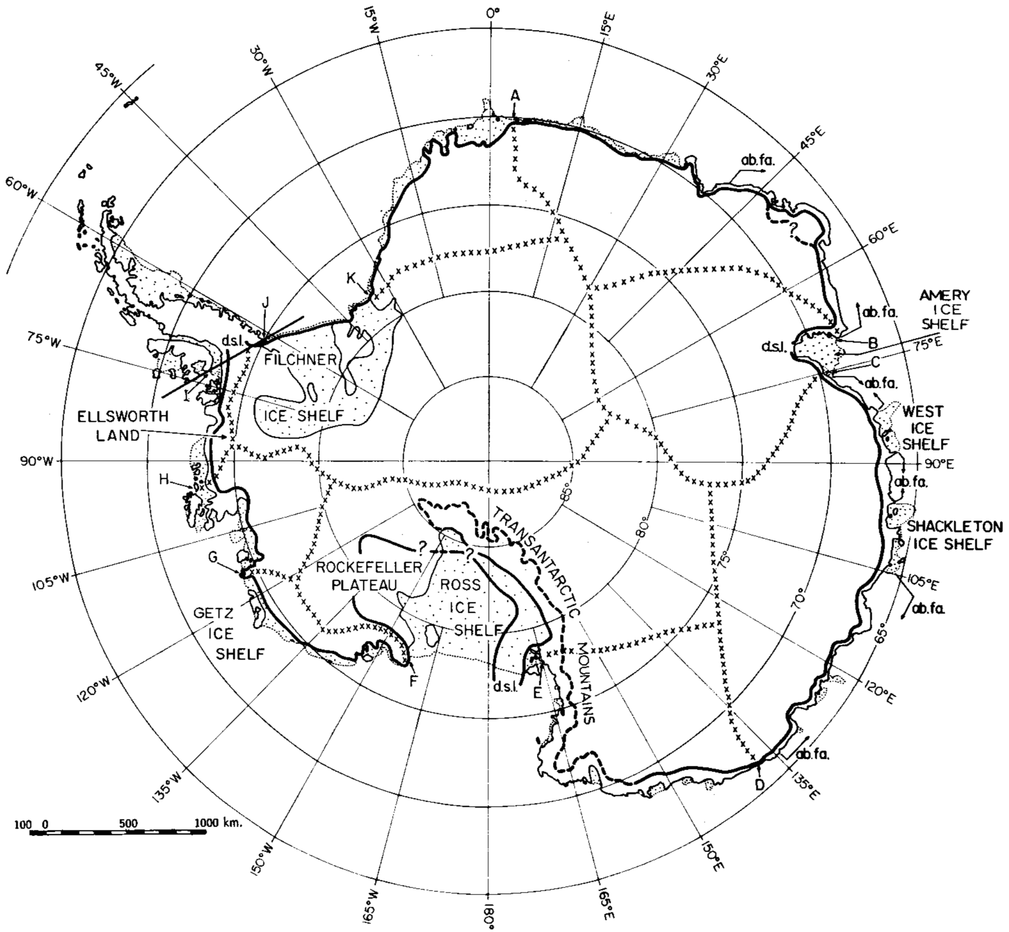

Fig. 1. Map of Antarctica showing the dry snow line (d.s.l.), the sectors where net ablation at the surface is predominant near the coast (ab.-fa.), and the drainage divides (xxxx; after Giovinetto 1963a).

DISTRIBUTION OF DIAGENETIC SNOW FACIES IN ANTARCTICA AND IN GREENLAND*

Mario B. Giovinetto†

I. Zones of net ablation at the surface

IN ANTARCTICA, excluding the region of the Antarctic Peninsula shown in Fig. 1 north of line IJ, the areas of the zones between the equilibrium line as defined by Müller (1962, p. 305) and the grounded ice terminus was estimated by Giovinetto (1963a) at 65,000 km.^{2}. This estimate is of the same order of magnitude as the estimate of 92,000 km.^{2} made by Dolgushin *et al.* (1962, p. 288).

The difference between the two estimates of area mentioned above is caused by differences in the distribution of the zones of net ablation at the surface. Dolgushin *et al.* assign net ablation zones to 40 per cent of the area of a strip 10 km. wide along 23,000 km. of coastline, excluding cliffs and the Antarctic Peninsula. Giovinetto places the net ablation zones in strips 10 to 20 km. wide along 4,500 km. of coastline distributed in four segments between 40°E. and 135°E., indicated in Fig. 1 as "ab. fa.". The two western segments are estimated to be 20 km. wide (Mellor 1959, p. 524). The area of net ablation in the segment between the West and Shackleton ice shelves is estimated at 40 per cent of a strip 10 km. wide (Dolgushin *et al.* 1962, p. 288). The eastern segment is estimated to be 10 km. wide (Hollin 1962, p. 176).

