

# ACCUMULATION IN THE REGION OF WILKES, WILKES LAND, ANTARCTICA

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ABSTRACT. Carrying on from the work initiated over the I.G.Y. period by the United States glaciological parties at Wilkes (cf. Hollin and Cameron, 1961), members of the Australian National Antarctic Research Expeditions have continued accumulation stake measurements to 80 km. inland on the plateau (lat.  $66^{\circ} 31' S.$ ) and extended them south 480 km. (to lat.  $71^{\circ} S.$ ). These stake measurements, supplemented by pit data and surface observations, supply a comprehensive account of the accumulation in this region; how it builds up during the year, how it varies from year to year and how it is affected by topography.

RÉSUMÉ. Continuant le travail commencé au cours de la période de l'A.G.I. par les équipes glaciologiques des États-Unis à Wilkes (cf. Hollin and Cameron, 1961), les Membres des "Australian National Antarctic Research Expeditions" ont continué les mesures d'accumulation à l'aide de balises jusqu'à 80 km à l'intérieur sur le plateau ( $66^{\circ} 31'$  lat. S) et les ont étendues plus au Sud jusqu'à 480 km ( $71^{\circ}$  lat. S). Ces mesures à partir de balises, complétées par les observations de surface et des puits, fournissent des données complètes sur l'accumulation de cette région: sa répartition au cours de l'année, sa variation d'année en année et les effets des caractères topographiques.

ZUSAMMENFASSUNG. Anknüpfend an die Untersuchungen US-amerikanischer Glaziologen während des IGJ in Wilkes Land (vergl. Hollin and Cameron, 1961) haben Teilnehmer der Australian National Antarctic Research Expeditions Messungen an Akkumulationspegeln bis 80 km landeinwärts auf dem Polplateau (Br.  $66^{\circ} 31' S$ ) fortgeführt und 480 km nach Süden (bis Br.  $71^{\circ} S$ ) ausgedehnt. Diese Messungen, ergänzt durch Beobachtungen in Schächten und auf der Oberfläche, vermitteln ein umfassendes Bild vom Schneeauftrag des Gebietes: sein Anwachsen im Jahresablauf, seine Schwankungen von Jahr zu Jahr und seine Abhängigkeit von der Gestalt des Geländes.

## PLATEAU TOPOGRAPHY

Wilkes is situated on a rock peninsula, 10 m. elevation, at lat.  $66^{\circ} 15.5' S.$ , long.  $110^{\circ} 31.5' E.$  (Fig. 1). From here the ice plateau rises steeply at first then more gradually farther inland (Fig. 5). A satellite station, S2, is situated 80 km. east-south-east of Wilkes at an elevation of 1,166 m. in lat.  $66^{\circ} 31' S.$ , long.  $112^{\circ} 12' E.$

South of station S2 the ice cap continues to rise to about 1,230 m. at 29 km. south, then falls to 880 m. at 90 km. south. From there the plateau rises gradually but less steeply to 2,990 m. at 480 km. south of station S2 in lat.  $71^{\circ} 00' S.$  Plateau slopes measured in 1961 and further elevations obtained in March 1962 indicate that the Budd Coast has a high region with a central dome over 1,500 m. in elevation at about lat.  $66^{\circ} 33' S.$ , long.  $113^{\circ} 00' E.$

To the south of this high region there is a low region less than 900 m. in elevation extending from the Totten Glacier to the Vanderford and John Quincy Adams Glaciers. Seismic soundings indicate that the bedrock surface reaches 3,200 m. below sea-level in this region (Jewell, unpublished).

It will be seen that this topographical depression has a marked influence on the accumulation in the region.

## STAKE SYSTEMS AND MEASUREMENTS

### *Wilkes local area*

In November 1957 a set of more than 35 stakes was placed from the rock peninsula coast, up over the steep ice ramp to about 13 km. inland on the plateau, at an elevation of 380 m. (Cameron and others, 1959). Except for several stakes which melted out in the summer months and had to be replaced, this stake system has been measured regularly until 1962. In 1959 the accumulation stakes were hollow or split bamboo. These tended to bend or

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break in strong winds and therefore they were gradually replaced by solid cane stakes 2.5 cm. in diameter. All these new stakes were painted white. This was found to greatly reduce melt water forming around them in summer.

Although the relative change in plateau surface has been recorded on this stake system since 1957, the variation in net accumulation is difficult to determine precisely, because of the

