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ACCUMULATION BETWEEN MOUNT CHAPMAN AND "BYRD" STATION, ANTARCTICA*

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ABSTRACT. In November and December 1965 accumulation measurements were made at 3 km. intervals and at networks of poles at six photogrammetric arrays on an oversnow traverse from Mount Chapman to "Byrd" station. The results at the photogrammetric arrays, which yield a mean accumulation of 16·4 g. cm.$^{-2}$ yr.$^{-1}$ for 1963–65, are compared with values determined from stratigraphic investigations in 1958–59 and in 1962–63, which gave 12·2 g. cm.$^{-2}$ yr.$^{-1}$ and 13·2 g. cm.$^{-2}$ yr.$^{-1}$, respectively.

RÉSUMÉ. *Accumulation entre Mount Chapman et la station "Byrd", Antarctique.* En novembre et décembre 1965, des mesures d'accumulation furent effectuées en des intervalles de 3 km et en des réseaux de balises de six zones repères photogrammétriques durant un raid de Mount Chapman à la station "Byrd". Les résultats obtenus par les réseaux donnent une accumulation moyenne de 16,4 g cm^{-2} an^{-1}; ils sont comparés aux valeurs obtenues par des recherches stratigraphiques en 1958–59 et en 1962–63 qui donnent respectivement 12,2 et 13,2 g cm^{-2} an^{-1}.

ZUSAMMENFASSUNG. *Akkumulation zwischen Mount Chapman und "Byrd Station", Antarktika.* Im November und Dezember 1965 wurden längs eines Profils zwischen Mount Chapman und der "Byrd Station" in Abständen von 3 km und an Pegelnetzen bei sechs photogrammetrischen Punktfeldern Akkumulationsmessungen vorgenommen. Die Ergebnisse an den photogrammetrischen Punktfeldern, die einen mittleren Akkumulationswert von 16,4 g cm^{-2} pro Jahr für 1963–65 liefern, werden mit Werten aus stratigraphischen Untersuchungen von 1958–59 und 1962–63, die bzw. 12,2 g cm^{-2} pro Jahr und 13,2 g cm^{-2} pro Jahr ergarben, verglichen.

DURING November and December 1965 a party consisting of Robert C. Gunn (surveyor), Bernard E. Brush (mechanic) and the author (glaciologist) made an oversnow traverse from Mount Chapman to "Byrd" station (Fig. 1). The primary purpose was to provide ground control for a photogrammetric determination of surface motion in this area. Markers to serve as photo-identifiable points for this purpose were erected originally in 1962–63. At that time accumulation was determined by strati-

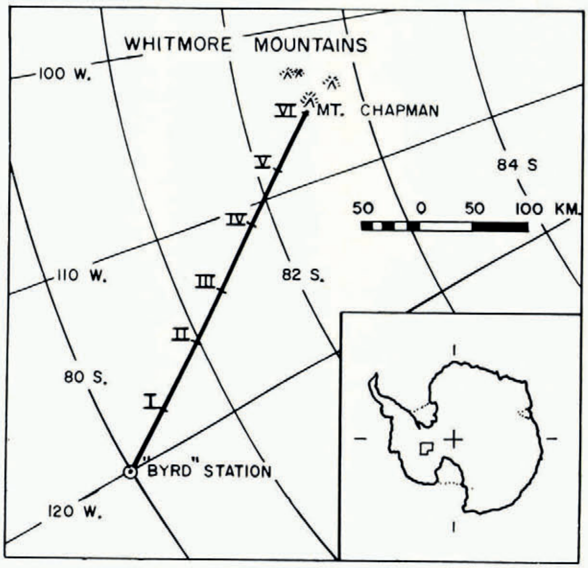

Fig. 1. Location map showing the positions of photogrammetric arrays where stake networks are located

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graphic techniques at six points along the route and 163 accumulation stakes were set out (Koerner, 1964).

The stakes are bamboo poles with boards on the 1962–63 surface. One of the natural nodes on the bamboo pole is the reference mark for the measurements. There is a single pole every 3 km., except in the interval between 250 and 300 km. from "Byrd" station, where the spacing is 7 km. In addition, there are networks of 10 to 15 poles at the six photogrammetric arrays. These are arranged in a 100 by 300 m. rectangle to measure areal variations in accumulation. The amount of snow accumulated was to be determined by probing from the new surface to the board. Re-measurement of the distance from the board to the reference mark would indicate the amount of settling of the firn (Koerner, 1964).

Measurements

An attempt was made to follow these procedures but it was found impossible to penetrate deeply enough to reach the board from the 1965 surface with the available probe. During the first part of the traverse, therefore, the accumulation of snow was determined by the usual method of measuring the distance from the reference mark to the surface and comparing this with the previous measurement of this distance. The error introduced by compaction was left undetermined. During the work at array IV, it occurred to the author that the board could be reached rather easily by drilling down to it with the SIPRE auger. This procedure was used at array IV and at all the markers from array III to "Byrd" station. A core approximately equal in length to the amount of accumulated snow was taken for the purpose of determining the mean snow density at each point.