In Antarctica there are no reports of zones of net ablation at the surface in the regions of the grounded ice sheet that are adjacent to ice shelves, at least from 135°E. clockwise to point I, and from point J clockwise to 33°E. (e.g., Pirrit and Doumani 1960, p. 10; Swithinbank 1960, p. 130). Mellor (pers. comm.) has reported the existence of zones of net ablation in regions of the grounded ice sheet that are adjacent to the Amery and Shackleton ice shelves.

* Geophysical and Polar Research Center, Contribution No. 124.

† Geophysical and Polar Research Center, Department of Geology, University of Wisconsin.

Furthermore there are no reports of net ablation zones in the ice shelves extending from 135°E. to I and from J to 33°E. No more than one third of the periphery of the grounded ice sheet is coincident with the ice terminus; the remaining two thirds are adjacent to ice shelves. Thus, the main objection to the estimate by Dolgushin *et al.* is that they overestimated the length of the zone where net ablation is predominant. The main objections to the estimate by Giovinetto are:
(1) There may be zones of net ablation at the surface in the grounded ice sheet adjacent to ice shelves, or on the ice shelves proper.
(2) The estimate does not consider the area of regions of net ablation that exist in many valley glaciers in the Transantarctic Mountains mainly between 71°S.155°E. and 85°30′S.130°W. (Gunn and Warren 1962, p. 50; Giovinetto 1963b, p. 14) and in the region of the Amery Ice Shelf (Mellor and Mckinnon 1960, p. 32).

The estimates made by Dolgushin *et al.* and by Giovinetto indicate that the area of the zones of net ablation at the surface may be between 50,000 and 100,000 km.^{2}.

Bader (1961, p. 14) summarized the area distribution of diagenetic snow facies (Benson 1962, p. 24) in Greenland. Bader estimated that 30 per cent of the area of the ice sheet is covered by snow of the dry facies, that 55 per cent of the area is enclosed between the dry snow line and the equilibrium line (percolation and soaked facies), and that the ablation facies are characteristic of 15 per cent of the area. In Antarctica the ablation facies cover less than 1 per cent of the area of the ice sheet as opposed to 15 per cent in Greenland. It is of interest to know how the relative area inside the dry snow line in Antarctica compares with that of Greenland.

II. Criteria

Three conditions are adopted in the following discussion:
(1) A particular locality is considered to be within the zone of a given facies when the melting phenomena corresponding to the facies occur in any one annual accumulation layer. This criterion is adopted to conform with that of Benson (1962, p. 24) for Greenland in order to make comparisons between the area covered by dry snow facies in Antarctica and in Greenland. Benson (personal communication) considers that a locality should be excluded from the zone of dry snow facies if melting-refreezing features are found in any one annual accumulation layer within a stratigraphic section composed of several annual layers. In regions where stratigraphic data are collected at many localities including a particular annual accumulation layer, the distribution of the snow facies can be described by specifying the corresponding year. However the stratigraphic data collected in Antarctica are not simultaneous. Therefore, this writer proposes that in future studies of the distribution of facies the proportion of annual occurrences of melting phenomena in an observed set of annual layers should be considered before a locality is excluded from the zone of dry snow facies. In the example mentioned

above this writer would place the locality into the zone of the dry snow facies because the relative annual occurrence of melting phenomena is less than 50 per cent.

(2) Granular, icy crusts found in the firn strata are not considered significant evidence of melting phenomena. These crusts generally have a thickness of between 1 and 2 mm. but sometimes they can reach a thickness of 5 mm. Such crusts are considered the product of insolation, of wind packing, or of intergranular melting (Kotliakov 1961, p. 95). The crusts are later consolidated by sublimation of water vapor moving vertically through the porous firn. Hence dry snow facies are considered to be predominant in regions where granular, icy crusts are found.

(3) Excluding the region of the Antarctic Peninsula (0.39×10^6km.^{2}), the area of the grounded ice sheet is assumed to be 12.00×10^6km.^{2}, and the area of the ice shelves and attached islands is assumed to be 1.62×10^6km.^{2}.

