wertung sowie über die bereits vorliegenden Bearbeitungen und Ergebnisse sehr umfangreich ist, sei hier nur auf einige Veröffentlichungen mit ausgedehntem Literaturverzeichnis verwiesen.


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# Preliminary Report on Drainage Systems of Antarctica*)


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Introduction:

Many studies have been made on the mass budget of Antarctica (Aver'yanov, 1960; Buinitsky, 1960; Lister, 1959; Loewe, 1959; Mellor, 1959; Rubin, 1962; Dolgushin and others, 1962). In general, the ratio between two particular estimates of the net mass budget is smaller than the ratio between the figures for a specific accumulation or ablation term used in the same two estimates (e. g. Wexler, 1961). Unfortunately, the physiographic complexity and the large area of Antarctica make it difficult to discuss in detail the merits of an assumption applied to the whole continent by a particular investigator and to evaluate the error in some of the accumulation and ablation terms he estimates. It is evident that it will take several decades of continuous field investigations before an adequate amount of data is available to assert the mass difference between accumulation and ablation. In the meantime, there is need to study the mass budget for Antarctica following methods that will foster accuracy in the computation of accumulation and ablation terms, and yet require less time to accumulate evidence to assert a positive or negative mass budget.

It would be possible to determine the net mass budget for particular drainage systems with relatively good accuracy and in relatively short time if international effort is directed to this end. Studies of the mass budget for particular drainage systems are of interest because -i) the net mass budget of a given system is not necessarily proportional to the area nor to the ice mass of the given system, and -ii) the net mass budget for a particular system and the net budget for Antarctica may have opposite signs. Therefore, a division of Antarctica into drainage systems is recommendable, and eventually a division of these into drainage basins.

This report presents a division of Antarctica into drainage systems, together with an estimation of the error in the computation of some of the accumulation terms considered in studies of the mass budget. The determination of the area of each system

*) Geophysical and Polar Research Center Contribution no. 121. The present work is as summary of a more detailied research paper to be submitted for publication under the same title and contribution number. In this work, prepared for oral presentation at the Karlsruhe meeting of the German Society for Polar Research (October 1963), full references will not be given.


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and the error in that determination are presented in Part 1. The estimation of the rate of net accumulation at the surface for each system and the error in the estimation are presented in Part 2. The variation, in area and in time, of the rate of net accumulation at the surface is presented in Part 3. Comments on the estimated rate of mass input and the error in the estimation are presented in Part 4, together with a comparison of present results and results from other studies. A brief discusion on the magnitude of mass flux at the periphery of the grounded ice sheet is included at the end of Part 4. Ablation terms and the mass budget for selected drainage systems will be discussed in future repors which are now in preparation.

### *Part 1. The area of the drainage systems*

Drainage divides are drawn on a chart of ice surface topography considering that ice flows in the direction of the surface slope. The drawing of drainage divides was started at the points of intersection between the coastline of the grounded ice sheet and the east and west ends of the Amery, Ross and Filchner ice shelves (Points B, C, E, F, J and K; *Figure 1).* Other divides have been started at less defined coastal points such as the cape north of the Mühlig-Hofmann Mountains (A; at 4 °E), the broad ridge extending SSW from Adélie Coast (D; at 138 ° E), Cape Herlacher (G; at 114 ° W), and the Dustin Island-Jones Mountains complex (H; at 94 ° W). The

