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RATE OF ACCUMULATION OF SNOW AT THE SOUTH POLE AS DETERMINED BY RADIOACTIVE MEASUREMENTS

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THE importance and the difficulties of estimating the annual rate of accumulation of snow on the Antarctic polar plateau have been stressed by various authors[1,2]. These difficulties are basically due to the very low annual rate of accumulation which could give rise to complete disappearance of an annual or seasonal layer by wind erosion or by some other mechanism. Thus all methods based on identification of annual layers would tend to under-estimate the number of years, whether these methods be stratigraphic or isotopic.

In order to overcome this difficulty two methods based on radioactive measurements have recently been proposed; these methods avoid the subjective interpretations inherent in glaciological and isotopic methods.

The first method[2] is based on radioactive fall-out from the Castle thermonuclear bomb test which is used to identify a reference-level corresponding to the 1954–55 austral summer. This method could be used to measure the mean accumulation over the past nine years. The second method[3,4] is based on the radioactive decay of the lead-210 contained in the precipitation. This method would normally allow the dating of the snow layers for up to one hundred years in the past.

During the course of a summer campaign supported by the U.S. Antarctic Research Program (U.S. National Science Foundation), two of us (E. P. and W. D. B.) were able, in December 1962, to collect a series of samples of snow and firn to be investigated by both methods.

A number of samples, at depths of up to 26 m, were collected in the 'Snow-Mine'[5] of the Amundsen–Scott South Pole Station and were brought frozen to Belgium.

Estimations of the rate of accumulation of snow at the South Pole published so far are based on three groups of results:

(1) *Stratigraphic observations.* The most extensive are those of Giovinetto[5], which deal with the 26-m section of the 'Snow-Mine' representing a period of more than two hundred years. He reports a mean annual accumulation of 6·6 cm of water during 1760–1947 with, however, an annual rate of 7·4 cm over the past hundred years.

More recent observations[6] confirm the figure of 7·0 cm of water as the annual rate over the past few years.

(2) *Direct measurements carried out, since 1957, on stakes placed in the vicinity of the station.* The mean value of these measurements kindly communicated by L. Aldaz, indicates an accumulation of 20 cm/yr. in the relative level, which, taking into account a density of 0·35 for the surface snow, confirms the value of 7·0 cm of water.

(3) *Variations in the oxygen isotope ratio.* Sharp and Epstein[1] note a systematic disagreement between the values of the annual accumulation deduced from their measurements of the 0–18/0–16 ratio and those obtained by direct measurement or deduced stratigraphically at various locations in West Antarctica. They suggest the possibility that the accepted rate of accumulation for the whole West Antarctica may have been under-estimated by a factor of 2.

They put forward an annual rate of accumulation of water at the South Pole of the order of 15 cm. This figure results from the analysis of an 80-cm ice section, showing only 3 isotopic alternations.

This article presents the results obtained by our stratigraphic observations, and by the measurements on the fission products and on lead-210.

(*a*) *Stratigraphy.* Fig. 1 presents the stratigraphic profile of a glaciological pit dug in the north-east quadrant, about 500 m from the Amundsen–Scott South Pole Station.

The stratigraphic features of the snow cover in this area have been previously described[3–7]. The identified summer layers are shown in Fig. 1. The average annual accumulation deduced for the period 1951–62 inclusive is 7·5 cm of water. One or more year-level having probably

Table 1. INDEPENDENT ESTIMATIONS OF THE ANNUAL ACCUMULATION AT THE SOUTH POLE

Annual interval (estimated)	Method of measurement	Snow accumulation (cm)	Water equivalent (cm)	Ref.
Feb.–Nov. 1962	Direct ('New Field', 140 stakes)	20	7·0	L. Aldaz (private communication)
Feb. 1958–Nov. 1962	Direct ('Old Field', 36 stakes)	18·5	6·6	,,
(1947–1850)	Stratigraphy ('Snow-Mine')		7·4	Giovinetto (ref. 5)
(1958–1954)	0–18/0–16		15	Sharp and Epstein (ref. 1)
(1963–1951)	Stratigraphy	20	7·5	Present work
(1963–1955)	Fall-out	17·5	6·5 ± 0·5	,, ,,
(1963–1850)	Lead-210		6 ± 1	,, ,,

