of 5·75 cm. per day, with individual stakes moving from 2·8 cm. to 11·3 cm. per day. A profile of the ice depth along this line is now being measured in detail using seismic methods.

Movement of the ice cliffs $1\frac{1}{4}$ km. east and west of Mawson averaged about 3 cm. per day, and individual stakes had speeds up to 4·7 cm. per day.

A number of measurements were made on the tongue of the small, but typical, Taylor Glacier (lat. 67° 28′ S., long. 60° 53′ E.). The stakes were situated just upstream of the hinge line, and the flow of the tongue averaged 33 cm. per day.

The measurements mentioned above were made by simple offset methods or by triangulation, but an attempt is being made to develop a more simple method for use on inaccessible glaciers. Repeated vertical photo runs by Beaver aircraft flying at 3500 m. were made over three large glacier tongues, and it is hoped that ice movement will be measurable from these.

5. *Drifting Snow*

It was thought that earlier attempts to measure the quantities of wind-blown snow were somewhat crude, and an attempt to develop more suitable gauges was made. Small, self-orienting, expansion type drift gauges were built in two forms: an aerofoil type for use close to the ground, and a "rocket" type for use above 50 cm. These gauges were capable of measuring drift intensities over half-hour periods and were used for profiling from ground level to 4 m. in winds up to 40 m./sec. From the results obtained it will now be possible to estimate the mass of snow swept from the continent into the sea each year at Mawson. Wind tunnel efficiency tests on the gauges themselves are now nearing completion at the Commonwealth Aeronautical Research Laboratories in Melbourne.

6. *Blizzard Static*

Whilst the drift gauges were in operation, the opportunity to study electrostatic charge on an antenna was seized. A 20-metre horizontal antenna was strung 2 m. above ground level close to the 2-metre level drift gauge. The antenna was then continuously discharged through a recording microammeter. Many more results will be required before conclusions can be drawn, but it now seems that mass flow of drifting snow, temperature, and possibly absolute particle energy are important variables.

7. *The Blizzard*

The characteristics of the fierce blizzards which occasionally rage at Mawson were studied in an attempt to explain the anomalies in blizzard frequency and intensity at various points along the coastline.

8. *Precipitation*

The most common form of snow experienced at Mawson was wind-driven drift. The grains of this drift were mainly in the size range 0·1 mm. to 0·2 mm. and were rounded or sub-angular. Prismatic crystals were common, and in the rare still-air snowfalls various types of radiating crystals were observed, the maximum diameters being generally around 3 mm.

9. *Stratigraphic Studies*

Five-metre pits were dug at a point 50 km. south of Mawson and 900 m. above sea level in the autumn and spring of 1957. Firn and temperature profiles were plotted and density measurements were made. The firn banding was neither simple nor, at first sight, systematic and final interpretations have not yet been made. A large number of 1·5-metre trenches were bulldozed during the southern journey and certain continuous crusts with a fairly regular spacing were found. The layers separating these crusts apparently correspond to annual accumulation increments, but no definite pronouncement can be made until the end of 1958 when specially prepared sites are re-examined.

During the course of the southern journey pits 5·5 to 7 m. deep were dug and profiles secured. On the highest section of the traverse, an area apparently fairly wind-free judging from the virtual absence of *sastrugi*, periodic variations of firn density with depth were found. If this effect can be related to that discovered by Sorge in Greenland, the annual accumulation of this wind-free zone must be nearly three times that of the regions swept by katabatic winds.

Stratigraphic work was hampered by the failure of the ice-coring drill, but this failure led to some interesting development work with γ-radiation equipment. Attempts to derive density profiles were made by drilling two parallel holes, lowering a cobalt-60 γ-ray source down one and a Geiger-Müller tube down the other, and measuring on a scaling unit the changes in γ-ray penetration with depth.

10. *Petrographic Work*

Thin sections of ice were prepared for examination under the microscope, and a rough, but usable, universal stage polarizer was built to determine crystal orientations. It was found that bubble analyses could be correlated with crystallographic results.

11. *Temperatures*

During the southern journey a number of temperature profiles were measured in 28 to 40-metre boreholes. Below the depth to which seasonal temperature changes penetrate (about 10 m.), the temperature continued to fall with a gradient rather less than 3° C. per 100 m. depth. There was a big change of firn temperature with altitude, but the latitude effect was found to be small. A table of temperatures measured 20 m. below the surface along the meridian 62° 07′ E. is given below.

Latitude	*Altitude* (metres)	*20-metre Temperature* (°C.)
68° 07′	1220	−22·5
68° 25′	1520	−26·0
68° 33′	1830	−29·0
68° 59′	2290	−30·0
69° 37′	2590	−32·5
69° 55′	2800	−33·5
70° 13′	2900	−37·0
70° 31′	2960	−38·0
70° 49′	2930	−36·0
71° 08′	2930	−36·5
71° 46′	2870	−34·5
72° 13′	2840	−33·5
72° 22′	2750	−33·0
72° 52′ (long. 60° 26′ E.)	2800	−36·0
72° 51′ (long. 61° 21′ E.)	2750	−33·0

The following is a typical temperature profile for this part of the ice cap.

