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COMMENTS ON ANNUAL RATES OF ACCUMULATION IN WEST ANTARCTICA (1)

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ABSTRACT

Several maps have recently been prepared showing annual accumulation over much or all of Antarctica. These maps, based on surface measurements and on interpretations of pit stratigraphy, differ in detail but are reasonably comparable in broad aspects. Data of this type provide the basis for various recent estimates of mean annual precipitation in Antarctica ranging from 7 to 20 cm of water, with a median value near 14 and an average of about 11.5 cm. For many reasons, it is important that this figure be as accurate as possible.

Well over five hundred analyses have been made of oxygen-isotope ratios ($0^{18}/0^{16}$) in snow samples from pits and bore holes at West Antarctic stations. These ratios display variations similar to those believed to be of seasonal origin in other areas, Greenland for example. If the variations in the accumulated Antarctic snow represent seasonal influences, they suggest annual accumulation rates 20 to 100 per cent higher than determined by other methods. The following comparative values ($0^{18}/0^{16}$ determinations in parentheses) illustrate this point: South Pole, 7 (15); Byrd station, 18 (36); Little America V, 15-24 (30); Wilkes satelite, 13 (15).

It is possible that annual accumulation rates in West Antarctica have generally been underestimated? It has not yet been established that the $0^{18}/0^{16}$ variations in the accumulated snow and firn of Antarctica are definitely of seasonal origin; some other type of cycle or influence may be represented. However, the consistency and large magnitude of these variations show that they are not the product of mere chance; a basic control of some sort is reflected. In our present state of knowledge seasonal control seems the most likely.

The short time interval over which surface measurements of accumulation have been made and the uncertainties attending interpretations of pit stratigraphy in Antarctica are such that every opportunity should be taken to check these methods by independent means, such as $0^{18}/0^{16}$ variations.

Commentaires sur les valeurs d'accumulation annuelles en Antrarctide Ouest

RÉSUMÉ

Plusieurs auteurs ont présenté des cartes d'accumulation annuelle sur une grande partie ou sur la totalité de la surface de l'Antarctide. Ces cartes, basées sur des mesures superficielles et sur l'interprétation de la stratigraphie du névé, diffèrent quant aux détails, mais leurs forme générales sont comparables. De tels documents servent à diverses estimations récentes de la précipitation moyenne en Antarctide, allant de 7 à 20 cm d'eau, avec une valeur médiane voisine de 14, et une moyenne d'environ 11.5 cm. Il est important, pour de nombreuses raisons, que cette estimation soit aussi précise que possible.

Plus de cinq cents analyses de la proportion des isotopes de l'oxygène ($0^{18}/0^{16}$) ont été effectuées dans des échantillons de névé provenant de forages ou d'excavations dans les stations de l'Antarctide Ouest. Ces proportions montrent des variations semblables à celles d'origine saisonnière observées en d'autres endroits, au Groenland par exemple. Si ces variations de la neige antarctique représentent des influences saisonnières, elles suggèrent des valeurs d'accumulation annuelle 25 à 100 pour cent plus élevées que les valeurs déterminées par d'autres méthodes. Les valeurs comparatives suivantes (déterminations basées sur les proportions $0^{18}/0^{16}$) illustrent ce point : Pôle Sud, 7 (15); Byrd Station, 18 (36); Little America V, 15-24 (30); Wilkes satellite, 13 (15).

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Les variations des proportions O^{18}/O^{16} sont suffisamment importantes et consistantes pour qu'il ne soit pas permis de les ignorer. Est-il possible que les valeurs d'accumulation annuelle dans l'Antarctide Ouest aient été sous-estimées ? Il n'a pas été prouvé que les variations des rapports O^{18}/O^{16} soient nécessairement d'origine saisonnière; d'autres influences cycliques peuvent être mises en cause. Cependant, les difficultés inhérentes aux mesures d'accumulation en surface et aux interprétations de la stratigraphie de névé en Antarctide sont telles qu'aucun effort ne doit être épargné pour contrôler ces méthodes par des moyens indépendants. Nous n'avons pas l'illusion que les proportions des isotopes O^{18}/O^{16} fournissent nécessairement la réponse finale à cette question, mais ils doivent être soumis en dernier ressort à une interprétation capable d'expliquer à la fois ces résultats avec ceux que fournissent les autres méthodes.