Several large discrepancies between accumulation measured from the board and from the reference mark on the pole were noted. It appears that these inconsistencies resulted because the measurements were made to different nodes on the bamboo stakes in the two seasons. Because the discrepancies were noted in the field, special care was taken to insure that the proper node was used for each measurement, but of course the possibility remains that the wrong node was used inadvertently in some cases. When inconsistencies were noted, the measurement was usually repeated. It is worth noting, however, that surprising as it may seem, it was quite easy to miscount the number of nodes from the top of the pole, especially when the number of nodes to be counted was larger than three. Some ambiguity arose in two or three places where there was a node exactly at the top of the pole. In view of these difficulties, it is strongly recommended that the top of the pole or an artificial mark, such as a saw cut, be used for a reference line.

At the beginning of the traverse (that is, at the first few stakes after leaving array VI near Mount Chapman), some confusion arose about the identity of the stakes. Two markers were missed out of the first eight encountered. It is reasonably certain that these were markers V-13 and V-14, and it is quite possible that they were buried. There was also one place where a stake was missing in one row of a network at an array, and it was impossible to determine with certainty which stake was missing. It is clear from these experiences that it is advisable to identify individual markers instead of relying on finding them in proper sequence.

Results

The mean annual accumulation for the period from summer 1962–63 to summer 1965–66 for each stake along the traverse route is given in Figure 2. The values between "Byrd" station and array III

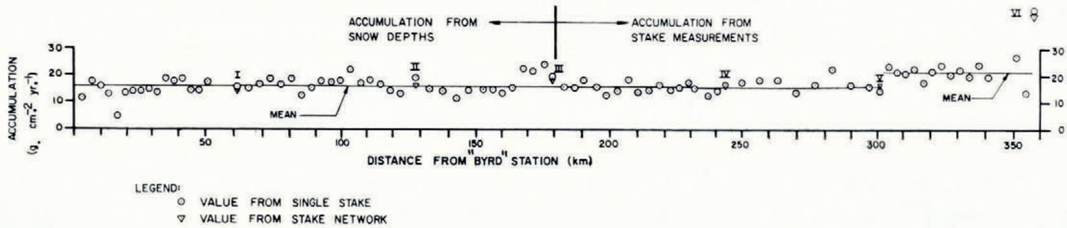

Fig. 2. Mean annual accumulation for the period summer 1962–63 to summer 1965–66

are based on measurements of the actual depth of snow above the board, while the other values are computed from the height of the reference mark above the surface. The mean accumulation determined from the stake network at each array and the means between "Byrd" station and array V, and between arrays V and VI are also shown.

The accumulation varies rather irregularly along the traverse route with no obvious relation to topography except in the vicinity of Mount Chapman. With very few exceptions, however, the values between "Byrd" station and array V (300 km. from "Byrd" station) cluster around their mean value of 16·1 g. cm.$^{-2}$ yr.$^{-1}$, the standard deviation being 0·4. Between arrays V and VI the value is higher, averaging 21·3 g. cm.$^{-2}$ yr.$^{-1}$ with a standard deviation of 0·8. The apparently highly anomalous value of 44·5 g. cm.$^{-2}$ yr.$^{-1}$ at array VI has not been included in this average.

No large areal variation was detected from the measurements at the stake networks, although the high value obtained at array VI does appear to be highly localized from other evidence in the area. Only about 1 m. of snow had accumulated at photogrammetric markers about 1 km. north and 1·5 km. south of the stake network. Partial excavation of a supply cache less than 1 km. south-east yielded a value of 80 cm., while the mean value from the stake network was 288 cm. of snow. The stakes here are about 5 km. from Mount Chapman and approximately 1 km. down-slope of the top of a gentle southward slope.

The standard deviations of the means at the networks ranged from 1 to 3 per cent and maximum deviations from the means ranged from 8 to 21 per cent. The maximum deviations are probably more meaningful than the standard deviations in estimating the inaccuracy to be expected from observations at a single stake. Table I is a summary of the stake network results.

TABLE I. STAKE NETWORK RESULTS

Array	Accumulation g. cm.$^{-2}$ yr.$^{-1}$ from: Single pole at marker	Mean of all poles	Maximum	Minimum	Standard deviation: Of mean g. cm.$^{-2}$ yr.$^{-1}$	Per cent	Of one observation g. cm.$^{-2}$ yr.$^{-1}$	Per cent	Largest deviation from mean g. cm.$^{-2}$ yr.$^{-1}$	Per cent
I	15·7	14·2	15·7	12·7	0·3	2	0·8	6	1·5	11
II	19·3	16·2	19·3	14·2	0·3	2	1·2	7	3·1	19
III	19·2	18·5	19·2	17·1	0·3	2	0·8	4	1·4	8
IV	16·6	16·1	17·3	14·5	0·2	1	0·9	6	1·6	10
V	14·3	16·8	20·3	14·3	0·5	3	1·8	11	3·5	21
VI	44·5	42·3	46·6	35·7	1·4	3	4·4	10	6·6	16