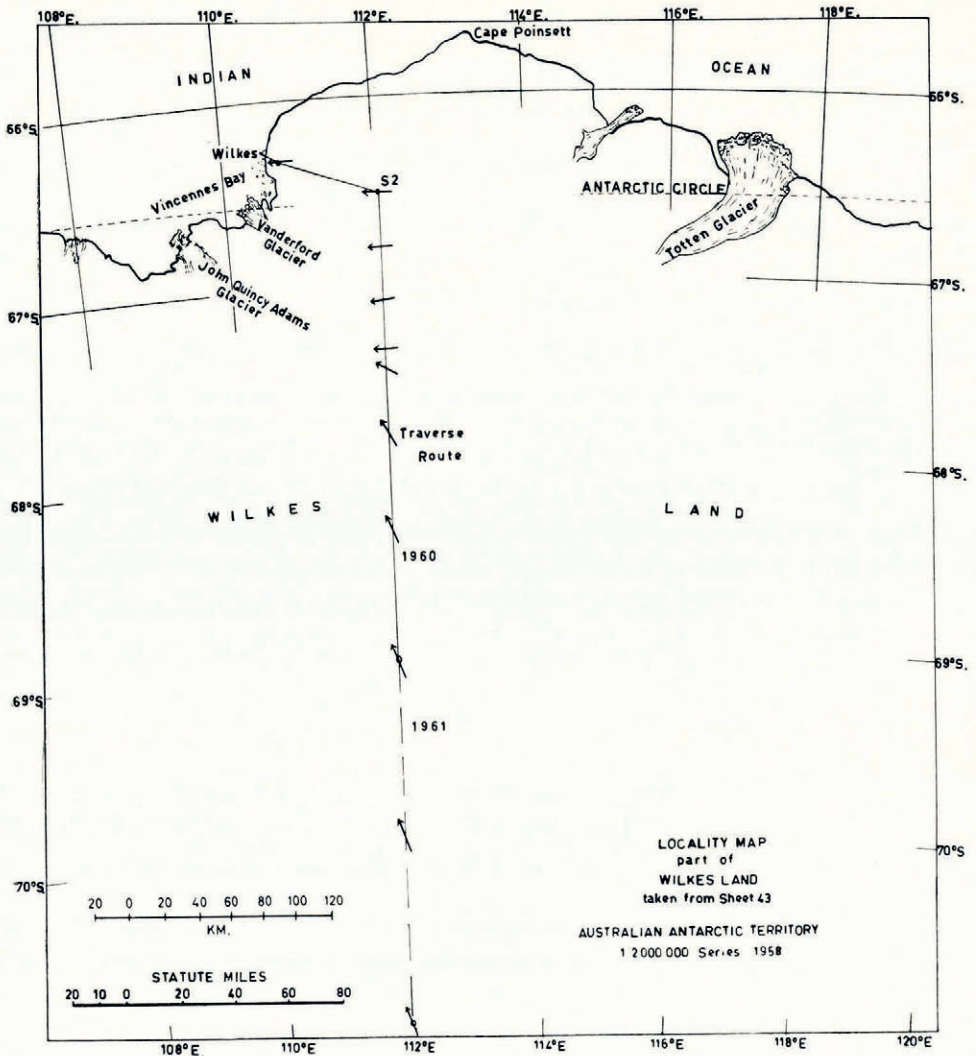


Fig. 1. Location map of Wilkes and traverse routes of 1960 and 1961. The arrows marked along the route indicate the prevailing wind directions as measured from the predominant sastrugi orientations of 1961 (cf. Mather, 1962, p. 169-71)

extensive metamorphism taking place at the surface. This metamorphism has been described in detail by Hollin and others (1961, p. 194-95). Not only does the relative height of the firn surface change but also the density of the snow at and near the surface changes due to such processes as wind packing, melting, refreezing, ice formation and crystal growth. Hence, in order to determine the net water equivalent accumulation it would be necessary to keep a stratigraphic and density record for each stake throughout the year.

As this was impracticable the procedure adopted for 1960 and 1961 was to measure the height of the stake relative to the surface and also to the ice and record the density and type of surface snow. Often there were several different layers of snow above the ice and their depths and densities had to be recorded separately. The ice itself changed little except near the surface where the density was found to range from  $0.65 \text{ g. cm.}^{-3}$ , for the small-grained "white" ice containing large bubbles, to  $0.85 \text{ g. cm.}^{-3}$  for the large-grained "blue" ice containing small bubbles.

During 1959 few density measurements were made. However, for each stake at every measurement the type of snow at the surface was recorded by a standard classification ranging from freshly fallen snow to ice. In order to obtain an estimate of the change in net water-equivalent accumulation during this year, density values have been assigned to the various types of snow (to the nearest  $0.05 \text{ g. cm.}^{-3}$ ) from the corresponding information, including densities, gathered during 1960 and 1961.

Measurements of the 35 stake system were made monthly in 1959 and 1960 and fortnightly in 1961.

#### *Station S2 trail*

Inland from the local area near Wilkes, a set of 8 stakes was placed in October 1957 at 8 km. intervals along the route to station S2 (Cameron and others, 1959). With these stakes no summer melt-out was encountered, and densities from pit and surface measurements were more accurately determined. The thickness and frequency of ice bands were found to gradually decrease with distance inland. Beyond station S2 no ice lenses or bands were encountered in pits; only numerous fine wind crusts were observed. A complete analysis of pit stratigraphy will be published at a later date.

From the pit studies it has been found that the snow is strongly wind packed and hard, with densities ranging from  $0.38$  to  $0.46 \text{ g. cm.}^{-3}$  in different layers. The average density, however, showed no significant increase from the surface to  $2.0 \text{ m.}$  depth (corresponding to more than 4 yr. accumulation). This indicates that the effect of compaction to this depth is negligible. The average density to  $2.0 \text{ m.}$  depth for the whole route was  $0.41 \text{ g. cm.}^{-3}$  and this has been used as a constant conversion factor for snow accumulation to water equivalent.

The accumulation results have been calculated from the following measurements: two in 1957, eleven in 1958, four in 1959, two in 1960 and seven in 1961-62.

#### *Station S2*

At station S2 two sets of stakes were used:

- (i) A set of three 5 cm. by 5 cm. U.S. Weather Bureau stakes was placed in 1957, and a large number of measurements were made on them until January 1962, although they have been replaced several times (to 200 m. across wind from the station) to avoid the station drift. These stakes give a detailed picture of how the accumulation rate has varied with time, but they cannot be taken as representative of the area as a whole.
- (ii) Station S2 strain grid. A set of 12 relative-movement stakes (3 cm. diameter) were placed over a  $20 \text{ km.}^2$  area at station S2 in March 1957 (Cameron and others, 1959). Although fewer readings are available for this system than the above stakes, they serve to give a more accurate estimate of the mean accumulation of the region and also its variation over this area.

The following measurements were made: four in 1957, three in 1958, one in 1959, one in 1960 and six in 1961-62.

Cameron and others (1959, p. 66) noted that the mean net accumulation rate measured from the three U.S. Weather Bureau stakes was higher than that of the mean of the relative movement network. It was suggested that this may be due to the influence of the station or to

the larger cross-section of the U.S. Weather Bureau stakes. However, it will be seen below that in view of the variability in net accumulation rates among the stakes of the relative movement network, due to slight topographic differences, the net accumulation rate at any one position (such as at station S2) cannot be expected to be representative of the area as a whole.