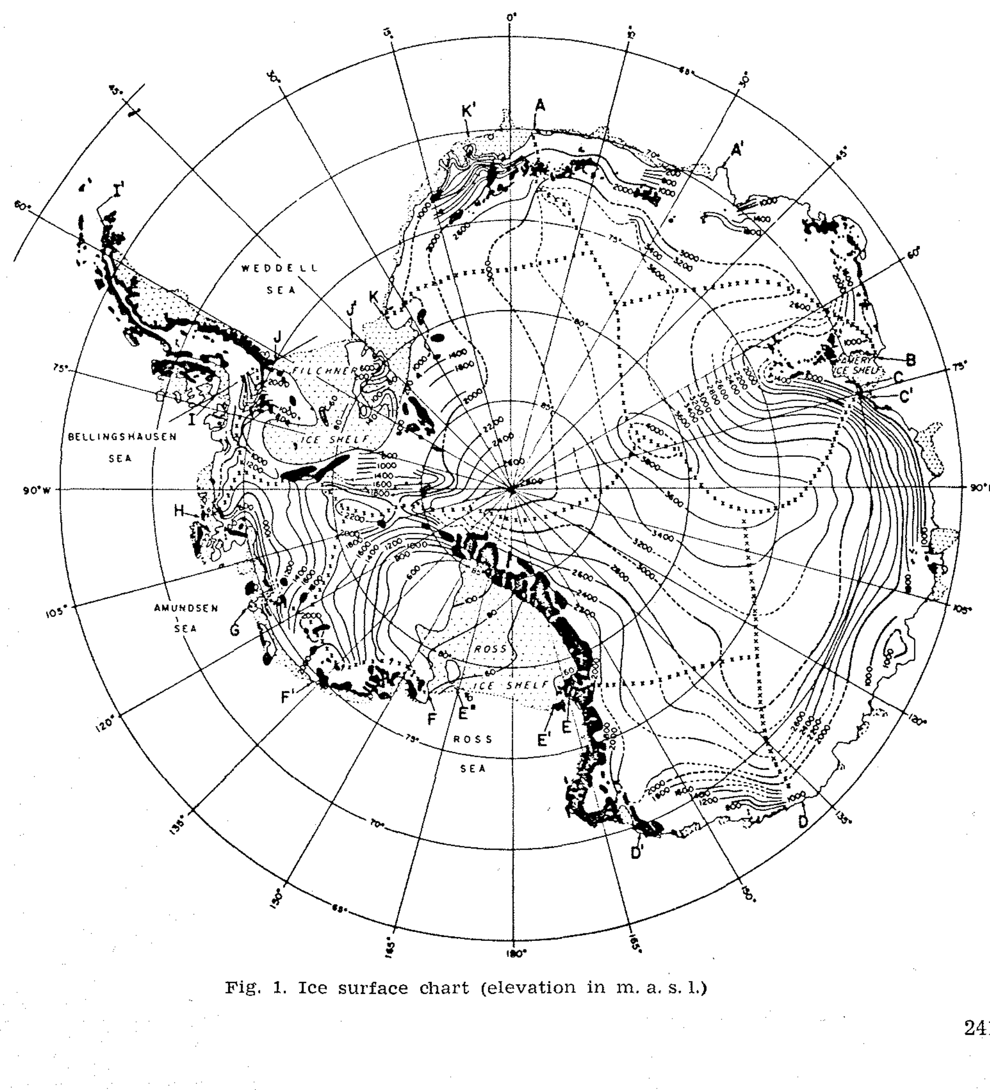


Fig. 1. Ice surface chart (elevation in m. a. s. l.)

region of the Antarctica Peninsula, north of line IJ, is not considered in this report. However, it is evident that at least one divide could be drawn along the peninsula, defining two systems; the first extending from point H to I′ and the second extending from point I′ to J. Therefore, point I is arbitrary.

The divides have been drawn with different accuracy. The mean error in the placement of a divide is estimated in km of misplacement normal to the divide. The error of placement for particular segments of the divides is relatively small in West Antarctica (between ± 25 km and ± 50 km), and is large in East Antarctica (between ± 50 km and ± 300 km). The error in placement of particular segments of the divides is estimated, after evaluation of the amount and quality of altimetry data (Bentley, 1962). *Table 1* shows the resulting

Table 1: Area of drainage systems

| System | Area | Divide | | Error in area | |
|---|---|---|---|---|---|
| | | Length | Error | | |
| | x 10⁶km² | km | km | x 10⁶km² | % |
| AB | 1,29 | 3000 | ± 135 | ± 0,41 | 32 |
| BC | 1,63 | 4450 | ± 110 | ± 0,49 | 30 |
| CD | 1,89 | 2950 | ± 120 | ± 0,35 | 19 |
| DE | 1,12 | 2150 | ± 100 | ± 0,22 | 20 |
| EF | 2,96 | 6575 | ± 65 | ± 0,43 | 15 |
| FG | 0,28 | 1400 | ± 50 | ± 0,07 | 25 |
| GH | 0,52 | 2175 | ± 50 | ± 0,11 | 21 |
| HI | 0,15 | 1125 | ± 25 | ± 0,03 | 20 |
| JK | 3,00 | 6175 | ± 90 | ± 0,56 | 19 |
| KA | 0,78 | 2175 | ± 130 | ± 0,28 | 36 |
| | 13,62 | | | | |
| North of IJ | 0,39 | | | | |
| Antarctica | 14,01 | | | | |