III. The dry snow line

The tentative location of the dry snow line (labelled "d.s.l.") is shown in Fig. 1. It has been determined after examining the stratigraphic descriptions made at 13°E. (Kruchinin 1962, p. 21), at 24°E. (Tongiorgi *et al.* 1962, p. 108), on the Ross Ice Shelf (Boyd 1960, pp. 8-191), on the Rockefeller Plateau (Anderson 1958, pp. 12-60; Long 1961, pp. I 30 - I 44; Neuburg 1959, pp. 6-23), at 114°W. (Pirrit and Doumani 1960, pp. I 13 - I 14 and I 43 - I 44), on the Filchner Ice Shelf (Aughenbaugh *et al.* 1958, pp. 15-150), at 10°W. (Schytt 1960, pp. 20-101), and at 3°W. (Lunde 1961, p. 11). The dry snow line is approximately 30 km. inland (800 m. altitude) at 63°E. (Mellor, personal communication), 100 km. inland (100 m.) at 93°E. (Kotliakov 1961, p. 97), 90 km. inland (1200 m.) at 112°E. (Hollin and Cameron 1961, p. 840), and 4.5 km. inland (250 m.) at 140°E. (Lorius, personal communication). It is suggested that the dry snow line, neglecting narrow sections of the coastal slope of the ice sheet where it is at sea-level, is located as follows:

(1) It is coincident with the periphery of the grounded ice sheet from 34°W. eastward to 33°E. and from 157°W. eastward to approximately 100°W.

(2) From 33°E. to the West Ice shelf it lies between 20 and 40 km. inland where the ice terminus is grounded, and between 500 and 1000 m. altitude in the regions adjacent to ice shelves.

(3) From the West Ice Shelf to 155°E. it is found between 5 and 100 km. inland where the ice terminus is grounded, and between 200 and 1200 m. altitude in the regions adjacent to ice shelves.

(4) It is coincident with both the western and eastern flanks of the Transantarctic Mountains extending from 71°S.155°E. to 85°30′S.130°W. — including the area of the McMurdo Ice Shelf centered at 78°S.167°E. (see Stuart and Bull 1963, pp. 339-413; Stuart, personal communication).

(5) It is found on the Ross Ice Shelf at distances ranging between 25 and 250 km. from the mountains to the southwest, and it lies east of the Rockefeller Plateau. The placement of the dry snow line is doubtful in the region centered

approximately at 84°S.145°W. Judging from charts of ice surface topography (e.g., Bentley, in press) and ice surface isotherms (e.g., Rubin 1962, pp. 88-89) the dry snow line could be linked, between 150°W. and 170°W. with the eastern part of the line placed as described in (4).

(6) It extends between 100°W. and line IJ at an altitude not greater than 500 m. The description of stratigraphic sections made in Ellsworth Land by Shimizu indicates that at altitudes of 558 m. or more only icy crusts, Section II (2), are found (Cameron, personal communication).

(7) It is parallel to the Filchner Ice Shelf front where it lies approximately 5 km. from the edge.

There are regions where despite high altitude and high latitude, melting occurs in the vicinity of exposed rocks or in sections with a steep slope in valley glaciers. In valley glaciers where the snow cover has been deflated, the adiabatic warming of the air masses flowing downslope and the relatively low albedo of the ice are conducive to local temperature rise and to intensive insolation capable of producing melting. Regions in which there are many rock outcrops such as the northern part of Enderby Land (67°S.53°E.) should be excluded from an estimate of the area of regions where dry snow facies are predominant. However, such regions are of small importance in the present estimate, except the region of the Transantarctic Mountains, III (4).

The area where the dry snow facies are predominant is estimated at 12 x 10^6km.^{2}, or 90 per cent of the area of the ice sheet including the ice shelves. This proportion would be larger if only the grounded ice sheet were considered because practically all the ice shelves except the Filchner Ice Shelf are excluded from the region of the dry snow facies. The relative area covered by snow of the dry facies is three times larger in Antarctica than in Greenland.

IV. The dry snow line and surface isotherms

Benson (1962, p. 74) shows that in Greenland the dry snow line lies at an altitude of 3100 m. at 69°N. and at 1700 m. at 81°N. In Antarctica it is found between 500 and 1000 m. at 67°S. (near 54°E.) and at only 100 m. at 85°S. (near 165°W.). The area enclosed by the dry snow line drawn along the Transantarctic Mountains is not considered representative of the ice sheet. Despite the fact that the dry snow line is at sea-level or close to it in many narrow sections, the dry snow facies do not cover any considerable area at altitudes below 100 m. with the exception of the southern and western regions of the Ross Ice Shelf, and the Filchner Ice Shelf.

