MOVEMENT OF THE ROSS ICE SHELF NEAR SCOTT BASE

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ABSTRACT. The rate of movement of the Ross Ice Shelf has been determined at its terminal face to the south-east of Scott Base. An average rate of movement of 23 cm./day in a direction 270° True was determined for the period March 1957 to October 1958. The terminating face of the ice shelf in McMurdo Sound is only about 3 metres thick compared with a thickness of several hundred metres in the Ross Sea. Altimeter heights are used to demonstrate a thinning of the shelf which is attributed to melting from below.

RÉSUMÉ. La vitesse de mouvement du Ross Ice Shelf a été déterminée à son front au Sud-Est de la Base Scott. La vitesse moyenne est de 23 cm par jour en direction du gisement de 270° pour la période de mars 1957 à octobre 1958. L'épaisseur du front de l'ice-shelf à McMurdo Sound n'est que de trois mètres, alors qu'elle est de plusieurs centaines de mètres dans le Ross Sea. Les altitudes déterminées avec des altimètres sont utilisées pour démontrer un amincissement du shelf, attribué à la fonte sous-glaciaire.

ZUSAMMENFASSUNG. Die Bewegung des Ross Ice Shelf ist in der Nähe seines Endes südöstlich der Scott Base gemessen worden. Es ergab sich eine durchschnittliche Bewegung von 23 cm/Tag in der Richtung 270° genau nach Nord für die Periode März 1957—Oktober 1958. Am Ende des Eisshelfs an der Scott Base ist die Front nur 3 m stark im Verhältnis zu mehreren Hundert Metern in der Ross Sea. Barometrische Höhen wurden gemessen um die Verringerung der Dicke des Eisshelfs nachzuweisen. Diese Verringerung der Dicke ist einem Schmelzen von unten her zuzuschreiben.

INTRODUCTION

To the eye (see Fig. 1, p. 865) the edge of the Ross Ice Shelf in McMurdo Sound shows no evidence of being the terminating face of such an impressive body of ice, especially when compared with the ice cliffs in which the shelf ends in the Ross Sea. To demonstrate its status some evidence must be produced.

The area south of Hut Point peninsula was first visited in February 1902 when *Discovery* found open water as far as Pram Point.[1] In 1903 as is well known, the bay ice did not retreat south of a point 6 km. north of Hut Point. In 1904 *Discovery* was freed but no observation of the ultimate southerly extent of the break-up was possible. Open water as far as Pram Point was again found in 1909 and 1911.

The apparent edge of the shelf in this vicinity is dominated by a series of pressure ridges which are broken and contorted near Pram Point (Figs. 1, 4 and 5, p. 866). "The Ross Ice Sheet presses against the sea ice on the south-east side of the Winter Quarters (Hut Point) peninsula and produces a series of hummocks some two miles [3·2 km.] long. Some of the hummocks rise as bucklings of the sea ice, here eight feet [2·4 m.] thick; in others the sea ice breaks into pieces about twenty feet [6 m.] long and these are forced up on end. Four parallel rows stretched out to the south-west of Pram Point and grew gradually before the movement of the ice sheet, only becoming conspicuous towards the end of the first winter (1902)."[2]

During the occupation of Scott Base by New Zealand expeditions (since January 1957) the ice has not broken out as far as Pram Point although it has broken out as far as the pressure ridges 2 km. south of Scott Base (March 1958).

On a visit to Cape Crozier from Scott Base in November 1958, L. H. Martin took altimeter readings. Unfortunately the readings were not closed but the barograph at Scott Base was steady and there was no wind. Martin's readings are shown in Figure 2. A. P. Crary, completing his Victoria Land traverse in January 1959, took looped altimeter heights from Scott's Corner Camp location to McMurdo Sound. Mr. Crary has kindly sent us these results and they are also shown in Figure 2. At the base of the figure Crary's altitudes are transferred into ice thicknesses using the relationships of Robin [3] for floating shelf ice. These altitudes demonstrate the thinning of the ice as it moves towards McMurdo Sound. They also