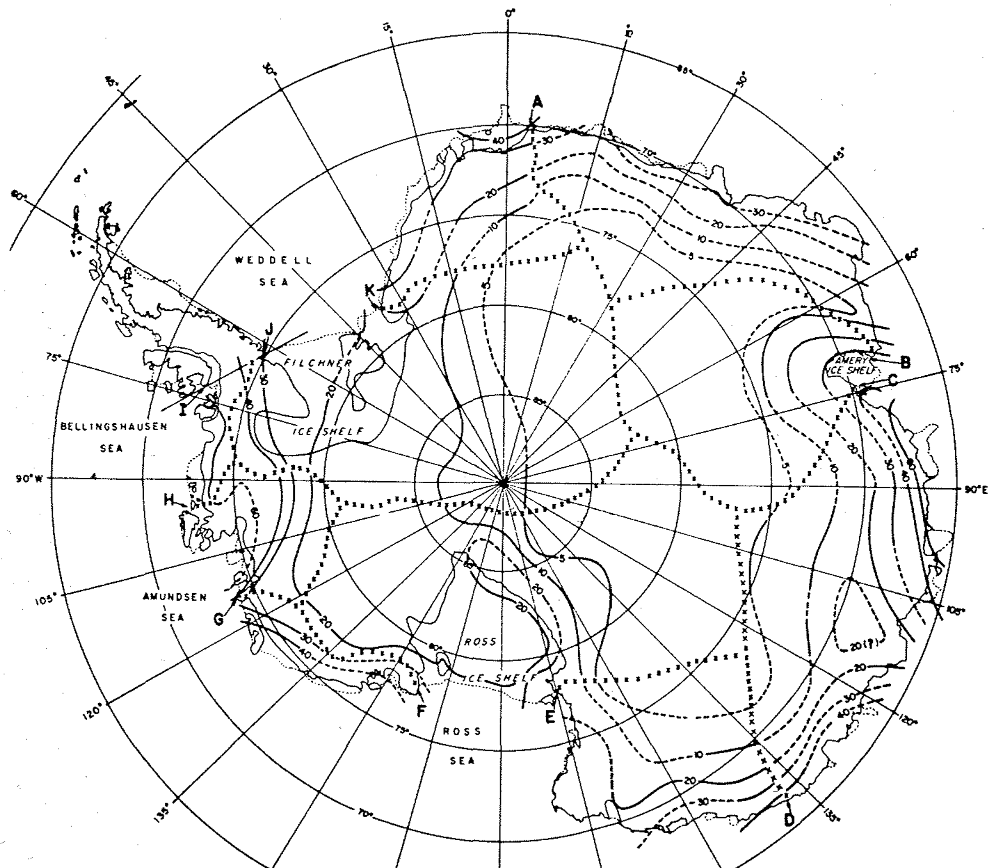


Fig. 2. Chart of net accumulation at the surface (g $cm^{-2}$ $yr^{-1}$)

area for each drainage system, and indicates the possible error in the determination of area due to the mean error in the placement of the divide (between ± 25 km and ± 135 km). Errors of approximately 30 % of the area or more correspond to systems AB, BC, and KA, which include large regions where the topography inland is not known. These systems extend considerably into the unexplored inland sector between 15 ° W eastward to 55 ° W.

The area north of line IJ is $0.39 \times 10^6$ km²; since this region is not considered, the area of Antarctica discussed in the following sections is $13.62 \times 10^6$ km².