The location of the dry snow line in Greenland and the dry snow line in Antarctica differs significantly in its general relationship with the mean annual air temperature at the surface. The dry snow line in Greenland lies in a region limited by the —26°C. and —28°C. isotherms, (see Benson 1962, p. 60). The dry snow line in Antarctica lies between —15°C. and —25°C. isotherms; the placement of the isotherms has been determined mainly from

data on snow temperatures measured at a depth of approximately 10 m.
(1) The dry snow line has been placed in the sector 34°W. to 33°E., III (1), at the junction between the grounded ice sheet and the ice shelves. The ice shelves lie below 100 m. altitude; Schytt (1960, Figure 20) indicates that the mean annual air temperature in localities below 200 m. at 10°W. is between —20°C. and —16°C. Therefore it is assumed that the dry snow line is coincident with the —18°C. isotherm in the sector 34°W.-33°E.
(2) The dry snow line at 63°E. is coincident with the —18°C. isotherm (Mellor 1960, Figs. 4 and 5), and it is assumed that this relationship prevails in the sector between 33°E. and the West Ice Shelf, III (2).
(3) The dry snow line in the sector between the West Ice Shelf and 155°E., III (3), is roughly coincident with the —22°C. isotherm at 93°E. (Bogoslovsky 1958, Figs. 5 and 6), with the —20°C. isotherm at 112°E. (Hollin and Cameron 1961, Fig. 6), and with the —14°C. isotherm at 140°E. (Lorius 1962, Fig. 3).
(4) The dry snow line drawn along the western and eastern flanks of the Transantarctic Mountains is not discussed in its relationship with surface isotherms because near rock outcrops and in valley glaciers melting is dependent on other variables.
(5) On the Ross Ice Shelf the dry snow line lies in the region enclosed between the —24°C. and —26°C. isotherms (Crary *et al.* 1962, Fig. 4), and on the Rockefeller Plateau it is roughly coincident with the —25°C. isotherm (Anderson 1958, p. 62; Long 1961, p. 9; Neuburg 1959, p. 5).
(6) The dry snow line is coincident with the periphery of the grounded ice sheet from 158°W. to approximately 100°W., III (1); the mean annual air temperature in the Getz Ice Shelf is estimated at —15°C. from data collected by Pirrit and Doumani (1960, p. 11), and at —19°C. in a locality 50 km. inland from the periphery and 850 m. altitude. Thus the dry snow line in the sector 158°W. to 100°W. is assumed to be coincident with the —16°C. isotherm.
(7) In the sector corresponding to Ellsworth Land, III (6), it is estimated that the dry snow line is coincident with the —15°C. isotherm; data on snow temperature collected in Ellsworth Land by Shimizu (Behrendt, personal communication) indicate that the mean annual air temperature is approximately —15°C. at an altitude of 500 m.
(8) It is assumed that the dry snow line is coincident with the —25°C. isotherm (Aughenbaugh *et al.* 1958, p. 39) along the front of the Filchner Ice Shelf, III (7).

It is difficult to understand why summer air temperature should not cause melting in localities where the mean annual air temperature at the surface is approximately —15°C. This discrepancy suggests that the tentative placement of the dry snow line described in Section III is subject to change. Future studies should be aimed at explaining the relationship between mean annual temperature and the dry snow line. Nevertheless it is believed that the changes will not effect the general location of the dry snow line shown in Fig. 1.

V. The snow facies

The distribution of the facies in given sections of the grounded ice sheet in Antarctica does not conform with the ice surface topography as it does in Greenland. In Antarctica there are regions, such as the ice sheet slope at 63°E., where the transition from the dry snow facies to the ablation facies is rather abrupt since the dry snow line and the equilibrium line are nearly coincident (Mellor, personal communication). In other regions, such as a section across the Rockefeller Plateau, the ablation facies are not present and the percolation and soaked facies (the latter only close to the ice shelf front) extend for approximately 500 km. inland before the dry snow line is met. Nevertheless, it can be concluded that in Antarctica, excluding the region of the Antarctica Peninsula and including the ice shelves, the dry snow facies cover approximately 90 per cent of the area, the percolation and soaked facies cover approximately 10 per cent of the area, and the ablation facies cover less than 1 per cent of the area.