1. Introduction

The mass budget of the Antarctic Ice Sheet, past, present and future, is a matter of considerable interest to disciplines such as meteorology, climatology, glaciology, and oceanography. It bears importantly on calculations of the dynamic response of ice sheets to climatic change (Nye, 1960; 1961; Weertman, 1961a; 1961b), on the past and future history of this great ice mass, and on evaluations of eustatic changes in sea level, among other things. Determination of the Antarctic ice budget is not easy (Wexler, 1961), partly because assessment of wastage is so difficult. Measurement of accumulation is easier, and good progress has been made using several methods,

Determination of current accumulation is best made by surface measurements, either with reference to arrays of stakes or even better with respect to shallow subsurface markers. Because of large variations from spot to spot such measurements must be made at a great number of widely spaced points, but this is possible and it is one of the great strengths of the surface procedure. Reliable measurements of mean accumulation for more extended periods can best be made with respect to subsurface reference horizons of known date, such as that defined by the buried Snow Cruiser at Little America III (Vickers, 1959). As yet reliable reference horizons are distressingly few, but ash falls or radioactive particles such as Sr^{90} (Drevinsky, *et al*, 1958) may prove useful. Perhaps steps should be taken at once to establish marker horizons in a number of key localities for use in future decades.

Accumulation determinations extending still farther back in time or to be made in situations where surface methods are not applicable, must be based largely on physical stratigraphy or on variations in other properties, such as oxygen or hydrogen isotopes (Gonfiantini and Picciotto, 1959; Picciotto, *et al*, 1960; Botter, *et al*, 1961), that can be observed or measured within the accumulated materials. Since these methods necessarily involve varying degrees of interpretation, it is important that they be checked at every opportunity by comparison with established and accepted procedures.

The objective of this brief article is to offer some interpretations of oxygen isotope ratios measured in well over 500 samples of snow and firn from United States IGY stations in West Antarctica.

The basic consideration underlying identification of annual layers in accumulated snow and firn by means of O^{18}/O^{16} variations is the well-established relationship of a lowering of the O^{18}/O^{16} ratio with decreasing temperature of precipitation (see for example, Epstein and Mayeda, 1953; Epstein, 1956; Dansgaard, 1953). There is no reason to doubt that this relationship applies in Antarctica just as it does in other parts of the world so far studied. Detailed stratigraphic studies, careful sampling, and analyses have demonstrated that variations in O^{18}/O^{16} ratios can be succesfully used to identify annual layers in the accumulated snow and firn of Greenland (Benson, 1960, p. 90-94; Epstein and Sharp, 1959). Hopefully, this same procedure can be applied in Antarctica, although it is recognized that factors affecting the O-isotope ratios of accumulated snow in Antarctica may be so varied and complex that relationships recognized in other regions do not hold here. The problem in Antarctica is to determine whether or not seasonal differences that existed in the snow when first precipitated are preserved in recognizable form and in proper sequence in the accumulated materials. For example, one might suspect that deep scour and reworking of snow by the powerful and prevailing Antarctic winds would eliminate or mask seasonal differences in the $0^{18}/0^{16}$ ratios of the accumulated material (Giovinetto, 1960, p. 4; Stuart and Heine, 1961a, p. 5; Morris and Peters, 1960, p. 163; Harlin, 1958, p. 121; Loewe, 1956, p. 658). Wind action undoubtedly complicates the situation, but it is not yet demonstrated that it necessarily invalidates either the stratigraphic or geochemical approaches.

As always, in attacking a new situation, understanding of the details and complexities is initially so incomplete that proper sampling constitutes a major problem. Best sampling procedures can usually be devised only after initial analyses have been made, and the problems defined. Our work has not yet attained this phase of sophistication.

In obtaining specimens from West Antarctica we have enjoyed the willing and devoted cooperation of the many Antarctic field scientists individually identified and acknowledged in succeeding pages. Our colleague, Irene Goddard, has contributed much assistance in laboratory work and data compilation. This investigation was sponsored by the U.S. National Committee of the IGY and supported by funds supplied through the National Science Foundation.