There was considerable variation in the amount of settling of the firn relative to the reference mark on the pole, but in a large majority of cases it ranged from 0 to 9 cm. The remaining measurements yielded figures which were unreasonably large or indicated an elevation of the surface. As a check, some rough calculations were made to ascertain the amount of settling to be expected from the increase in density, determined in pits at the arrays, of the material below the 1962–63 surface. This yielded values ranging from 2 to 10 cm. Only figures smaller than 10 cm. were therefore considered to represent compaction. The larger values were attributed to errors caused by measurement to different nodes in the two seasons. No pattern could be discovered in these values. The mean settling of the surface in 3 yr. was 4 cm. with a standard deviation of 0·3 cm. Thus the error introduced by measuring from a mark to the surface 3 yr. apart to determine the accumulation in this area is less than 0·5 g. cm.$^{-2}$ yr.$^{-1}$ on the average. Because of the irregularity of the settling and its small effect on the mean annual accumulation, no attempt has been made to "correct" the values between arrays III and VI for settling.

ACCURACY

The accuracy of the determination of mean annual accumulation in this case depends on the precision of the measurements of (1) depth of snow accumulated, (2) its mean density, and (3) the time over which the accumulation took place, and can be evaluated by applying the expression for the standard error of a function of several independent variables,

$$m_f = \pm\left[\left(m_a\frac{\partial A}{\partial F}\right)^2 + \left(m_b\frac{\partial B}{\partial F}\right)^2 + \ldots \left(m_n\frac{\partial N}{\partial F}\right)^2\right]^{\frac{1}{2}},$$

where m_a, m_b ... m_n are standard errors of the respective variables.

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The estimated error in the measurement of the depth of snow is ±1 cm., the error in the length of the core is ±2 cm. and the time is known to ±3 days in all but one interval, where it is known to ±6 days. The errors in weight and radius of the core are negligible. Using the estimated errors in place of standard errors, the error computed from this expression ranges from ±0·34 to ±0·47 g. cm.$^{-2}$ yr.$^{-1}$. The higher value is approximately 3 per cent of the annual accumulation over most of the traverse route.

The error resulting from the possibility that some of the measurements between arrays III and VI were made to incorrect reference marks cannot be estimated. It has, however, been possible to make a rough check of these values from measurements of the heights of the photogrammetric markers above the surface in 1965 and in 1962–63. Since the 1965 measurements were made only to the nearest 0·1 m. and because the value is likely to reflect the influence of the marker itself, a "calibration curve" for these readings was constructed from 44 points where both a true accumulation figure and a measurement at the marker were available. It is estimated that the "calibrated" values yield results accurate to approximately ±15 cm.

A measurement at the photogrammetric marker was available at 27 of the 38 points at which the accumulation was determined by measurement from a node on the bamboo pole. The "calibrated" value from the photogrammetric marker agreed very well with the value from the pole measurement in all but one case, where the difference was 70 cm. Since, in addition, the accumulation determined from the stake measurement was abnormally low, the value from the photogrammetric marker was adopted for this station (station III-6). Furthermore, since the accumulation figures obtained in this interval do not differ substantially from those where the actual snow thickness was measured, it seems reasonable to suppose that no serious errors have been introduced in most of the measurements.

The stake networks at the arrays indicate that there is not too great a variation of accumulation over a limited area, the largest deviation from the mean being 21 per cent. It would seem, therefore, that a single stake will give a reasonable idea of the accumulation even if it represents the maximum or minimum figure one would obtain in a small network of stakes.

Conclusion

Table II gives a comparison of accumulation values determined from pit stratigraphy (Koerner, 1964) and from the present stake measurements. The determinations from stratigraphy are all smaller, although there is a considerable range in the differences. It must be kept in mind that different time intervals are covered by the two determinations. Nevertheless, it appears that determinations from stratigraphy tend to underestimate the accumulation. Long covered essentially the same route in 1958–59 (Cameron, 1964). His pit studies were in slightly different locations and his interpretations of stratigraphy yielded a result somewhat lower than Koerner's, the mean being 12·2 g. cm.$^{-2}$ yr.$^{-1}$, 26 per cent lower than the mean of the stake network measurements.

Table II. Accumulation from Pit Stratigraphy (Koerner, 1964) and from Stake Measurements

Station	*Pit* g. cm.$^{-2}$ yr.$^{-1}$	*Years covered*	*Stakes* g. cm.$^{-2}$ yr.$^{-1}$	*Years covered*	*Difference as percentage of stake value*
I	13·7	1959–62	14·2	1963–65	4
II	12·0	1958–62	16·2	1963–65	21
III	13·1	1957–62	18·5	1963–65	28
IV	13·7	1958–62	16·1	1963–65	17
V	13·5	1958–62	16·8	1963–65	19
VI	13·0	1958–62	42·3	1963–65	66
Mean excluding station VI	13·2		16·4		19

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