When physiographic units of the antarctic ice sheet are studied in detail, it will be interesting to know the relationships between diagenetic facies and variables such as altitude, latitude, mean annual air temperature, and load as studied by Benson (1962, pp. 69-74) in Greenland and to compare the effects of these variables on diagenetic facies in Antarctica. When drainage systems are selected as the physiographic units (after Giovinetto 1963a) it is seen in Fig. 1 that:

(1) The ablation facies cover a significant area only in systems AB and CD.

(2) The area covered by the percolation and soaked facies is considerable in system HI where they cover more than 50 per cent of the area, and in systems EF, FG, and GH where they cover less than 50 per cent and more than 25 per cent of the area.

(3) The dry snow facies cover practically the whole area of system JK.

The inclusion of new details in the definition of each facies and the revision of the methods used in current studies to place the limits of each zone, will affect the preceding estimates of area. There is scant information on which to base a division of the area enclosed between the dry snow line and the equilibrium line into percolation facies and soaked facies. However it can be stated that the ratio between the area of the soaked facies and the area of the percolation facies is smaller in Antarctica than in Greenland, where it is approximately one fifth (Bader 1961, p. 14).

The subdivision of the percolation and soaked facies made by Müller (1962, p. 305; 1963, p. 106) may be determined for particular sections in Antarctica. Müller subdivided the percolation facies into an upper (A) and a lower (B) zone and the soaked facies in slush zone and superimposed ice zone. Hollin (1959) determined that the superimposed ice zone at 111°E. lies from 3.5 to 8.5 km. from the coast, at altitudes between 225 and 375 m. Kotliakov (1961, p. 97) determined at 93°E. that the "infiltration-congelation (ice) zone" extends from the coast to approximately 1.5 km. inland (superimposed ice zone?), that the "cold infiltration (firn) zone" extends to approximately 12 km. inland and up to 400 m. altitude (lower percolation zone?), and that melting features that affect only the summer layer are found up to 100 km. inland and 1000 m. altitude (upper percolation zone?).

VI. Sources of errors in estimates of area

The errors in the estimation of area covered by given facies due to the methods used in determining the limits of the corresponding zone may introduce large revisions in the figures of area. For example, if areal reconnaissance instead of stratigraphic methods is used to determine the location of the equilibrium line it is possible for the observer to include, although erroneously, the zone of superimposed ice in the zone of the ablation facies. It is then clear that the area of the zone of ablation facies would be overestimated, and the area of the zone of superimposed ice would be underestimated. In the future, if the relative occurrence of melting phenomena in a set of annual layers is considered before a particular locality is included or excluded from the zone of the dry snow facies, II (1), the estimates of the area of the dry snow facies in Greenland and Antarctica will be increased.

VII. Summary

The areas of the zones of particular diagenetic snow facies are estimated for Antarctica and compared with estimates of other workers for Greenland. The ablation facies cover less than 1 per cent of the area, the percolation and soaked facies cover approximately 10 per cent of the area, and the dry snow facies cover 90 per cent of the area. The dry snow line generally lies above 100 m. altitude, ranges between 85°S. and 67°S., and extends in regions limited by the –15°C. and –25°C. annual isotherms.

References

Anderson, V. H. 1958. Byrd Station glaciological data 1957-1958. The Ohio State University Research Foundation, Rept. 825-1, Pt. II, 269 pp.

Aughenbaugh, N., H. Neuburg and P. Walker. 1958. Ellsworth Station glaciological and geological data 1957-1958. The Ohio State University Research Foundation, Rept. 825-1, Pt. I, pp. 1-232.

Bader, H. 1961. The Greenland Ice Sheet. U.S.A.C.E. Cold Regions Research and Engineering Laboratory, I-B2, 18 pp.

Benson, C. S. 1962. Stratigraphic studies in the snow and firn of the Greenland Ice Sheet. U.S.A.C.E. Snow, Ice and Permafrost Research Establishment, Res. Rept. 70, 93 pp.

Bentley, C. R. In press. The land beneath the ice. New Zealand Antarctic Society.

Bogoslovsky, V. N. 1958. The temperature conditions (regime) and movement of the antarctic glacial shield. International Association of Scientific Hydrology, Pub. No. 47, pp. 287-305.

Boyd, W. W. 1960. Ross Ice Shelf traverse. The Ohio State University Research Foundation, Rept. 825-I, Pt. IV, 193 pp.