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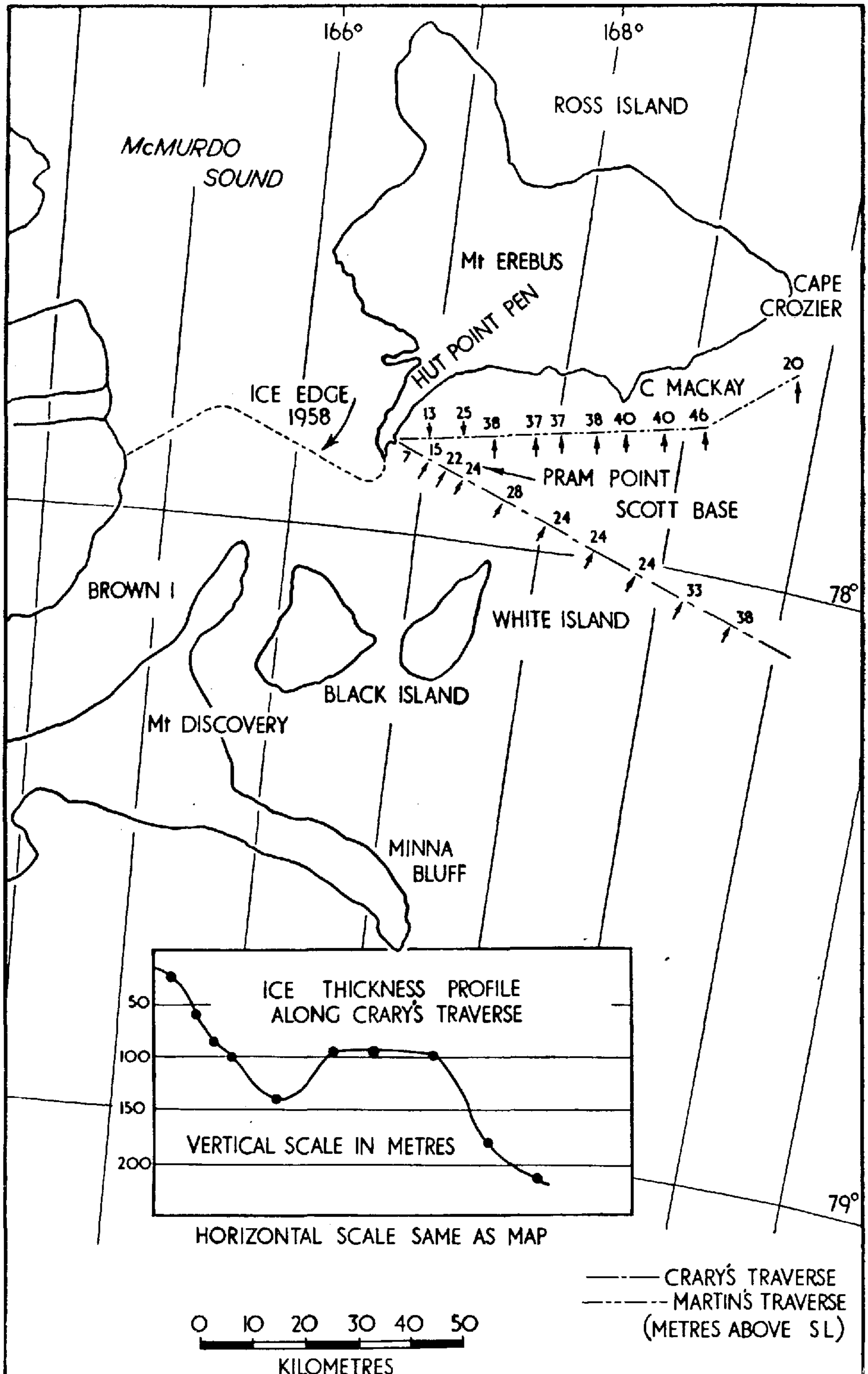