*Part 2. Accumulation and ablation at the surface.*

Net accumulation at the surface is the difference between accumulation and ablation in a given unit of area. Hence mass input is defined as the summation of net accumulation at the surface and other relatively minor terms of accumulation such as freezing of sea water to the bottom of ice shelves and glacier tongues. Mass output is defined as the summation of oceanic melting, calving, and ice spreading beyond an assumed constant boundary of the ice sheet. The net mass budget is therefore the difference between mass input and mass output. *Figure 2* ist a chart of the net accumulation at the surface based on data for 336 locations (after Giovinetto, 1963; modified after Shimizu, personal communication; and Budd, 1963). There are numerous reports indicating a large range of net accumulation and net ablation from section to section in the coastal zone of the ice sheet in East Antarctica (Cameron and others, 1959; Dolgushin, 1961). In particular sections, the rate of accumulation can be augmented, and in other sections rates of net ablation can be indicated. However, few regions have been described in such detail, and even in those cases it would be impossible to show the variation of accumulation from section to section in charts such as Figure 2, where the scale is large. Hence, the rates of accumulation indicated for the coastal zone are only general. *In Table 2* are listed the provisional estimates of the total accumulation corresponding to particular drainage systems; some related corrections are discussed below.

*First Correction.* In the coastal zone of the grounded ice sheet lying below an elevation of 1000 m. a. s. l. with surface slope $\geq$ 1 % the rate of accumulation indicated in Figure 2 should be reduced by at least one half, due to the amount of snow deflation reaching the sea (Hollin, 1959; Mellor, 1958; Dolgushin, 1958; Loewe, 1956). The reduction introduced by the first correction ranges from 1 % to 8 % of the total net accumulation estimated provisionally for six of the ten drainage systems.

Table 2: Net accumulation at the surface

| System | Accumulation | First correction | | | Second correction | Net accumulation | | Composite error * | |
|---|---|---|---|---|---|---|---|---|---|
| | | Area | Accumulation | Correction | | total | mean | | |
| | $\times 10^{15}$ g.y$^{-1}$ | km² | g.cm$^{-2}$y$^{-1}$ | $\times 10^{15}$ g.y$^{-1}$ | $\times 10^{15}$ g.y$^{-1}$ | $\times 10^{15}$ g.y$^{-1}$ | g cm$^{-2}$y$^{-1}$ | g.cm$^{-2}$.y$^{-1}$ | % |
| AB | 183.21 | 112,500 | 25.0 | — 14.06 | — 6.60 | 162.55 | 12.6 | ± 8.3 | 26 |
| BC | 130.97 | | | | | 130.97 | 8.0 | ± 2.1 | 26 |
| CD | 439 62 | 136,500 | 35.0 | — 23.89 | — 6.00 | 409.73 | 21.7 | ± 4.7 | 22 |
| DE | 170.32 | 96,500 | 30.0 | — 14.47 | | 155 85 | 13.9 | ± 3 1 | 22 |
| EF | 315.22 | | | | | 315 22 | 10.6 | ± 2.2 | 21 |
| FG | 109.46 | 4,500 | 50.0 | — 1.12 | | 108.34 | 39.7 | ± 9.8 | 25 |
| GH | 210.05 | | | | | 210 05 | 40.4 | ± 8.9 | 22 |
| HI | 85.16 | 22,000 | 65.0 | — 7.15 | | 78.01 | 52.0 | ± 11.3 | 22 |
| JK | 339.40 | | | | | 339.40 | 11.3 | ± 2.5 | 22 |
| KA | 166.35 | 9,500 | 35.0 | — 1.66 | | 164.69 | 21.1 | ± 4.4 | 21 |
| Antarctica | 2149.76 | | | 62.35 → | 74.95 | 2074.81 | 15.2 | ± 3.0 | 20 |

* From Table 4, column 13

*Second Correction.* In regions of net ablation at the surface, the rate of accumulation indicated in Figure 2 has already been reduced by 50 % when the first correction is applied. Therefore the second correction should be a reduction of at least 50 % in the rate of accumulation indicated in Figure 2, times the area of the regions of net ablation. The area has been estimated after studying reports by Mellor (1959), Hollin (1962), Dolgushin (1961), Kotliakov (1961), Takahasi (1960), Yoshikawa and Toya 1957), and Lorius (1962). The second correction is applied only to systems AB and CD as shown in Table 2. The summation of the first and second corrections is $75 \times 10^{15} g.y^{-1}$. Thus, the total net accumulation at the surface is estimated at $2075 \times 10^{15} g.y^{-1}$, or a mean net accumulation of 15 g. $cm^{-2}$. $y^{-1}$. The rate of mean net accumulation for particular systems ranges from 8 to 52 g. $cm^{-2}.y^{-1}$.