Crary, A. P., E. S. Robinson, H. F. Bennett and W. W. Boyd. 1962. Glaciological regime of the Ross Ice Shelf. J. Geophys. Res. 67:2791-807.

Dolgushin, L. D., S. A. Yevteyev and V. M. Kotliakov. 1962. Current changes in the antarctic ice sheet. International Association of Scientific Hydrology, Pub. No. 58, pp. 286-94.

Giovinetto, M. B. 1963a. Preliminary report on drainage systems of Antarctica. Pap. pres. at the Karlsruhe meeting of the German Society for Polar Research.

————1963b. Glaciological studies on the McMurdo-South Pole traverse. 1960-61. Institute of Polar Studies, Rept. No. 7, The Ohio State Univ. Res. Found., 39 pp.

Gunn, B. M., and G. Warren. 1962. Geology of Victoria Land between the Mawson and Mulock glaciers, Antarctica. New Zealand Geological Survey, Bull. n.s. 71, 156 pp.

Hollin, J. T. 1959. The glacial economy at Wilkes Station, Antarctica. Pap. pres. at the Buenos Aires Antarctic Symposium organized by the Instituto Antártico Argentino.

————1962. On the glacial history of Antarctica. J. Glaciol. 4:173-95.

Hollin, J. T., and R. L. Cameron. 1961. I.G.Y. glaciological work at Wilkes Station, Antarctica. J. Glaciol. 3:833-42.

Kotliakov, V. M. 1961. Results of a study of the processes of formation and structure of the upper layer of the ice sheet in eastern Antarctica. International Association of Scientific Hydrology, Pub. No. 55, pp. 88-89.

Kruchinin, Iu. A. 1962. Izuchenie stratigrafii verkhnikh sloev snezhnofirnovoi tolshchi shel'fovogo lednika Lazareva (A study of the stratigraphy of the upper layers of the snow and firn thickness of the Lazarev ice shelf). Informatsionnyi Biulleten' Sovetskoi Antarkticheskoi Ekspeditsii (Bulletin of the Soviet Antarctic Expedition), Bull. 32, pp. 19-24.

Long, W. E. 1961. Glaciology, Byrd Station and Marie Byrd Land traverse, 1958-1959. The Ohio State University Research Foundation, Dept. 825-2, Pt. XI, 20 pp.

Lorius, C. 1962. Contribution to the knowledge of the antarctic ice sheet; a synthesis of glaciological measurements in Terre Adélie. J. Glaciol. 4:79-92.

Lunde, T. 1961. On the snow accumulation in Dronning Maud Land. Norsk Polarinstitutt, 48 pp.

Mellor, M. 1959. Mass balance studies in Antarctica. J. Glaciol. 3:522-33.

————1960. Temperature gradients in the antarctic ice sheet. J. Glaciol. 3:773-82.

Mellor, M., and G. Mckinnon. 1960. The Amery Ice Shelf and its hinterland. Polar Record Vol. 10, No. 64, pp. 30-34.

Müller, F. 1962. Zonation in the accumulation area of the glaciers of Axel Heiberg Island, N.W.T., Canada. J. Glaciol. 4:302-18.

————1963. An arctic research expedition and its reliance on large-scale maps. Can. Surv. 17:96-112.

Neuburg, H. A. C. 1959. 1958-1959 I.G.Y. airborne traverse. The Ohio State University Research Foundation. Rept. 825-2, Pt. I, 26 pp.

Pirrit, J., and G. A. Doumani. 1960. Glaciology, Byrd Station and Marie Byrd Land traverse 1959-60. The Ohio State University Research Foundation, Rept. 968-2, 177 pp.

Rubin, M. J. 1962. The Antarctic and the weather. Sci. Am. 207:84-94.

Schytt, V. 1960. Glaciology II. Norwegian-British-Swedish Antarctic Expedition, 1949-52. Scientific Results. Vol. IV. Norsk Polarinstitutt, 179 pp.

Stuart, A. W., and C. Bull. 1963. Glaciological observations on the Ross Ice Shelf near Scott Base, Antarctica. J. Glaciol. 4:399-414.

Swithinbank, C. 1960. Glaciology I. Norwegian-British-Swedish Antarctic Expedition, 1949-52. Scientific Results, Vol. III, Norsk Polarinstitutt, 158 pp.

Tongiorgi, E., E. Picciotto, W. DeBrueck, T. Norling, J. Giot and F. Pantanetti. 1962. Deep drilling at Base Roi Baudouin, Dronning Maud Land, Antarctica. J. Glaciol. 4:101-10.