Fig. 2. Map of environs of "McMurdo Ice Shelf" showing traverses with altimeter heights. The estimated ice thicknesses along the Crary traverse are shown in the profile in the lower part of the diagram. The thicker ice 23 km. from Scott Base is substantiated by seismic measurements

disclose the presence of a ridge off the northern tip of White Island. According to Crary this ridge is underlain by ice of greater thickness than that on either side. It must be expected that the rock barriers of Minna Bluff, Black and White Islands tend to divert the western edge of the shelf in a north-north-easterly direction away from McMurdo Sound, with little ice flowing into the sound. The presence of the ice ridge on its eastern boundary, the wedge shaped vertical section and other unique features, lead us to believe that the area of the shelf west of the White Island-Cape Mackay line, although part of the Ross Ice Shelf, requires a separate identity for purposes of discussion. For the present we shall refer to it as the "McMurdo Ice Shelf". On the other hand the more significant feature in the profile of Figure 2 may be the thinner ice between 35 and 55 km. from Scott Base. The magnetic, gravity and seismic results along this profile are awaited with interest.

Movement of the Ice

The survey was initiated by Lieutenant-Commander R. Brooke, R.N., a surveyor with the New Zealand section of the Trans-Antarctic Expedition. Brooke measured a 10 chain (201·17 m.) base line on the ice shelf and triangulated a series of observation cairns on the rock slopes of Crater Hill (Fig. 3). A series of bamboo poles were placed in appropriate positions on the ice. The positions of these markers were established and two fixes made before winter 1957. In the following spring the project was taken over by the I.G.Y. team at Scott Base. The poles were replaced by snow cairns surmounted by oil drums for easier observation, and fixes made at intervals until the end of the International Geophysical Year. Table I gives the rates of movement of the markers; directions of movement are about 270° True (Fig. 3) and remained constant throughout the period of observation.

Table I. Average Daily Rate of Movement (in cm.) of the Shelf Ice Near Scott Base

	Bamboo A	B	C	D	E	F	G	H
Number of days between first and last observation	571	387	29	547	331	*	547	547
Average rate of movement	20·0	23·9	24·4	24·0	18·5		23·1	24·3

* From 30 November 1957 to 3 March 1958 bamboo F remained stationary.
From 3 March 1958 to 10 September 1958 it moved 8·5 m. north-north-west.
From 10 September 1958 to 3 November 1958 there was no movement.

It is only in the case of marker F which is on the western side of the most chaotic disturbance that there appears to be any significant seasonal variation in the rate of movement. The overthrusting of the ice waves in this vicinity is no doubt due to the shallow depth of rock offshore at Pram Point. The continuity of Pram Point below the ice can be seen in Figure 4. The movement of bamboo F suggests that during the summer the faster rate of melting allows the stress to be relieved entirely at the pressure ice. During winter there is some strain between the pressure ice and The Gap. The shielding effect of Pram Point can be clearly seen in Figure 4. The velocity of bamboo E on bay ice is lower than the velocity of the other markers, and this is due to the loss in velocity due to buckling between the edge of the shelf ice and bamboo E.

The rate of movement of the ice shelf near Scott Base is taken to be the average of bamboos A, B, D and G, i.e. 22·8 cm./day. This is low when compared with the rates estimated and measured by others for the main part of the Ross Ice Shelf.[4, 5]

Problems Arising from the Observations

1. *Disposal of the Shelf Ice near Scott Base*

We can consider the ice to consist of two sections: that to the east of Scott Base which runs into the Hut Point peninsula, and that to the west of Scott Base which has its outlet into