*Error in the estimation of net accumulation at the surface.* The error in the estimate of mean net accumulation at the surface of Antarctica (± 3 g. $cm^{-2}$. $y^{-1}$) is a composite error including term I: the error in the determination of the rate of accumulation at single locations (± 0,5 g. $cm^{-2}.y^{-1}$), term II: the error in the assessment of data in accumulation profiles and accumulation charts (± 2 g. $cm^{-2}.y^{-1}$), and term III: the error in computation of data which are not simultaneous in all locations (± 2g. $cm^{-2}$. $y^{-1}$).

Term I was computed using the law of propagation of error. The accumulation data, collected at 62 stakes networks and in 274 stratigraphic sections, are distributed in the corresponding fifty one regions of accumulation into which Antarctica is divided (Figure 2). The rate of accumulation, the error in its determination (20 % to 50 %), and the area for which the rate is considered representative are assumed to be constant for purposes of computation.

Term II was computed by three different methods using estimates of mean net accumulation at the surface.

Term III was computed after examining the relationship between local temporal and areal variabilities of accumulation.

*Part 3. Temporal and areal variability of accumulation.*

The summation of local temporal and areal variabilities is shown in *Figure 3* as a func-

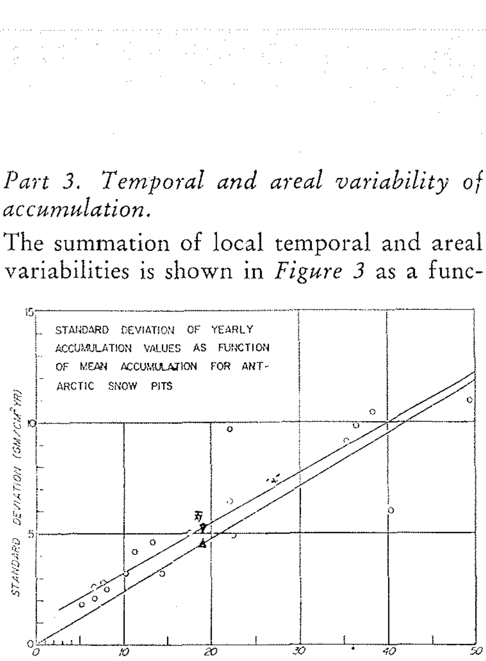


Fig. 3: Accumulation (GM/CM² YR)

tion of mean accumulation in locations where the data cover more than 15 years. *In Figure 3* it is shown that the relative total annual variability (line "a") decreases from approximately 36 % at locations where the mean accumulation is 30 g. $cm^{-2}$. $y^{-1}$ to 26 % at locations where the mean accumulation is 30 g. $cm^{-2}.y^{-1}$.

The local areal variability has been estimated at 3 g. $cm^{-2}.y^{-1}$ for the majority of the stations for which there are data. Assuming that total variability is non-existent at a location where there is no accumulation, and assuming that the total variability can be reduced at point $\overline{xy}$ (Figure 3) by the amount of the temporal variability, the local temporal variability is estimated at 25 % (line "b", Figure 3).

*Part 4. Error in the estimation of mass input*

The rate of mass input is dependent on the rate of total net accumulation at the surface. The error in the estimation of mass input is the summation of the error in the determination of area and in the estimation of mean net accumulation at the surface. *In Table 3,* the summation of the two errors (percent) is given for each system. This error varies from 36 % in system EF to 58 % in system AB. The error for Antarctica is only 20 % because there is no systematic error in the determination of area.