Depth (metres)	*Temperature* (°C.)
0	−19·0
1·52	−29·8
3·05	−33·7
6·10	−35·3
9·15	−36·2
11·2	−36·7
15·2	−36·8
18·3	−37·0
21·3	−37·0
24·4	−37·3
27·4	−37·3
30·5	−37·8
33·5	−37·8
36·6	−38·0
38·1	−38·0

Temperature profiles down to 8 m. were obtained at the plateau site 50 km. south of Mawson in March and July. These profiles confirm that the penetration depth of seasonal variations of temperature is about 10 m. in this type of firn.

A small pit at Mawson was used to record the penetration of cold waves as well as for observations on snow metamorphosis.

12. *Solar Radiation*

The radiation equipment taken to Mawson was very primitive and did not function satisfactorily. Many hours were spent in repairs to (and the manufacture of) actinometers, pyrgeometers, and balance meters, but the only reliable results were base records of total radiation and a few scattered albedo measurements over the plateau and sea ice.

13. *Sastrugi*

Sastrugi were found to vary widely in form, size and orientation from place to place. *Sastrugi* formed in new soft snow in a matter of hours and newly formed *sastrugi* were found to migrate downwind at speeds of 13 cm. to 23 cm. per hour in winds of 8 m./sec.

Along the meridian 60° 07′ E. *sastrugi* heights rose to a maximum of 1·4 m. in lat. 69° 52′ S. before falling to only a few centimetres in lat. 70° 50′ S. South of this region the heights again began to increase and *sastrugi* over 1 m. high were common in lat. 72° 40′ S. High *sastrugi* are often found downwind of ice-dome belts where the plateau gradients are steeper than average. Incidentally, these ice domes are apparently subject to fairly intense wind scouring and are, in effect, local ablation zones.

Along the meridian 62° 07′ E. the *sastrugi* underwent a progressive change in direction. At lat. 68° the bearing is about 150° true; at 70° 20′ S. the bearing has come round to 180°; at 72° 30′ S. they have swung to 228° true. This change is probably due largely to the surface form of the ice cap.

Transverse ripples sometimes formed in cold, dry snow, their wave lengths ranging from 10 cm. to 40 cm. In breezes from 5 to 8 m./sec., ripples in snow having a grain size of 0·1 to 0·4 mm. progressed at speeds between 5 and 18 cm./min.

Compilation of all measurements of *sastrugi* orientation could lead to useful data on the surface wind patterns of Antarctica.

14. *Ice Thickness*

A meridional seismic traverse was made along long. 62° 07′ E. by M. J. Goodspeed of the Commonwealth Bureau of Mineral Resources. Seismic shots were spaced approximately 32 km. apart and these measurements of the ice thickness were supplemented by gravimeter readings every 8 km. The results of this work will be published separately.

15. *Margin Variations*

There are no obvious signs of a recent glacial recession. There has been no significant change in the position of the ice-rock contact at Mawson since February 1955, and in the mountains 15 km. inland from Mawson, lichens are growing within two or three metres of the ice-rock contact. It is hoped that a detailed comparison of the positions of the ice front in 1936 and 1957 will be possible soon.

In the Prince Charles Ranges and in the mountains of Enderby Land there is ample evidence of a thinning of the ice sheet of up to 600 m. Melt water erosion in certain localities indicates that this recession probably occurred several thousand years ago.

16. *Moraines*

Moraine studies brought out several interesting features of surface and submerged moraines in the Mawson area. Stone polygon and permafrost measurements were made on the extensive moraines of the Prince Charles Mountains and cryoconites were studied. Some shear bands containing basal moraine were found in rock-based ice cliffs, and ice from these bands was analysed for included material, bubble size and elongation, and crystal orientation.

17. *Black Ice*

Several past reports have mentioned black or dark green ice other than that containing moraine material. Some icebergs contain "black ice" overlaid with normal bubbly ice, the boundary between the two being plane. Many examples of this were examined in detail and the "black ice" was found to be re-frozen melt water having a very low air content. This black ice sometimes passes through an area of local accumulation and acquires an over-burden of bubbly ice. It is suggested that this is not necessarily an explanation of all cases.

18. *Other Ice Studies*

Density determinations were made and bubble arrangements and crystal forms were studied. Ice specimens were brought back to Melbourne and compression creep tests under loads of 10 kg./cm.^{2}, 5 kg./cm.^{2}, and 1·5 kg./cm.^{2} are being carried out at a temperature of $-33°$ C.

19. *Sea Ice*

Measurements of sea ice accretion, ablation, and basal decay were made at Mawson and Davis. Spot measurements of ice thickness were made along 800 km. of coastline and a log of ice formation and break-up between Amundsen Bay and the Vestfold Hills was kept. The behaviour of tide cracks, pressure ridges, and over-thrusts was followed throughout the year, and reconnaissance flights defined the northern limit of the fast ice for part of the year.

Temperature, albedo, density and salinity measurements were made and the formation of sea ice and spray ice was studied.

The writer is deeply grateful to Dr. Fritz Loewe and Dr. Uwe Radok for their constant advice and assistance, and to all expedition members who have helped with the various projects.

MS. received 19 May 1958. The results of the author's work in Antarctica had not been fully processed at this date but he wishes it to be made known that he will endeavour to supply more detailed information promptly to any glaciologist who may be interested.—Ed.