All figures on $0^{18}/0^{16}$ ratios cited herein are expressed as a deviation (δ) from the ratio of a standard, in parts per thousand, ($^{0}/_{00}$) as calculated by the following formula. The standard is mean ocean water.

$$\delta = \left[\frac{0^{18}/0^{16}\,\text{sample}}{0^{18}/0^{16}\text{standard}} - 1 \right] \times 1000.$$

The accuracy of δ is $\pm$ 0.1 $^{0}/_{00}$ or 1% of the δ value whichever is the larger. Since all fresh waters are poorer in 0^{18} than ocean water, their δ values are negative.

2. Results from individual stations

(a) *South Pole (Amundsen-Scott) Station*

A good opportunity for direct comparison of $0^{18}/0^{16}$ data with stratigraphic interpretations was provided through generous cooperation by Mario Giovinetto (1960), who accomplished a careful, thorough and productive study of accumulation at the South Pole station in 1958. Giovinetto furnished a suite of samples from pit No. 11 at the Pole station and provided, via personal letter, details of his stratigraphic interpretations. The samples were taken in continuous succession from the surface to a depth of 78 cm, each specimen representing a 3 cm increment. The essential data are summarized in Figure 1.

The $0^{18}/0^{16}$ curve has a normal appearance, and were it from some other region, would be interpreted as indicating "summer" (S) and "winter" (W) periods as shown. Interpretation is handicapped by the short length of the curve which introduces uncertainty as to whether or not the relative high δ value at 8 cm and the low value at 74 cm represent additional "summer" and "winter" periods respectively. Aside from that, the only obvious departure from the above interpretation would be to assume that the high δ value at 66 cm does not represent a "summer" period and that the "winter" low now placed at 60 cm should be shifted to 74 cm. We prefer the interpretation offered.

Worth noting is the fact that layers centering at 23 and 66 cm, stratigraphically identified as summer snow by Giovinetto, also yield "summer" peaks on the O-isotope curve (Fig. 1). Furthermore, the "winter" lows on the O-isotope curve at depths of 12, 60 and 74 cm occur within layers of stratigraphically identified winter snow. In these respects the O-isotope curves and stratigraphic data agree remarkably well. However, a crucial difference appears with regard to stratigraphic identification of summer layers at 40 and 50 cm for which no corresponding significant "summer" peaks can be found on the O-isotope curve.

The $0^{18}/0^{16}$ curve suggests that the section between 23 and 66 cm depth represents one year of accumulation rather than 3 as indicated by stratigraphic studies. It is perhaps significant that Giovinetto placed queries (?) alongside some of his interpretations through this part of the section. It is hard to see how these differences can be attributed to partial removal of the section by wind scour. Such action should affect both the O-isotope and stratigraphic relationships in the same way.

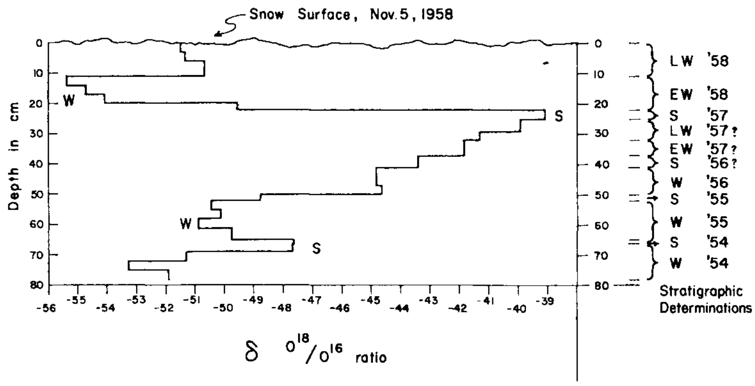

Fig. 1. — Oxygen-isotope ratios in pit No. 11 at South Pole, 1958. Collection and stratigraphic determinations by Giovinetto (1960). On O-isotope curve, interpretations indicated are S for "summer" peak and W for "winter" low. Same for stratigraphic column at right, with LW = late winter and EW = early winter.

At a mean density of 0.35, the 43 cm of snow between 23 and 66 cm depth in pit No. 11 is equivalent to 15 cm of water. This represents one year of accumulation according to O-isotope interpretations, or 3 years according to stratigraphic data. From careful study of sections in a number of pits, Giovinetto (1960, p. 26, 45, 76, 87) arrives at a mean annual accumulation at the Pole of 7 cm of water. Giovinetto's (1960, p. 26, 29, 41) stratigraphic studies suggest large and irregular variations in annual accumulation, 3.3 to 13.3 cm of water, from spot to spot within a single year and from year to year at a single site. Thus, a one-year determination based on O-isotope ratios, or on any other method, at a single site has little meaning with respect to a mean value. However, the 15-cm value based on O-isotope variations has this significance : it was obtained from a section for which stratigraphic studies indicate a mean annual accumulation of 5 cm of water. If Giovinetto's many stratigraphic observations and interpretations at the Pole station are consistent, and there is every reason to believe they are, then it is possible that the mean value of 7 cm derived from these interpretation may be too low.