#### *South of station S2*

In November 1960 a total of 180 stakes were placed over a distance of 180 miles (290 km.) due south from station S2 to lat.  $69^{\circ}$  S. The interval between successive stakes was 1 statute mile (1.6 km.), and the stakes were numbered 1 to 180 commencing at station S2.

During 1961 stakes 1 to 120 were remeasured in February and again in March, and stakes 1 to 180 were remeasured in November and again in December. In December 1961 the stake line was extended to 300 miles (480 km.) south of station S2, as far as lat.  $71^{\circ}$  S., for remeasurement in 1962 and 1963.

The properties of the firn were studied by a series of pit and surface measurements. In November 1961 eighteen 2 m. pits were dug next to an accumulation stake, one each 32 km. from Wilkes to station S2 and 480 km. south of station S2. Surface density was also recorded each 8 km. Because of the high accumulation over most of the route, the average densities of the annual layer (sometimes in excess of 2 m.) obtained from the pits were needed for water equivalent calculations rather than the more closely spaced surface density observations. The firn densities varied from an average of  $0.44 \text{ g. cm.}^{-3}$  in hard wind-packed winter layers to  $0.37 \text{ g. cm.}^{-3}$  in softer summer layers. These values were slightly higher for deeper layers more than one year old.

## RESULTS

### *Wilkes local area*

(a) *Accumulation during the year*: The pattern of accumulation during the year appears to depend largely upon the pattern of precipitation. The difficulties of measuring precipitation in Antarctica are well known. However, at Wilkes during 1961 most of the precipitation as recorded daily from the snow gauges occurred with light winds and when totalled over a period without strong winds agreed closely with the local increase in accumulation. Stronger winds following soon after removed a large proportion of this new snow, the remainder becoming packed hard. This resulted in a net accumulation which increased with heavy precipitation but only as a proportion of it. This pattern is illustrated in Figure 2. When precipitation was small ablation still went on so that a decrease in net accumulation resulted. The difference between cumulative precipitation and net accumulation in Figure 2 represents the cumulative loss. Drift transport by wind, sublimation and melt contributed to the ablation. Of these only drift transport has been directly measured. The measurements of drift transport carried out at Wilkes in 1959 (Dingle and Radok, 1961) were extended in 1960 and 1961. Analysis of the results, not yet completed, will aim in particular at estimating the loss of snow by wind from Wilkes and inland as far as station S2.

(b) *Accumulation in different years*: For the years 1957 and 1958 several points are noted from Hollin and others (1961).

First, for the summer of 1957–58 ablation was extensive, melt streams were observed below 150 m. elevation, and the zone of ablation extended to 230 m.

Secondly, “accumulation appears to have been relatively small during the first half of 1958”. This has also been a feature of later years and so may be a general result for this region.

Thirdly, “ablation in the summer of 1958–59 was far less than that of 1957–58. Few streams were observed and the whole of the area down to sea-level remained in the accumu-

lation zone". Average net accumulation from 24 February 1958 to 2 February 1959 for stakes 402 to 429 (at elevations of approximately 100 to 380 m.) was about  $10 \text{ g. cm.}^{-2}$ .

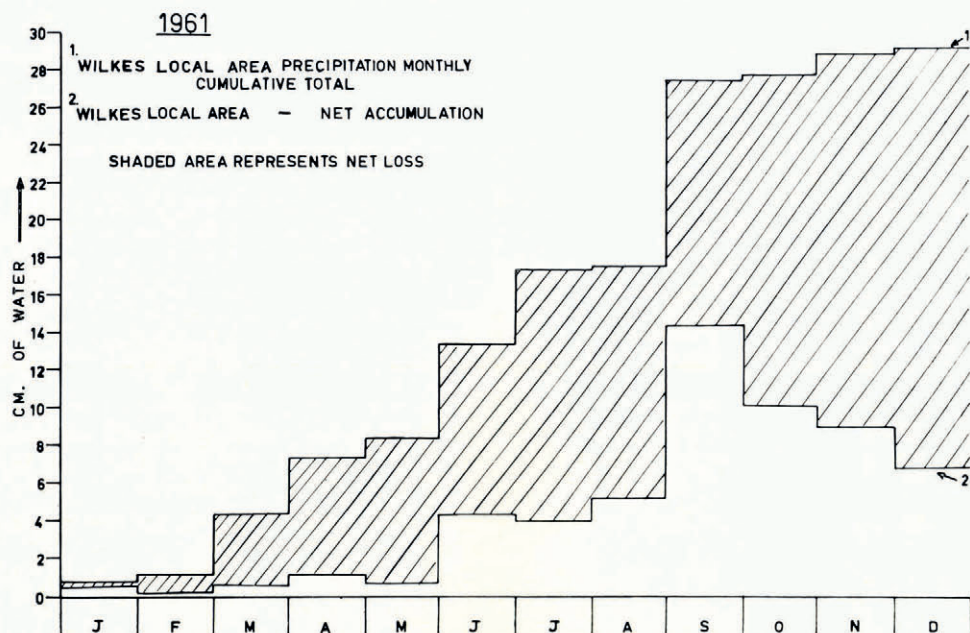


Fig. 2. (1) Wilkes precipitation for 1961; cumulative monthly totals. (2) Wilkes local area average net accumulation. The difference between the two values represents the cumulative net loss