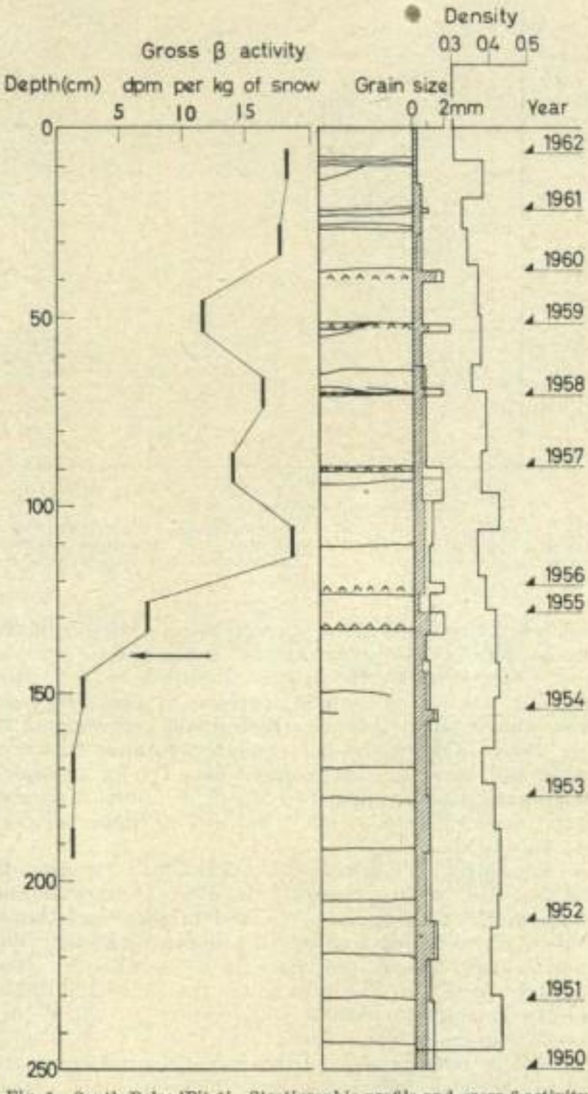

Fig. 1. South Pole: 'Pit 1'. Stratigraphic profile and gross β-activity. The interpretation of the stratigraphic profile in terms of annual layers is given on the right side of the figure

been missed, this value must be considered an upper limit. For the period 1955–62 inclusive, for which the stratigraphy is more clearly marked, the average annual increase is 6·3 cm.

(*b*) *Fission products*. Fig. 1 also shows the values of the

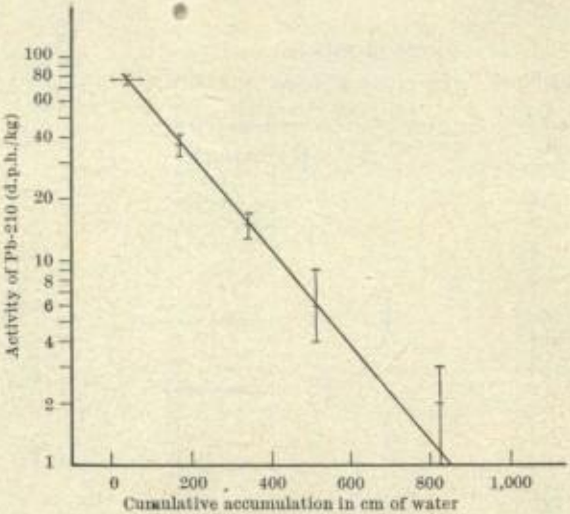

Fig. 2. South Pole: 'Snow-Mine'. Variation of the lead-210 activity in the firn as a function of depth. The slope of the line, in semi-logarithmic co-ordinates, corresponds to an annual accumulation of (6 ± 1) cm of water

gross β-activity of the snow as a function of depth in the same pit (cf. ref. 2 for experimental details and interpretation). According to the results obtained at the King Baudouin Base, the sudden increase in the β-activity noted above the −145-cm level should correspond to early 1955. The results here reported confirm this conclusion and are in good agreement with the stratigraphic interpretation of the upper 140 cm. They indicate a mean annual accumulation of $6{\cdot}5 \pm 0{\cdot}5$ cm of water between 1955 and 1962.

(c) *Lead*-210. We have measured the lead-210 activity on a 2-m deep section covering the 1962–54 interval and on 60-cm thick specimens collected in the 'Snow-Mine' at intervals of about 4 m up to a depth of 26 m. The experimental details are described elsewhere[4]. The results are shown in Fig. 2 in which the logarithm of the lead-210 activity is plotted with respect to the depth, expressed in cm of water.

It will be noticed that, within experimental error, the lead-210 activity decreases exponentially with the depth, the most plausible interpretation[3,4] being that the rate of accumulation of the water and the initial activity of lead-210 in the snow have remained constant over the past hundred years. Taking the half-life of lead-210 as 21·4 years[5], the mean annual accumulation over the past century is found to be 6 ± 1 cm of water.

This value is slightly lower than that deduced by Giovinetto from the 'Snow-Mine' stratigraphy for the same period, but confirms, however, the excellent quality of his observations carried out under particularly difficult conditions. The results are summarized in Table 1.

In conclusion, three completely independent methods (stratigraphy, fission products and lead-210) lead to a mean value of the annual rate of accumulation between 6 and 7 cm of water at the South Pole. The two former methods lead to an average over the past nine years, whereas the lead-210 activity decay (in agreement with the stratigraphic observations of Giovinetto) indicates that this average has not appreciably varied over the past hundred years.

The value of 15 cm of water put forward by Sharp and Epstein does not appear to be acceptable. Possible reasons for this disagreement have been already discussed[9].

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