The data so far published on surface stake measurements at the Pole suggest an annual accumulation in the neighborhood of 10 cm of water (Giovinetto, 1960, p. 87). This is a none-too-reliable figure as it involves extrapolation from 10 months and covers a calendar year rather than a precipitation year. Later surface measurements are said to indicate an annual accumulation of 6 to 7 cm. The O-isotope data suggest these values may not yet give a reliable average figure.

(b) *Byrd Station*

Analyses were made of a large number of specimens from 1957 deep pit and the deep core hole at Byrd Station. A painstaking job of sampling by V. H. Anderson (1958, p. 73) furnished specimens representing each centimeter between the depths of 1050 and 1250 cm in the 1957 deep pit. Analyses of this material yield a good-looking $0^{18}/0^{16}$ curve (Fig. 2). The large abrupt drop off on either side of the "summer" peak at 1107 cm may be due to removal of material by wind scour.

The $0^{18}/0^{16}$ curve (Fig. 2) suggests that not quite 3 years of accumulation are represented by this 200 cm of material. Stratigraphic interpretations indicate that a little over 4 years are involved (Anderson, 1958, p. 74). As at the Pole station, stratigraphic data confirm the 3 "summer" peaks on the O-isotope curve, but again more summer layers are recognized stratigraphically than are indicated by the $0^{18}/0^{16}$ curve. The O-isotope curve "summer" peaks and the stratigraphically identified summer layers line up as follows, depths in cm:

$0^{18}/0^{16}$ "Summer" Peaks	Stratigraphically Identified Summer Layers
1070 cm	1063 cm
1107 cm	1104 cm
	1145 cm
1198 cm	1203 cm
	1252 cm

There are no indications of "summer" peaks on the O-isotope curve at 1145 and 1252 cm to match the stratigraphic data, and there is nothing in the shape of the O-isotope curves suggesting a hiatus produced by wind scour at these depths. Otherwise, the agreement between the O-isotope curve and the stratigraphic interpretation is consistent.

The "summer" peaks on the $0^{18}/0^{16}$ curve define two annual layers equivalent to 21 and 51 cm of water. If "winter" lows are considered and a little extrapolation is made at the top of the section, 3 annual layers of 25, 16, and 67 cm of water can be identified. Both sets of figures average out at 36 cm.

Personnel of SIPRE have generously cooperated in supplying samples from the deep core hole at Byrd station (Marshall and Gow, 1958; Bender, 1958; Patenaude, *et al*, 1959). The results from some of these analyses are erratic, possibly because the specimens involved suffered from evaporation. If the most obvious irregularities in analyses are ignored and general trends are followed, curves are obtained which are similar to that shown in Figure 3. The data for Figure 3 are based on samples that are believed not to have experienced evaporation, thanks to special handling by A. J. Gow. The various $0^{18}/0^{16}$ curves obtained from analyses of the deep-hole core, as interpreted by us, yield the following annual accumulation values (Table 1). The mean value of 37 cm thus obtained is consistent with the 36 cm obtained from the 1957 deep pit.

The commonly accepted value for mean annual accumulation at Byrd station is 18 cm of water (Giovinetto, 1961, p. 388; Cameron and Goldthwait, 1961, p. 8). This figure is based on surface-stake measurements (Long, 1961, p. 13) and interpretations of pit stratigraphy (Anderson, 1958, p. 74). Here again interpretation of $0^{18}/0^{16}$ variations suggests an annual accumulation at Byrd station roughly twice that now measured on the surface or derived from stratigraphic studies. It is important