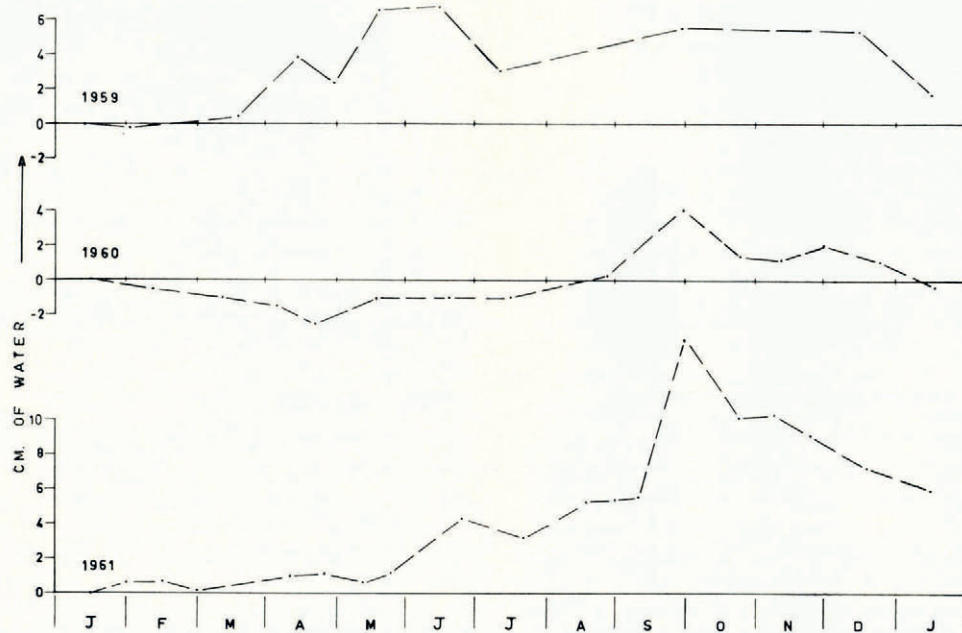


Fig. 3. Wilkes local area average net accumulation for 1959-61

For the years 1959 to 1961 the pattern of net accumulation is illustrated in Figure 3. The general trends appear to be: ablation or little gain by April–May, then a steady build-up to a maximum about September–October, after which summer ablation sets in and net loss continues until the following March to May.

In 1961 the average net accumulation from 15 January was only  $0.6 \text{ g. cm.}^{-2}$  by May, after which a continual build-up occurred to a maximum of  $11.5 \text{ g. cm.}^{-2}$  in September, then ablating to  $6.0 \text{ g. cm.}^{-2}$  by 15 January 1962.

The corresponding figures from 15 January 1960 are  $-2.5 \text{ g. cm.}^{-2}$  by April to  $+4.1 \text{ g. cm.}^{-2}$  in September and  $-0.3 \text{ g. cm.}^{-2}$  by January 1961.

(c) *The extent of the ablation zone*: In 1960 the net ablation zone extended to about 260 m. elevation—similar to the extent observed in 1957. The average net accumulation for the 3 km. below this line was  $-2.0 \text{ g. cm.}^{-2}$  compared with  $+2.5 \text{ g. cm.}^{-2}$  for the 3 km. immediately above it. However, the ablation zone has no well-defined limit, for it gradually merges into the accumulation zone and to different extents in different years. In 1961, as in 1958, there was a positive net accumulation over the whole of the local area extending down to sea-level.

From this it is seen that the resultant change in the plateau surface in this area over 5 yr. has been small, with annual net accumulation fluctuating from positive to negative in different years.

#### *Wilkes to station S2*

The trail stakes to station S2 show a steady build-up of accumulation since 1957, with average annual net accumulation from 1958 to 1961 of: 13.5, 8.2, 8.8 and  $10.1 \text{ g. cm.}^{-2}$ , giving an average rate of  $10.2 \text{ g. cm.}^{-2}$  per annum over the 4 yr.

The pattern of accumulation during the year is characterized by a rapid build-up from autumn to spring and slight loss from December to March, e.g. from December 1960 there was a loss of 1.6 cm. of water by March 1961, then a gain of  $11.0 \text{ g. cm.}^{-2}$  to December 1961 and a loss of  $1.2 \text{ g. cm.}^{-2}$  by March 1962. This general pattern is similar to that at station S2 which is discussed in the next section.

The variation in the average net accumulation rate ( $10.1 \text{ g. cm.}^{-2}$ ) for different stakes along this profile is small. The standard deviation for the eight stakes was  $1.3 \text{ g. cm.}^{-2}$ . The mean rate of net accumulation for the four stakes nearest the coast varied from 0.89 to 0.84 times that of the four stakes farther inland from 1959 to 1961. Application of Student's *t* test to the difference between the two means shows this to be quite significant. Hence, the rate of net accumulation increases slightly with elevation and distance inland. This is in agreement with the results found for the coast and for station S2.

#### *Station S2 (80 km. inland)*

The net accumulation at station S2 from 1957 to 1962 is illustrated in Figure 4. This shows that net accumulation has been almost linear with time, except for the cyclic variation during a particular year. This variation during the year appears to be similar from year to year, and shows an autumn–spring build-up which causes an excess of snow in spring, followed by a summer ablation causing a deficiency from the average rate, late summer to autumn. Variations from the overall linearity follow from variations in annual net accumulation, e.g. as with the more coastal regions the net accumulation of 1958 was slightly higher than for other years.

The average rate over the whole period for the three stakes was  $16.0 \text{ g. cm.}^{-2}$ . This value, however, cannot be considered representative of the area because of the possible influence of drifts caused by the station. For a measure of the average accumulation of the area the results of the grid system are needed.

The 35 m. pit at station S2 (Cameron and others, 1959) gave the average accumulation rate from 1783 to 1957 as  $13.3 \text{ g. cm.}^{-2}$ , with five-year means varying from  $9.0$  to  $17.4 \text{ g. cm.}^{-2}$ .