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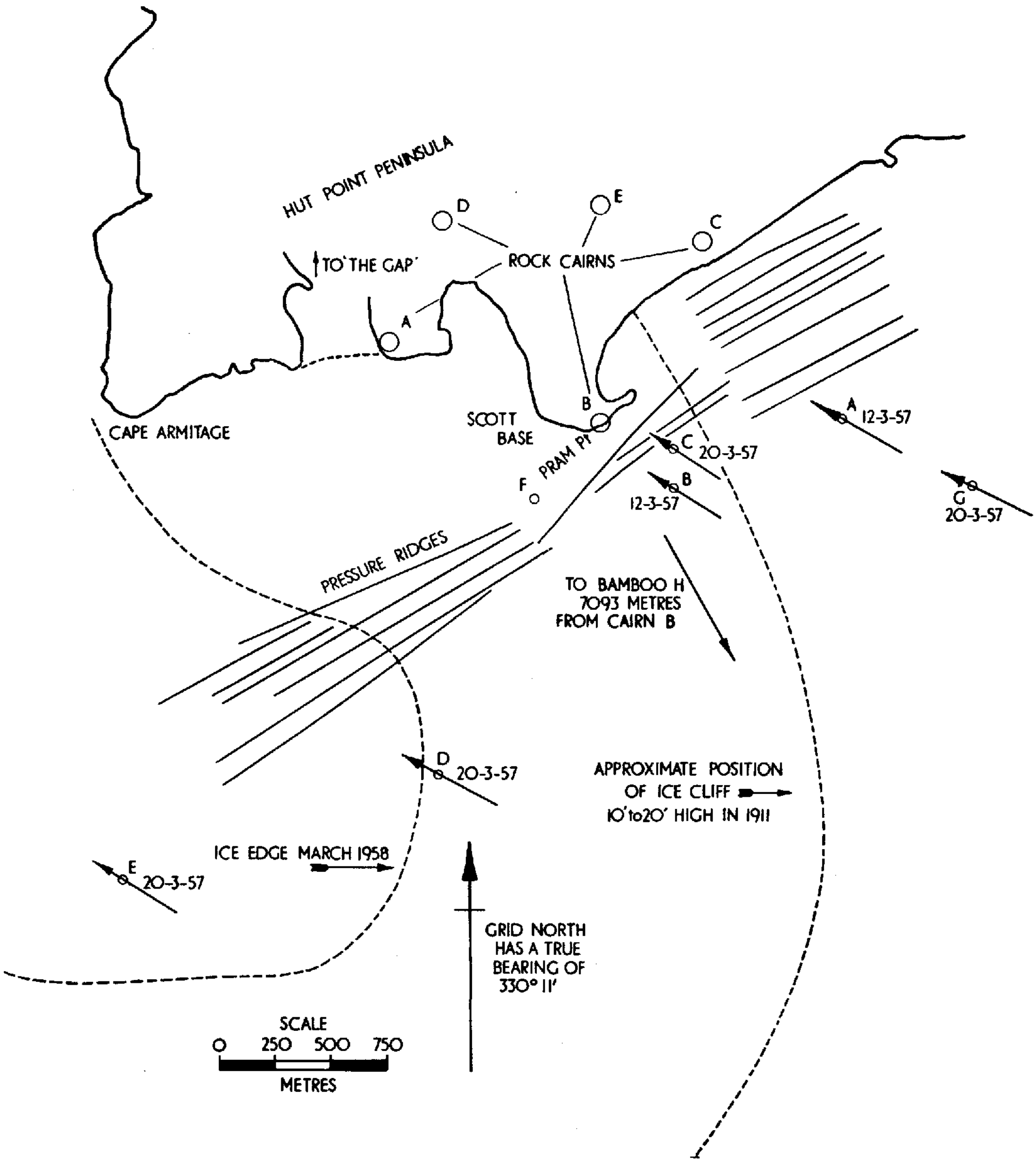

Fig. 3. Map of environs of Pram Point showing survey cairns, markers and directions of movement. The markers were first fixed in the positions shown on the map at the dates indicated

McMurdo Sound. The ice fronting McMurdo Sound clearly loses its surplus in break-outs during favourable summers. During the winters, and summers without break-outs, the movement of this ice is dispersed in the buckling of the sea ice as can be seen quite plainly in Figure 1 (March 1957) and Figure 4 (February 1958).

The ice to the east has no means of relief. Nevertheless there is no build up of ice and to maintain equilibrium conditions it is necessary to invoke removal by melting from below.

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2. *Thinning of the McMurdo Ice Shelf*

The Ross Ice Shelf at its northern face between Cape Crozier and King Edward VII Land, has an impressive terminal face which rises as a cliff to between 20 and 40 m. above sea-level. At Scott Base this cliff stands less than 2 m. above sea-level. Figure 2 shows how the thickness of the ice shelf decreases as it approaches Scott Base.