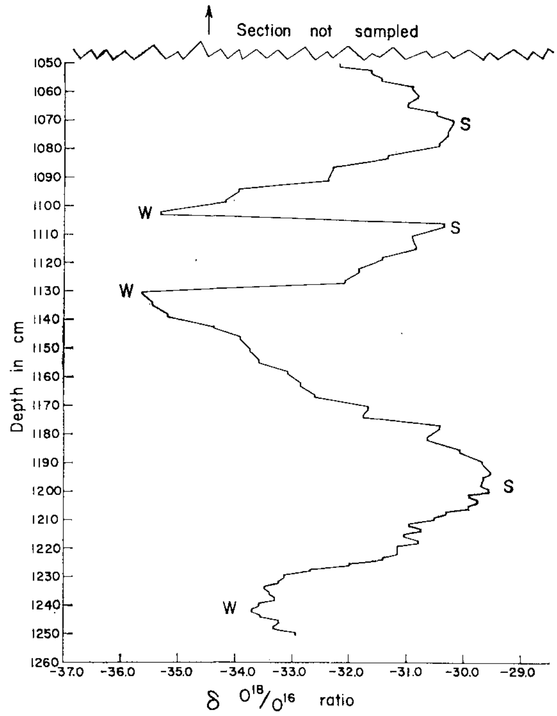

Fig. 2 — Oxygen-isotope ratios in 1957 deep pit at Byrd station, collection by Anderson (1958, p. 73). W is interpreted as "winter" low and S as "summer" peak. Sharp drop off on each side of "summer" peak at 1170 cm may reflect wind scour or unusual meteorological events.

TABLE I

Annual Accumulation Rates Derived from Interpretation of O^{18}/O^{16} Analyses of Specimens from Deep Core Hole, Byrd Station

Depth Interval in Meters	Average Annual Accumulation Cm of Water
66.38 — 66.63	43
114.90 — 116.05	44
214.89 — 215.47	27
287.89 — 288.35	35
304.81 — 306.04	36
	Final —
	Average = 37

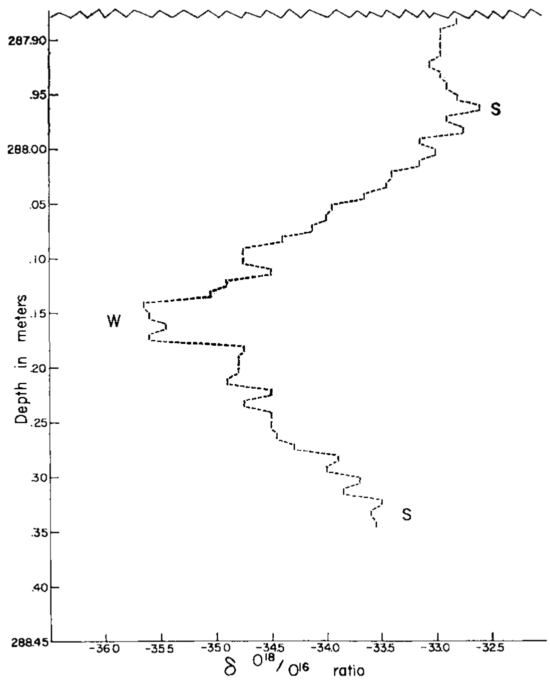

Fig. 3 — Oxygen-isotope ratios in specimens from one section of deep-hole core at Byrd station, sampling by A. J. Gow of SIPRE. Interpretation shown as S ("summer" peak) and W ("winter" low). Note depth is in meters.

to note that the O-isotope data are derived from materials deposited decades and centuries ago. Direct comparison with surface measurements are necessarily qualified by this age difference. The O-isotope data cover a longer period of time and should give a better average value for that reason.

(c) *Little America V*

A large collection of samples taken at close intervals between the depths of 15 and 19 meters in a pit at Little America V in May of 1957 by A. P. Crary and Hugh Bennett has been analyzed. The resulting $0^{18}/0^{16}$ curve (Fig. 4) can be interpreted as suggesting annual accumulation layers equivalent to 40.5, 15.8, 27, 27, 40.5 and 31.5 cm of water, for an average of about 30 cm. The irregularities in this curve are more numerous, abrupt and erratic than in the curves obtained at other Antarctic stations. This may reflect a greater effect from wind activity.

The interpretations offered in Figure 4 may be too conservative. A more radical interpretation is suggested by small letters (*s*) and (*w*) on Figure 4. This would lead to identification of 14 annual layers rather than 6 and to an average annual accumulation value of about 13 cm of water. However, for the present we favor the conservative interpretation largely because of the large annual range known to occur in Antarctic temperatures (Wexler and Rubin, 1961, p. 8) which should result in large variations in the δ values.