The strain grid of 12 stakes gives an average rate of accumulation over  $20 \text{ km.}^2$  (1957 to 1962) of  $14.2 \text{ g. cm.}^{-2}$ , with a standard deviation of  $3.1 \text{ g. cm.}^{-2}$ . This relatively large variation among stakes, in contrast to that of the trail to station S2, is not a random variation due, for example, to sastrugi (which are comparatively small in this region) but more a

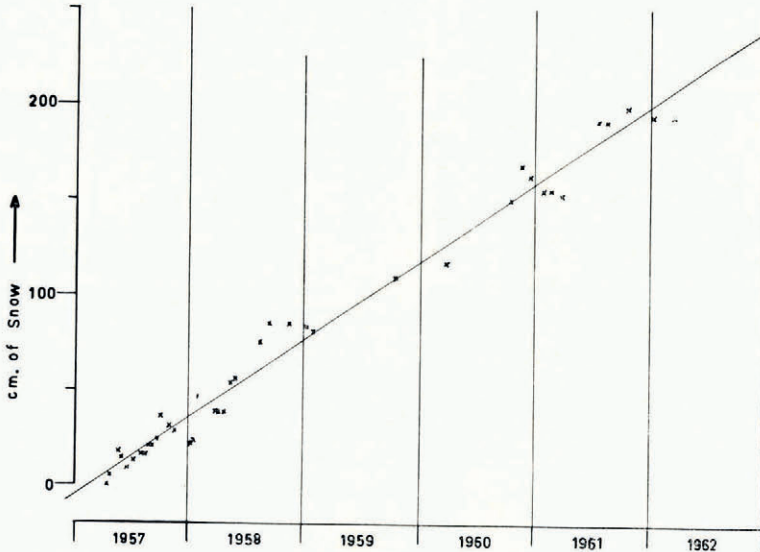


Fig. 4. Average net snow accumulation at station S2, from 1957 to 1962, measured from the three  $5 \text{ cm.} \times 5 \text{ cm.}$  stakes. The straight line is the least squares regression line for net accumulation with time. The actual net accumulation total tends to be below this line in late summer and above it over late winter and spring

property of position. This follows from the result that the proportional differences in the net accumulation rates for different stakes has varied only slightly over the period. Although the maximum slope in this area is less than  $40 \text{ min. of arc}$ , slight variations in surface topography appear to be responsible for the variation in the net accumulation rates. This is brought out more clearly by a closer examination of the accumulation figures for the strain-grid stakes.

The network consists of four inner stakes surrounded by eight outer stakes. The distance between neighbouring stakes is about  $1.5 \text{ km.}$  For the inner four stakes, A, B, C and D, the relative elevations of their surrounding neighbours are available. From these, estimates of the average slope of the line of greatest slope through each of B, C and D have been made, together with the degree of convexity or concavity. The curvature was assumed to be the average of the increases in slope going through the point in the direction of maximum slope and across this slope. (Stake A was omitted because it is in the station area.)

For each of these stakes the ratio of its accumulation rate to that of the mean of the network is listed in Table I for periods from 1957 to 1962, together with the slope and curvature of the stake position.

The accumulation rate has been consistently greatest for stake C, in a relative flat concave position, and least for stake D in a steeper convex position. For position B, with the same curvature as C but where the slope is greater, the accumulation rate has been midway between that of C and D.

From this it appears that both slope and curvature may play an important part in the topographical effect on accumulation rate. This becomes more evident south of station S2 where the topographical variations and the corresponding net accumulation rate variations are much larger.

TABLE I. RELATIVE ACCUMULATION RATES AND TOPOGRAPHY IN THE REGION OF STATION S2

Stake	C	B	D
Deviation from mean slope (27')	-1.4'	+1.6'	+0.6'
Convexity (-) or concavity (+) (min./mile)	+7.0	+7.0	-18.7
Relative accumulation rate from			
20 March 1957 to 18 January 1958	1.24	1.17	0.49
18 January 1958 to 10 January 1959	1.20	0.82	0.42
10 January 1959 to 1 March 1961	1.01	0.94	0.83
1 March 1961 to 2 January 1962	1.26	1.11	0.69
20 March 1957 to 2 January 1962	1.13	0.99	0.67

### South of station S2

For this region only one year's data are available at present. Also, because of the high accumulation the pits did not extend far into the past, so that the results cannot be taken as indicative of general trends as the above longer-term data. However, where the pits covered two or more years the pattern shows accumulation values of the same order as measured at the stake next to the pit from November 1960 to November/December 1961. Stakes 0 to 50 which were remeasured in March 1962 and gave an average of  $13.1 \text{ g. cm.}^{-2}$  net accumulation from November 1961, compared with  $13.7 \text{ g. cm.}^{-2}$  for these stakes over the similar period during 1960-61. This suggests the same order of accumulation may be expected for 1962.

The average net accumulation over the whole profile from Wilkes to station S2 and 480 km. south was found to be  $33 \text{ g. cm.}^{-2}$ . This is of similar magnitude to that recorded south of Dumont d'Urville (Lorius, 1962), and south of Mirny (Dolgushin, 1961). However, south of station S2 there is a region for which the profile over 200 km. gave an average net accumulation in excess of  $56 \text{ g. cm.}^{-2}$ .

Stake tops were originally 214 cm. above the surface; after 12 months several stakes were covered completely and many others protruded by only a few centimetres. The snow in this region was very hard and wind packed with an average density of  $0.42 \text{ g. cm.}^{-3}$ . Hard wind-eroded sastrugi often reached heights of 1.5 m.

The most remarkable feature of the accumulation south of station S2 is its apparent variation with topography on both major and minor scales.

(a) *The variation of accumulation with major topography (illustrated in Figure 5)*: South of station S2, as the elevation increases to a high region between 20 and 29 km., the average annual net accumulation (from November 1960 to November 1961) decreases to 5 cm. of water. From here southwards the accumulation increases rapidly in the large trough about 90 km. south and up the following slope to averages of 80 cm. of water equivalent. This average gradually decreases to 30 cm. of water at 290 km. south of station S2.