Table 3: Mean ice thickness and rate of mass input

| System | Mean ice thickness | Mass | Rate of mass input | | |
|---|---|---|---|---|---|
| | | | Input | | Total |
| | m | x $10^{21}$ g | x $10^{21}$ g $(1000y)^{-1}$ | % | error * % |
| AB | 1900 | 2.21 | 0.16 | 7 | 58 |
| BC | 1800 | 2.64 | 0.13 | 5 | 56 |
| CD | 2100 | 3.57 | 0.41 | 11 | 41 |
| DE | 1700 | 1.71 | 0.16 | 9 | 42 |
| EF | 1700 | 4.53 | 0.32 | 7 | 36 |
| FG | 900 | 0.23 | 0.11 | 48 | 50 |
| GH | 1600 | 0.75 | 0 21 | 28 | 43 |
| HI | 600 | 0.08 | 0.03 | 100 | 42 |
| JK | 1700 | 4 59 | 0.34 | 7 | 41 |
| KA | 1400 | 0.98 | 0.16 | 16 | 57 |
| Antarctica | 1700 | 21 29 | 2.07 | 10 | 20 |

From Table 1, column 6 and Table 2, column 10

The role of the error in the estimation of mass input in studies of the mass budget is appreciated in its full significance, if the ice mass of each system is considered. A chart of ice thickness *(Figure 4)* is used to estimate the mean ice thickness for each system (Table 3). The rate of mass input [$\times 10^{21}$ g $(1000y)^{-1}$] relative to the ice mass ($\times 10^{21}$g) of each drainage system, indicates the following: to study the mass budget it would be more feasable to obtain conclusive data for a short period in system HI where the relative mass input is 100 % every 1000 years ± 400 years, despite an error of 40 % in the estimation of mass input, than e.g. in system EF, where the error is 35 % and where the