Mean annual accumulation at Little America V has been given as 15.5 cm by Vickers (1958a, p. 240; 1959, p. 182), 21 cm by Giovinetto (1961, p. 388), and 23.7 cm

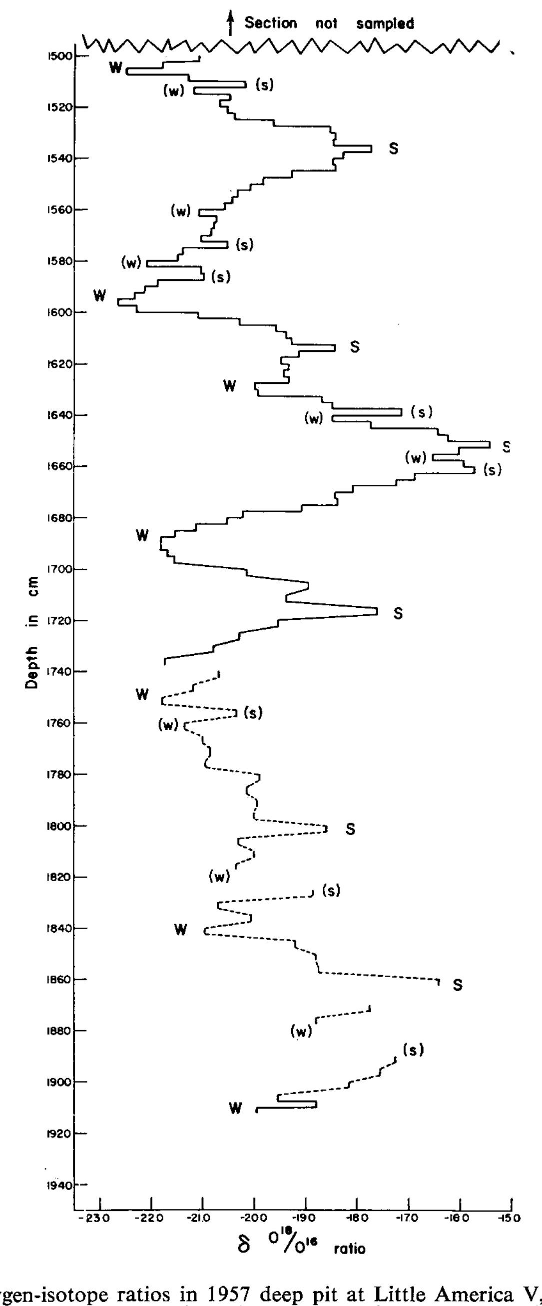

Fig. 4 — Oxygen-isotope ratios in 1957 deep pit at Little America V, collection by A. P. Crary (1961, p. 38) and Hugh Bennett. Preferred interpretation represented by S ("summer" peak) and W ("winter" low). Alternate interpretations represented by (s) and (w), not favored.

by Crary (1961, p. 77). These figures are based on surface stake measurements and stratigraphic data from shallow pits.

One of the most reliable determinations of mean annual accumulation yet made in Antarctica was obtained at Little America III, 80 km west of Little America V, by Vickers (1958a, p. 239; 1958b, p. III-4; 1959, p. 182-183). Here excellent control is provided for stratigraphic studies in a 7-meter pit through identification of the 1939 surface by the buried Snow Cruiser and of the 1947 level by other debris of human occupation. The mean annual accumulation for the 18 years from 1940 to 1958 is 16.2 cm of water. This figure must be accepted for this location. The distribution of Sr^{90} suggests about 14 cm of water accumulation between 1953 and 1956 at Kainan Bay near Little America V (Drevinsky, *et al*, 958, p. 33).

Thus, the preferred interpretation of $0^{18}/0^{16}$ variations in material possibly 35 to 40 years old at Little America V suggests an average annual accumulation (30 cm of water) which is considerably greater than that indicated by surface measurements and stratigraphic data at Little America V (15.5-23.7 cm) or at Little America III (16.2 cm) 80 km west. It is worth noting that Vicker's stratigraphic interpretations at the Snow Cruiser pit indicate a better than 3-fold variation in annual accumulation rates and an annual maximum of 50 cm of water. Wade (1945, p. 168) measured a surface accumulation of roughly 30 cm of water at Little America III in 1940-41. The interpretations of $0^{18}/0^{16}$ variations at Little America V are entirely compatible with the magnitude of these variations and with the maximum values.