Three mechanisms could cause this thinning out; plastic flow, ablation and melting from below, or any of these mechanisms in combination. No similar case of such extreme thinning appears to exist among other Antarctic ice shelves which suggests that the phenomenon is due to local influences rather than some general law. Local events influence considerably the two last-named causes of thinning. The ice shelf in the vicinity of McMurdo Sound is bounded by rock surfaces. Glaciers in the region (e.g. Ferrar, Skelton) are well known for their lack of accumulation, and there is a dry valley complex nearby. Dust and moraine in the region of White, Black and Brown Islands cause considerable devastation of the ice surface. Gould [5] observed a marked increase in the ablation of snow beacons up to 90 km. from the mountains bounding the southern edge of the shelf. However, an examination of the deep snow-covered surface of the shelf ice suggests that any ablation is very local in character. For instance in the nearby Dailey Islands-Koettlitz Glacier region where Debenham [6] has recorded the finding of sea bottom deposits on the surface of the ice, it is quite possible that the moraines and dust so lower the albedo that greater surface ablation than accumulation occurs. Measurement of accumulation on the ice shelf in the vicinity of Scott Base indicates that there is an annual increase of about 40 cm. of snow a year. Thus there remains the factor of melting from below.

Consider the area of shelf ice bounded by the lines joining Pram Point to the northern tip of Black Island and the northern tip of White Island to Cape Mackay (Fig. 2). The thickness of the shelf is assumed to be 150 m. at the eastern end, and is known to be about 6 m. at the western end. This thinning out takes place in, say, 30 km., and with the ice moving 23 cm./day a point on the eastern margin will take about 400 years to reach the terminal face to the west. A unit column 150 m. thick will thus reduce its thickness by about 0·4 m./year. In addition annual accumulation equivalent to, say, 0·3 m./year of ice will have to be removed, making a total of 0·7 m./year. For a 30 km. unit section of the column this requires the removal of 58 $m.^3$/day per metre of ice front. If it is assumed that the temperature of the 600 m. of water below the ice can be lowered 0·1° C. without causing freezing, and if 50 per cent mixing occurs of the water under the ice then a flow of about 150 m./day is required to melt the above quantity of ice. Even a much lower mixing would give flow rates well within the feasible range. At present there is insufficient information to indicate whether such an anti-clockwise flow takes place around Ross Island.

3. *Buckling of the Ice Shelf at Scott Base*

The line of greatest south-easterly break-out of ice recorded (1902) is shown in Figures 1 and 4. If this is taken to be the edge of the shelf then the greater part of the buckled ice is bay ice, and the only part of the shelf which is deformed is the area immediately east of Pram Point.

The buckles in the bay ice have wave lengths of about 25 m. and amplitudes (March 1958) up to 2 m. After break-out buckling proceeds in the manner described by Ferrar,[2] the amplitude and extent of the buckling being a function of time from the last break-out. The wave lengths of the buckles in the shelf ice (see Fig. 5) are about 50 m. on formation decreasing as the buckles approach the Hut Point peninsula; amplitudes reach 3 m. The shelf buckles die out rapidly to the east and north-east, presumably due to the rapid thickening of the ice (see Fig. 4). The axes of these shelf buckles are by no means at right angles to the direction of movement (270°) of the markers, but the closest marker to the shelf buckles, bamboo A, is only on the southern edge of them.

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Conclusions

A few very simple measurements and observations indicate that the ice to the east of Scott Base is part of the Ross Ice Shelf, but that several characteristics of the local shelf ice may be the result of local modifying influences. In particular:

(*a*) the rate of movement of 23 cm./day is small compared with previous reported movements of the Ross Ice Shelf proper;

(*b*) this slow rate of movement combined with melting from below has a thinning action on the shelf so that its terminal face in McMurdo Sound is only the thickness of bay ice; and

(*c*) restraint of movement by the land results in buckling of the ice shelf to an extent locally dependent on the thickness of the ice; movement of the free face of the shelf edge is taken up by buckling of the sea ice.

Acknowledgements

The authors are indebted to Wing-Commander J. R. Claydon, A.F.C., R.N.Z.A.F., for the photographs used in Figures 1 and 4, and to Mr. A. L. Burrows who made the measurements during 1958.