From 290 to 480 km. south of station S2 the pit data indicate a continued steady decrease to  $20 \text{ g. cm.}^{-2}$  per annum. Here, at lat.  $70^{\circ} 52' \text{ S.}$ , the plateau elevation reaches 2,990 m. and the plateau slope is less than 10 min. of arc in any direction. Ram-hardness values to 4 m. depth and lack of sastrugi indicate that this region is beyond the zone of strong surface winds.

The variation in accumulation rate during the year (for stakes 0 to 120) to 192 km. south of station S2 is illustrated in Figure 6. Over the summer period, November (1960) to March (1961), the high region 20 km. south of station S2 showed an average slight ablation of approximately  $1 \text{ g. cm.}^{-2}$ . Farther south there was a substantial build-up over this period,



the average overall rate being  $1.7 \text{ g. cm.}^{-2}/\text{month}$ . This can be compared with  $2.8 \text{ g. cm.}^{-2}/\text{month}$  during March,  $2.3 \text{ g. cm.}^{-2}/\text{month}$  from March 1961 to November 1961, and  $1.8 \text{ g. cm.}^{-2}/\text{month}$  from November 1961 to January 1962.

(b) *Variation with minor topography*: The elevation profile for each position in the region 90 to 300 km. south of station S2 shows, superimposed upon the steady slope (seen in Figure 5),

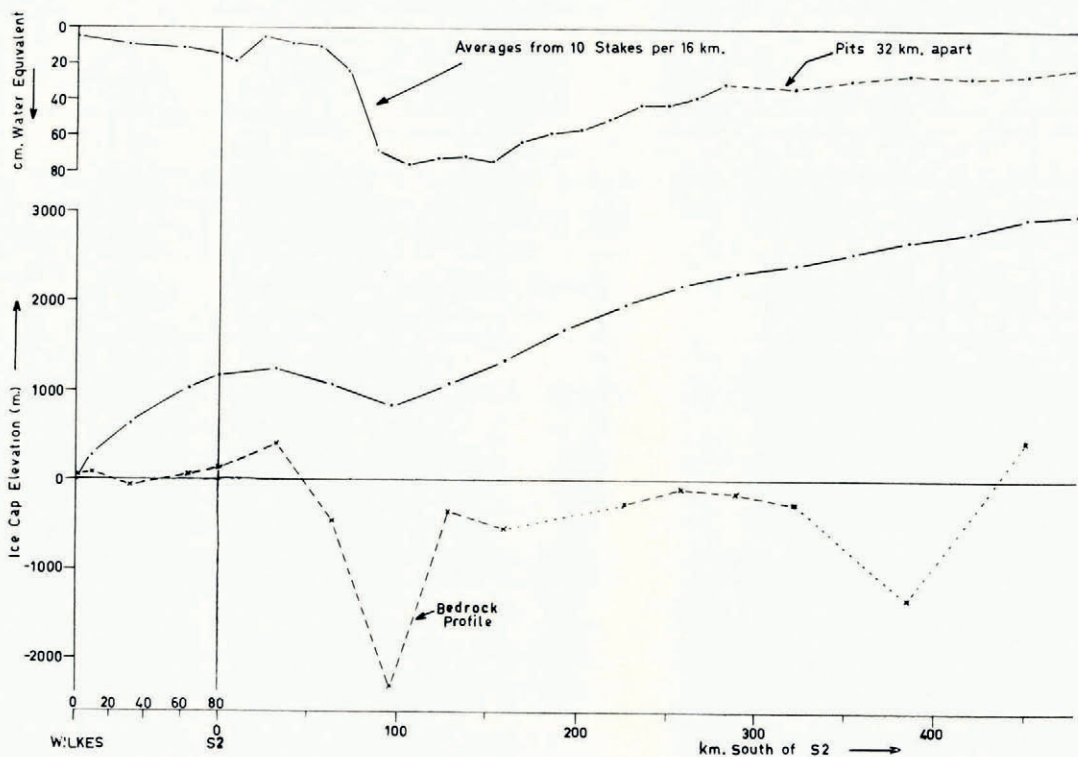


Fig. 5. Ice sheet profile from Wilkes east-south-east to station S2 and south to lat.  $71^{\circ}$  S. along the traverse route of Figure 1. Above this is shown the net accumulation profile over this route for November 1960 to November 1961. Values are taken from the average of 10 stakes per 16 km. from station S2 to 290 km. south, and from data from pits 32 km. apart from 290 to 430 km. south of station S2. The bedrock profile is taken from Jewell (unpublished)

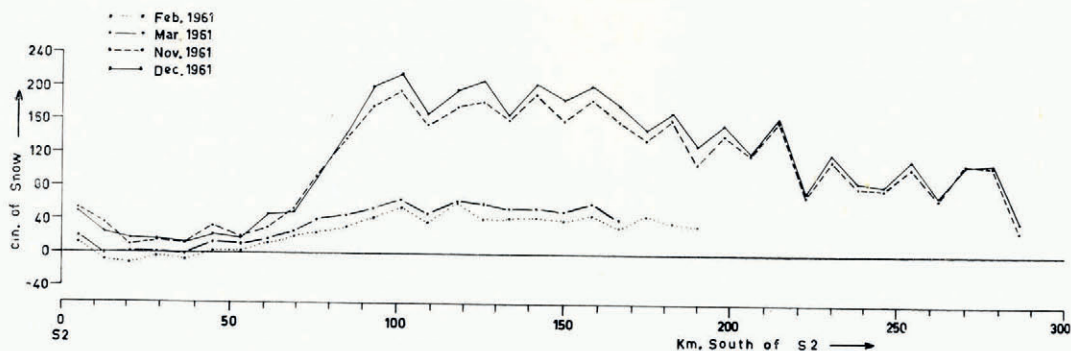


Fig. 6. Variation in net accumulation south of station S2 during the year. The net snow accumulation from November 1960 is plotted for the four measurements of 1961. The results are from the average of five stakes each 8 km. The origin is November 1960

a series of irregular undulations of wave-lengths 5 to 15 km., and amplitudes 7 to 50 m. (Fig. 7). These undulations caused large variations in net accumulation (up to 215 cm. in 3 km.) with remarkable regularity.