(d) *Wilkes Satellite Station*

John T. Hollin kindly provided a collection of 23 specimens taken from pit 3 near the Wilkes satellite station (S_2), 80 km inland from the Wilkes base station on the Budd Coast. These samples were collected on January 10, 1959, from the surface to a depth of 139 cm, at intervals of between 3 and 10 cm. Each specimen was selected to represent a distinct stratigraphic horizon. The curve obtained (Fig. 5) by $0^{18}/0^{16}$

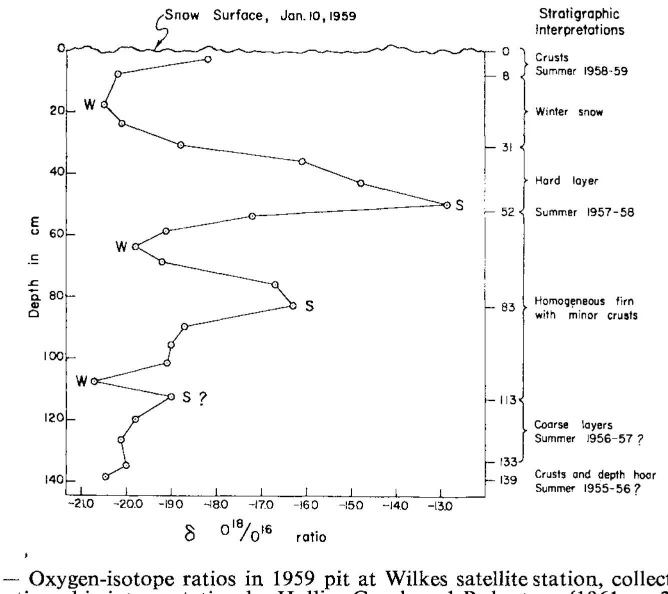

Fig. 5 — Oxygen-isotope ratios in 1959 pit at Wilkes satellite station, collection and stratigraphic interpretation by Hollin, Cronk and Robertson (1961, p. 205-206). O-isotope curve interpretations are S ("summer" peak) and W ("winter" low).

analysis of this collection has a normal "seasonal" appearance except for uncertainties toward the bottom. To the right of the $0^{18}/0^{16}$ curve (Fig. 5) are shown tentative interpretations of stratigraphic relationship made by Hollin, *et al* (1961, p. 205-206). The agreement, in places, is gratifying.

At its top the $0^{18}/0^{16}$ curve rises steeply, just as it should, toward the January (summer) snow surface. The "winter" low at 18 cm is in stratigraphically identified winter snow, and the "summer" peak at 50 cm comes almost exactly on the stratigraphically identified summer layer at 52 cm. Hollin, *et al*, specifically note that no summer layer could be found between depths of 52 and 113 cm, but the $0^{18}/0^{16}$ data show a good "summer" peak at 83 cm. Possibly the O-isotope variations serve as a more sensitive indicator than stratigraphic techniques in this particular instance. The "winter" low on the $0^{18}/0^{16}$ curve at 108 cm is compatible with stratigraphic data, but the stratigraphically suggested summer layer between 113-133 cm is not strongly expressed on the O-isotope curve. The "summer"? peak at 113 cm might be so interpreted with more confidence if more of the curve were seen below 140 cm. Considering the difficulties of stratigraphic interpretations in the Wilkes area (Hollin, *et al*, 1961, p. 192-193) these agreements are impressive.

Using "summer" peaks on the O-isotope curves, an annual accumulation of 14 cm of water is suggested; using "winter" lows the value is 16 cm. This compares with an estimate of 13 cm from pit stratigraphy and stake measurements (Hollin *et al*, 1961, p. 193). A more general mean value obtained by stratigraphic studies representing 174 years is 13.3 cm (Hollin and Cameron, 1961, p. 838). Since the O-isotope data represent only a little over 2 years the value of 15 cm is not a reliable mean, and the departure from the stratigraphically determined value of 13.3 is not particularly significant.

3. Discussion

To sum up, our interpretation of $0^{18}/0^{16}$ data consistently suggest annual rates of accumulation larger than determined by surface measurements or stratigraphic studies at West Antarctic stations (Table 2). Only at the Wilkes satellite station (S_2) is there reasonable agreement.