MS. received 8 September 1959

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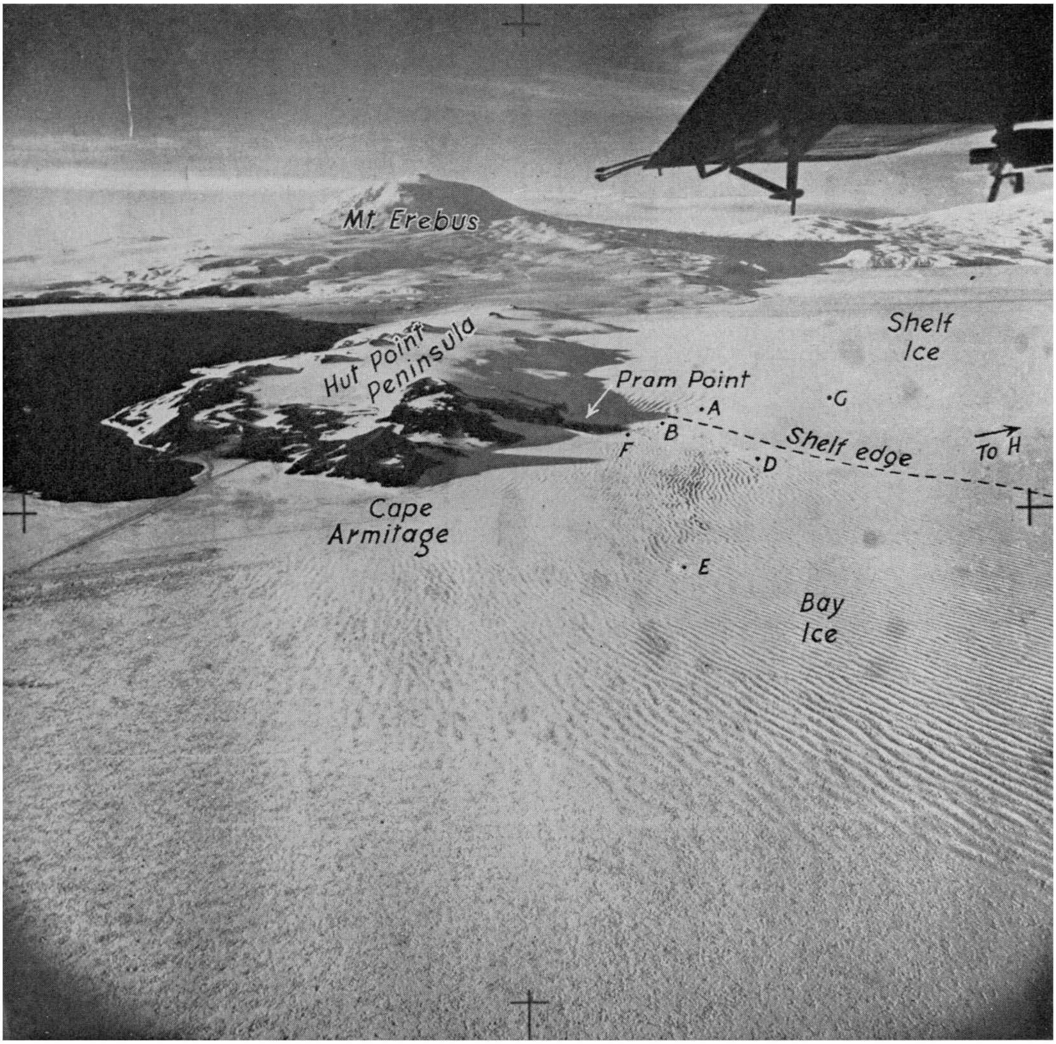

Fig. 1. Oblique aerial view (looking north-east) of McMurdo Sound, Hut Point Peninsula, Pram Point and Ross Ice Shelf (March 1957). Photograph by Wing-Commander J. R. Claydon, A.F.C., R.N.Z.A.F.