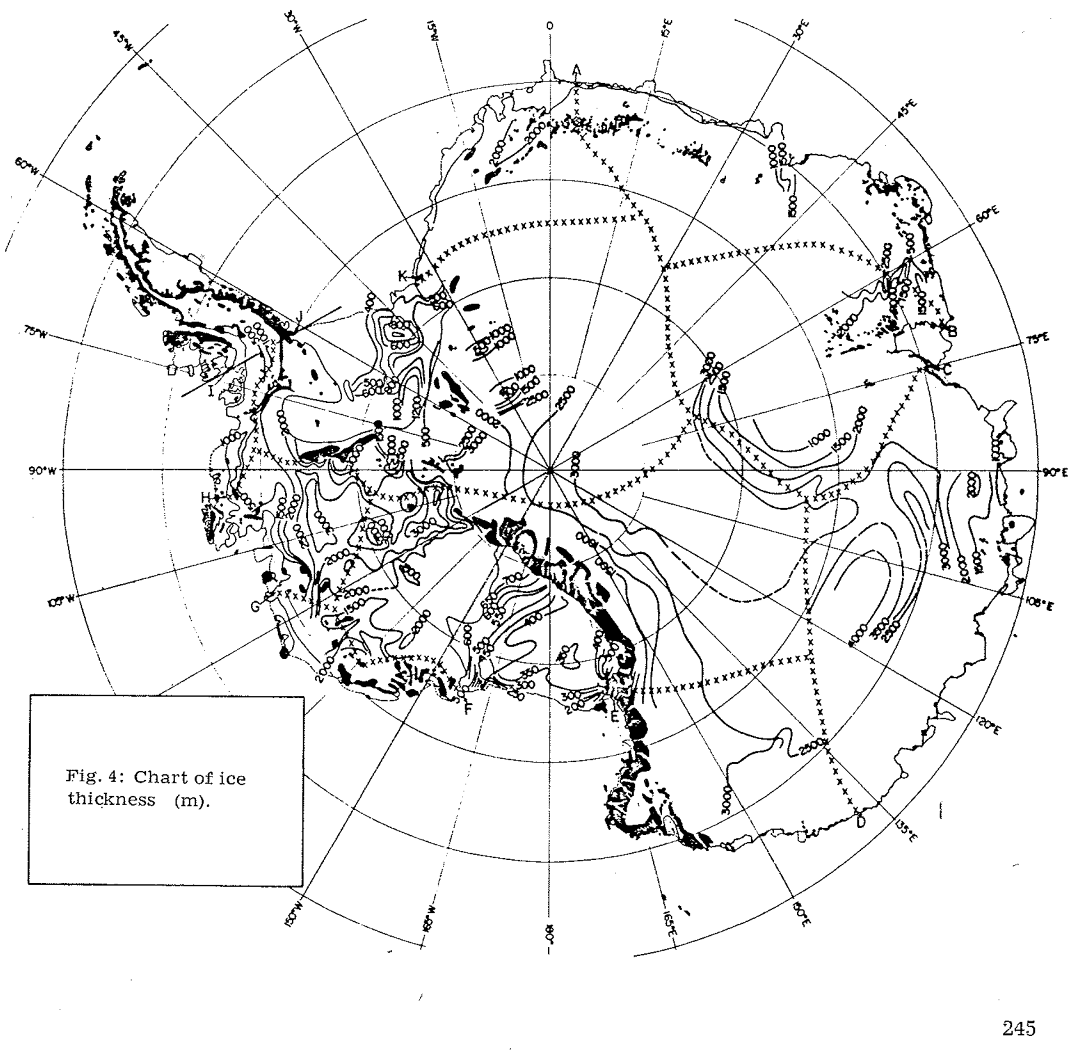


Fig. 4: Chart of ice thickness (m).

relative mass input is 100 % every 14,000 years ± 5000 years.

The estimate of mean ice thickness (grounded ice and ice shelves) for each system results in a mean ice thickness for Antarctica of 1700 m. In other study, Bentley (in preparation) estimated the mean ice thickness at 1730 m ± 250 m. Therefore, the estimates of mean ice thickness shown in Table 3 are believed adequate within ± 300 m.

*Comparison of results.* The results of the estimates of area and of accumulation for each drainage system presented in the preceding sections, are comparable in magnitude to estimates of area and accumulation, and to measurements of mass output made by other investigators. Mellor (personal communication) estimated the net accumulation for the drainage system corresponding to the Lambert, Fisher and Mellor glaciers draining the plateau SW of the Ross accumulation in a sector of 58,000 km² in Terre Adélie; Crary and others (1962) estimated the net accumulation for the Ross Ice Shelf drainage system; Swithinbank (1963) measured surface flow in seven major glaciers draining the plateau SW of the Ross Ice Shelf; Behrendt (1962) estimated the area and the net accumulation corresponding to the mass output measured in the eastern Filchner Ice Shelf. All the estimates made in this work compare favorably with the estimates just mentioned i. e. any two estimates of the sale term are within the computed error.

*Current studies.* Ablation terms are being examined in the manner used to discussed accumulation terms. Attempts are being made to estimate errors in the determination of mass flux in particular drainage systems due to the regional temporal and areal variabilities. At present it is possible only to estimate the order of magnitude of mass flux at the periphery of the grounded ice sheet. The listener is cautioned that the following figures are not the results of final computations, but are included as an exercise.

The area of the ice shelves and attached islands is $1.62 \times 10^6 km^2$ (± 10 %) and the net accumulation at the surface is 30 g $cm^{-2}y^{-1}$ (± 20 %) or $500 \times 10^{15}$ $g.y^{-1}$ (± 30 %). The area of the grounded ice sheet is $12.00 \times 10^6 km^2$ (± 1 %) and the net accumulation is 13 g $cm^{-2}y^{-1}$ (± 20 %) or $1600 \times 10^{15} g.y^{-1}$ (± 20 %). The periphery of the grounded ice sheet from point J eastward to point I is 19,000 km ± 1000 km. Considering the error in the estimation of mass input and the error in the measurement of the length of periphery, a minimum estimate of mass flux would be 0.06 x $10^{15}$g $km^{-1}y^{-1}$ and a maximum estimate would be 0.11 x $10^{15}$g. $km^{-1}y^{-1}$.

Assuming that the mean ice thickness at the periphery is 300 m ± 100 m, with a mean specific gravity of 0.85 g $cm^{-3}$, the figures of mass flux correspond to rates of mean ice movement between 100 m $y^{-1}$ and 500 m $y^{-1}$. This estimate is comparable to the estimate made by Hollin (1962, p. 176) "in the order of hundreds of meters per year."

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