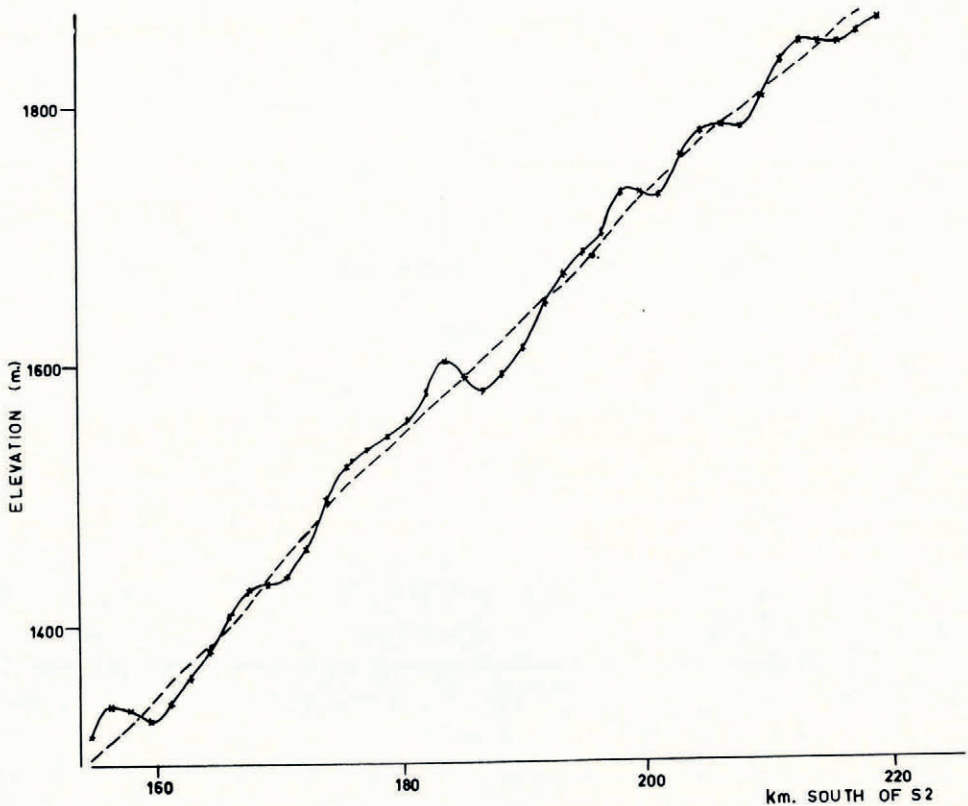


Fig. 7. Undulations on a steady slope. Between 150 and 200 km. south of station S2 the elevation for each mile (1.6 km.) position is plotted. The broken line has been obtained from the 10 mile (16 km.) running-mean elevation

Dolgushin (1961) reported similar "waves" along a 150 km. profile between Mirny and "Pionerskaya". These were observed to be between 2 and 6 km. wide, perpendicular to the dominant direction of the wind, and to move slowly in the direction of the wind. In Terre Adélie, from the coast to "Charcot", a distance of 500 km., accumulation was observed to vary greatly with local changes in slope (Cornet and others, 1960). Swithinbank (1959) reported a series of stepped ridges on a slope inland of Maudheim. Accumulation variations over these were found to be of the same order as those south of station S2. The accumulation stakes were too widely spaced to give an accurate picture of the net accumulation over these stepped ridges but Swithinbank noted that net accumulation appeared to be greatest where the slope was least. He concluded that eventually there would be a gradual smoothing of the topography but that owing to movement the irregularities would persist (Swithinbank, 1959, p. 134).

After comparing the accumulation data south of station S2 with the elevation profile, it appeared that net accumulation maxima occurred near the bottom of depressions and minima occurred near the crests. However, closer analysis revealed that the net accumulation

profile is more closely related to slope. A comparison of profiles 1 and 2 in Figure 8 shows that net accumulation minima tend to occur down-wind of the tops of the crests, and the net accumulation maxima down-wind of the troughs.