TABLE II

Comparison of Annual Rates of Accumulation

Station	Annual Accumulation (cm of water)	
	Surface Measurements or Stratigraphic Studies	Oxygen-isotope Variations
South Pole	7	15
Byrd	18	36
Little America V	15.5 to 23.7	30
Wilkes Satellite (S_2)	13.3	15

There is every reason to assume that the O^{18}/O^{16} ratios of Antarctic snows reflec seasonal variations when first precipitated. Indeed, measurements of new-fallen snow samples at Ellsworth station carefully collected by the late Paul T. Walker, and at the Belgian (King Baudouin) station (Gonfiantini and Picciotto, 1959, p. 1557) support the concept of seasonal control. The question is to what degree is the seasonal influence preserved in the accumulated materials? Accumulation may be controlled primarily by wind regime, although this remains to be proved. Even so, wind regime may itself reflect seasonal influences.

Interpretation of the O^{18}/O^{16} variations recorded in accumulated Antarctic snow and firn is admittedly a subjective procedure, but no more so than interpretations of firn stratigraphy. The fact that the O^{18}/O^{16} data do not generally agree with surface measurements, while stratigraphic interpretation frequently does, is one reason for exercising care in attributing a seasonal origin to O^{18}/O^{16} variations found in the accumulated materials. Nonetheless, this is not a sufficient ground for concluding that O-isotope variations are without value in determinig annual rates of accumulation for the following reasons: 1) Surface measurements have not yet been long-enough continued to give a reliable average value for comparison. 2) Most of the materials for which O^{18}/O^{16} ratios have been determined are from a few to hundreds of years old. If secular changes in accumulation have occurred, comparisons with present-day rates have limited meaning. 3) The O^{18}/O^{16} curves show large consistent variations that can hardly be the product of chance. They must be the product of some control or influence. For the present we fail to see a more logical or compelling explanation than seasonal variations.

Both the stratigraphic and O-isotope studies are likely to suffer if part of the section has been removed by wind scour or if no net deposition occurs during the year because of wind action. According to reports, this happens in localized areas (Loewe, 1956, p. 658; Stuart and Heine, 1961 b, p. 998). Whenever the accumulation of an entire year has been lost, both stratigraphic and O-isotope data will give erroneous average values. Vickers (1958 a, p. 239; 1958 b, p. III-4) missed 2 out of 18 years in his initial stratigraphic interpretations at the Snow Cruiser pit. On second try he apparently found the missing years, but if he hadn't his mean accumulation figure would have been 18.4 cm rather than 16.2 cm, a difference of 14 per cent.

One might assume that wind mixing of materials would so smear out seasonal differences that winter and summer snow could not be differentiated on the basis of O^{18}/O^{16} ratios. Analyses of a large number of wind-blown snow specimens collected by Walter Boyd at Little America V over a 6-month period in 1957 suggest that this need not be so. These specimens show a normal, albeit somewhat irregular, trend of lower O^{18}/O^{16} ratios with lower temperatures. If Antarctic snows sifted down quietly out of the sky and accumulated directly upon the surface without extensive scour and reworking by the wind, almost surely variations in the O^{18}/O^{16} ratios would faithfully identify annual layers within the accumulated section. Although reworking and scour by the wind can unquestionably complicate the situation, the effect must vary in degree and with time and place. Wind action may be sufficient to destroy the seasonal rela- tionship in some localities most of the time and in other places only part of the time or, perhaps, not at all. This can be a complex relationship involving local topographic setting, wind regime and patterns, sources of wind-drifted materials, depth of scour and storm patterns.

From these considerations, we conclude that variations in O^{18}/O^{16} ratios will ultimately prove valuable in the identification of annual layers in the accumulated snow and firn in many parts of Antarctica. The O-isotope variations are large, follow defined patterns and have meaning. Our present interpretations of them may be in error, but the O-isotope data have a basic significance which cannot be ignored and, which, when thoroughly understood, will advance our knowledge of the Antarctic environment.

The interpretations of O^{18}/O^{16} variations offered herein suggest that past accumulation rates in Antarctica may have been significantly larger than indicated by current surface measurements or stratigraphic determinations. This possibility should stimulate further critical evaluation of methods used and should motivate a continued attack on the problem of determining Antarctic accumulation, present and past, until the differences are resolved.

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