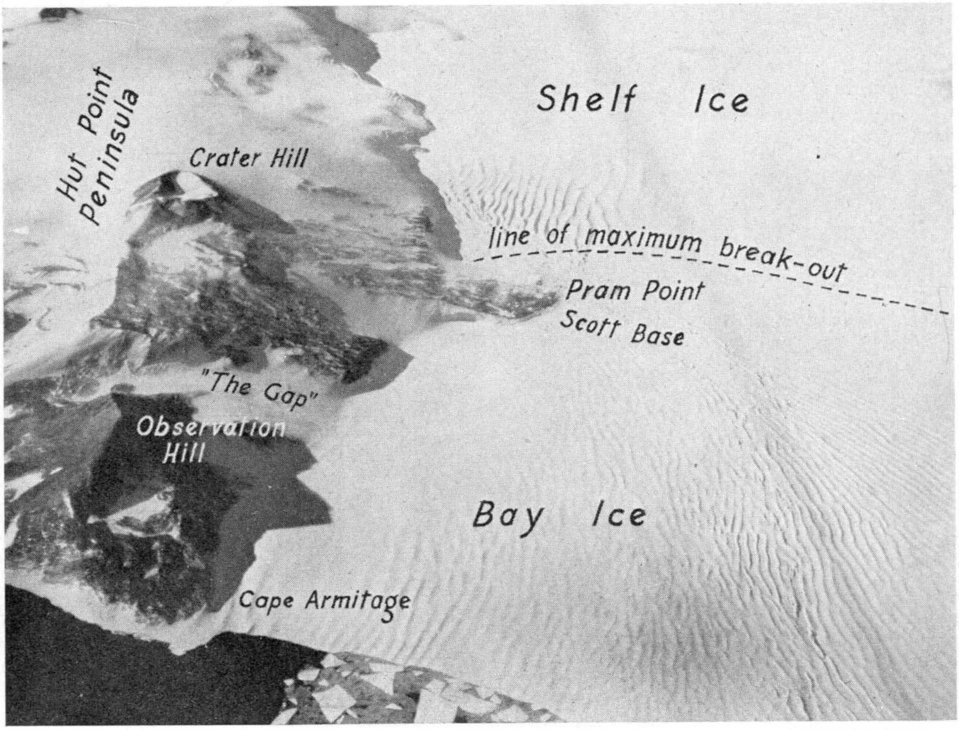

Fig. 4. Oblique aerial photograph (28 February 1958) showing buckling of the sea ice and shelf ice. Photograph by Wing-Commander J. R. Claydon, A.F.C., R.N.Z.A.F.

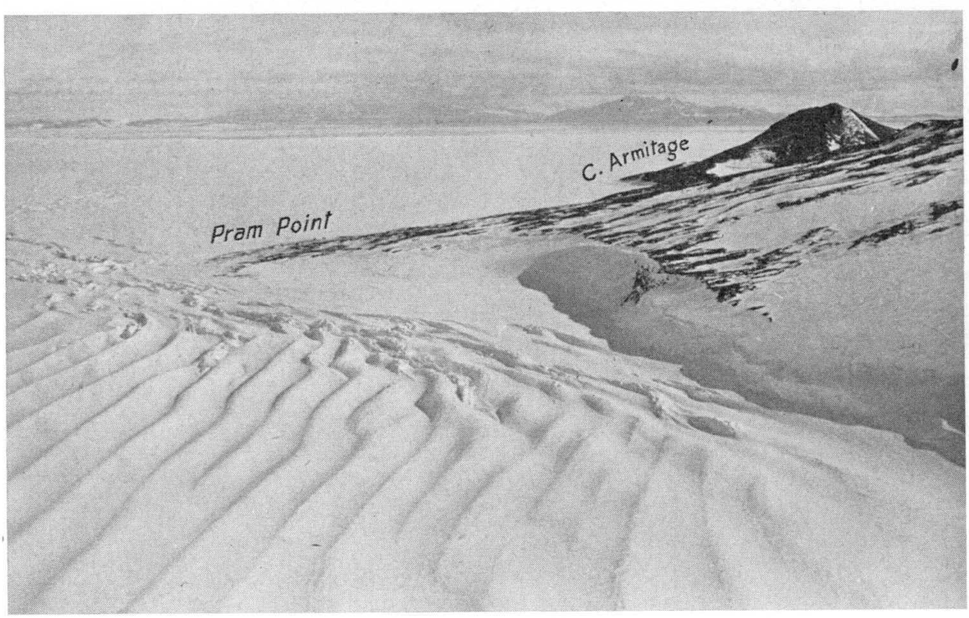

Fig. 5. Oblique aerial photograph (November 1957) of shelf ice waves, north-east of Pram Point. Photograph by R. H. Orr

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