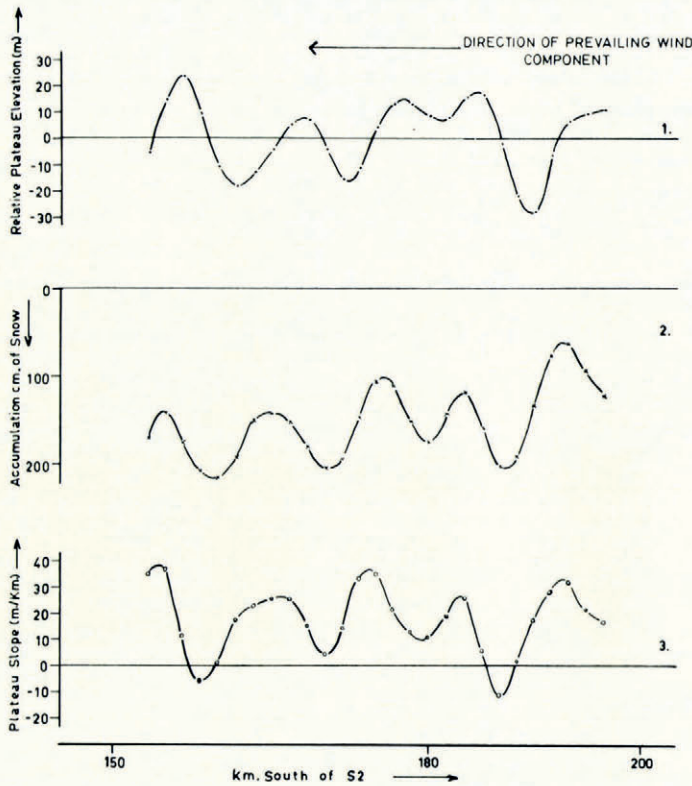


Fig. 8. Accumulation over an undulating slope. For a typical section of the traverse route in the region of high accumulation the following are plotted: (1) Relative elevation, obtained from the difference between the elevation at each stake and the 10 mile (16 km.) running mean (which represents the steady slope upon which the undulations are superimposed). (2) Annual net snow accumulation for each stake. (3) The average slope at each stake position. Each profile has been smoothed according to

$$X'_i = \frac{X_{i-1} + 2X_i + X_{i+1}}{4}$$

Comparing profiles 2 and 3, it may be seen that the net accumulation profile closely follows slope, not only in phase but also in relative magnitude. By least squares linear regression, the following expression has been found for the deviation in accumulation,  $A$ , from its mean in terms of the deviation in slope,  $S$ , and deviation in relative elevation,  $E$  (units used as in Figure 7):

$$A = -0.85 S - 0.21 E.$$

This suggests that rather than being filled in by the high accumulation the "waves" would advance up-slope, into the wind (in contrast to those reported by Dolgushin (1961)).

If it is assumed that the accumulation does not destroy the waves but just causes them to advance up-slope at a constant rate, together with an overall rise of the surface, then an estimate of the rate of movement may be made in terms of the variation of accumulation over a wave and the corresponding variation of slope.

For, suppose a series of waves is moving up a uniform slope at a constant speed,  $v$ , then the profile at a time,  $t$ , may be represented by an equation of the form:

$$y = Ax + Bt + f(x - vt),$$

where  $x$  and  $y$  are the horizontal and vertical coordinates of the profile,

$A$  is the uniform slope (assumed constant),

$B$  is the overall average rate of net accumulation of the surface as a whole, and

$f$  is a continuous periodic function with a continuous derivative and with zero integral over a period,

e.g. for a series of regular waves of amplitude  $a$  and wave-length  $\frac{2\pi}{p}$ ,

$$f(x) = a \sin px.$$

Then the accumulation rate is given by

$$\frac{\partial y}{\partial t} = B - vf'(x - vt)$$

and the slope by

$$\frac{\partial y}{\partial x} = A + f'(x - vt).$$

Hence,

$$\frac{\partial y}{\partial t} = B + Av - v \frac{\partial y}{\partial x}.$$

This implies that the variation in net accumulation rate over the "waves" is proportional to the variation in slope. This appears to be in agreement with the net accumulation results obtained and is a condition for the preservation of the form of the waves.

To obtain  $v$  we note that over any wave

$$\left(\frac{\partial y}{\partial t}\right)_{\min.} - \left(\frac{\partial y}{\partial t}\right)_{\max.} = -v \left[ \left(\frac{\partial y}{\partial x}\right)_{\max.} - \left(\frac{\partial y}{\partial x}\right)_{\min.} \right].$$

Over the region considered in Figure 8 the average variation in net accumulation over a wave was 83 cm. of snow, and the average change in slope was  $\frac{31}{1000}$ . Hence, an estimate for  $v$  (in m./yr.) is given by

$$0.83 = v \frac{31}{1000} \quad \text{or } v = 27 \text{ m./yr.}$$

To obtain a more exact relationship for the variation of net accumulation over an undulating slope and to test the rate of movement it would be desirable to have a series of closely spaced stakes over a complete "wave". The study of the variation of drift transport with wind and the variation of wind down an undulating slope is expected to throw light on the cause of these phenomena.

## CONCLUSION

### *Annual net accumulation*

The Wilkes area from the coast to about 560 km. inland may be considered in four main regions with merging boundaries.

- (i) Within about 15 km. of the coast, or below about 350 m. elevation there is a region of very small net accumulation over the longer period, because the annual net accumulation varies from positive to negative values in different years.
- (ii) From the coastal region going inland to about 100 km. the net accumulation rate since 1957 increases from about 10 g. cm.<sup>-2</sup> yr.<sup>-1</sup> over most of the slope to 14 g. cm.<sup>-2</sup> yr.<sup>-1</sup> in the vicinity of station S2.

- (iii) Farther south from station S2 over a topographical depression and up the following slope there is a region of very high annual net accumulation with averages from 80 to 68 g. cm.<sup>-2</sup> between 90 and 200 km. south of station S2.
- (iv) Still farther south of station S2 the annual net accumulation decreases gradually to about 18 g. cm.<sup>-2</sup> by lat. 71° S., at an elevation of 3,000 m., beyond the zone of strong surface winds.

#### *Variation in accumulation rate during the year*

The pattern of accumulation during the year is characterized by a period of rapid accumulation, autumn to spring, but net ablation during the summer. This net summer ablation varies from about 8 g. cm.<sup>-2</sup> at the coast to 2 g. cm.<sup>-2</sup> 100 km. inland, at an elevation of 1,200 m. In the region farther south there was no net ablation over summer (November to March) but the accumulation rate was only about two-thirds of that from March to October.

#### *Topography influence*

The accumulation pattern is strongly influenced by topography on both large and small scales.

On the large scale the accumulation profile suggests that concave depressions gain accumulation at the expense of convex rises.

On the small scale, "waves" on a slope cause net accumulation maxima near points of least slope (including negative values) and minima near points of maximum slope. This should perpetuate the waves, but move them up-slope, into the wind, at a rate of the order of 25 m./yr., for the slopes and accumulation rates observed inland.

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