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Glaciological interpretation of microparticle concentrations from the French 905-m Dome C, Antarctica core

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ABSTRACT Sixty-one sections of the French 905-m Dome C, Antarctica core were analysed for microparticle concentration and size distribution. These 6160 samples represent the most detailed microparticle analysis of any core spanning the transition from post-glacial to the last full glacial. Average particle concentrations in late glacial ice exhibit an 800% increase over average particle concentrations in Holocene ice. A microparticle time scale has been developed for the core and indicates a minimum age of 22 000 years and a maximum age of 30 000 years for the bottom of the core.

INTRODUCTION

The 905-m core was drilled at Dome C (74°39'S, 124°10'E) during the 1977/1978 austral summer by the French as part of the International Antarctic Glaciological Project (Lorius & Donnou, 1978). Dome C (3240 m a.s.l.) has a mean annual temperature of -53.5°C and mean annual ice accumulation of approximately 0.035 m a^{-1} (Petit *et al.*, unpub.). This was an exceptional core for microparticle analysis for the following reasons: (a) almost complete sections provided by the French allowed detailed sampling, (b) the core was recovered without drilling fluid which eliminates a potential contaminant and (c) the effects of flow dynamics upon the stratigraphy are minimized as ice sheet thickness is ~3400 m. In the Dome C core the end of the last glaciation occurs between 400 and 500 m depth (Lorius *et al.*, 1979), ~3000 m above the bedrock, while in the Camp Century core this transition occurs ~240 m above the bedrock (Dansgaard *et al.*, 1971) and ~890 m above the bedrock in the Byrd station core (Epstein *et al.*, 1970). Not only is the Dome C core from the upper part of the ice sheet, but also the borehole is on a present day ice divide and there is no difficulty in determining the origin of the ice as with the Byrd core. Assuming the ice divide has not shifted over the last 30 000 years, then the snow has undergone simple compression with no shear due to ice flow.

MICROPARTICLE ANALYSIS

The concentration and size distribution of microparticles in 5367 samples representing fifty-one 0.8-m core sections were determined in a class 100 clean room by the Coulter technique (Thompson, 1977a). In addition 10 sections (793 samples) of the core were processed using the Coulter technique under similar clean room conditions by J. R. Petit. The microparticle size distribution encompasses 15 intervally scaled channels between 0.5 μm and 16.0 μm with an average sample size of 0.0067 m ice (Thompson) and 0.0080 m ice (Petit). The small size allows a resolution which averages 5.5 samples per annual increment of accumulation. For some sections lower in the core the sample size was reduced to 0.003 m of ice for better resolution. In Fig. 1 the average concentration of particles with diameters >0.63 μm per 500 μl sample ($\bar{C}$) for each section of the core are presented in the profile on the left and the $\delta^{18}O$ measurements (Lorius *et al.*, 1979) are presented in the profile on the right. This temporal correlation between increased particle concentration and more negative $\delta^{18}O$ ratios (lower temperatures) at Dome C, is nearly identical to those found in the Byrd station and Camp Century cores (Thompson, 1977b). For the upper 27 sections of the Dome C core (surface to 485.9 m) $\bar{C}$ is 6670 while for the lower 24 sections (505.4 - 886.6 m) representing the end of the last glaciation $\bar{C}$ is 40 562. This increase in Dome C particle concentrations is double that found in the Byrd station core. The magnitude of this increase requires further substantiation as only selected sections of these cores have been processed.

MICROPARTICLE CHRONOLOGY FOR THE DOME C CORE

If the particle concentration cycle is annual and the post-depositional processes have not completely disrupted the stratigraphy, the microparticle concentration variations can be employed to estimate the net annual accumulation over the portions of the core for which analyses have been performed. Figure 2 illustrates the relationship of particle variations to total β activity peaks in recent snow layers. Using the total β activity peaks to determine the 1955 and 1965 horizons, the microparticle variations suggest there are 10 particle peaks in this 10-year period. It must be emphasized that this is only one site and additional measurements are required to establish the areal variability of the annual variations in particle concentration within surface snow at Dome C. The following discussion presents the data supporting the annual nature of the microparticle concentration variations, explains the estimation of annual layer separation (a_i) for each section and the utilization of these data to construct a relative time scale for the core.

As with any stratigraphic study there are two major sources of error which must be considered. When more than one peak in particle concentration is contained within one year's accumulation, an overestimation of the age in subsequent layers results. When all or part of an entire year's accumulation along with the

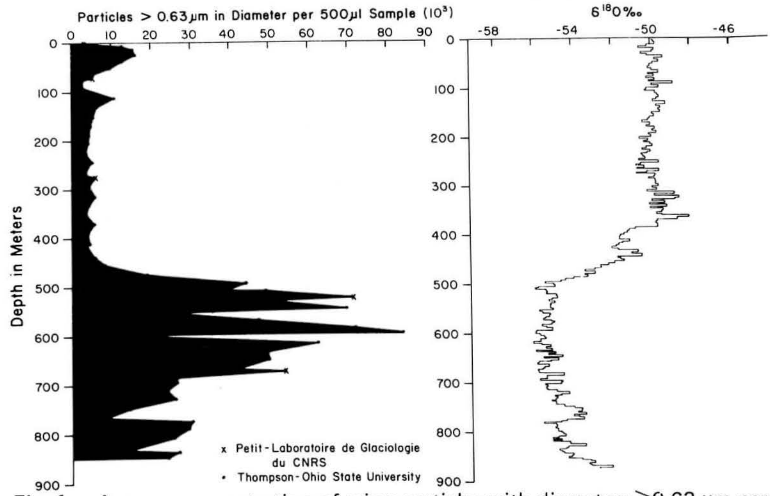


Fig. 1 Average concentration of microparticles with diameters ⩾0.63 μm per 500 μl sample for 61 sections of the Dome C core are presented. Fifty-one sections were analysed at The Ohio State University (designated by dot) and 10 sections were analysed at the Laboratoire de Glaciologie (designated by ×). The $\delta^{18}O$ measurements plotted on the right (Lorius *et al.*, 1979) illustrate the strong temporal correlation between high particle concentrations and more negative $\delta^{18}O$ measurements.

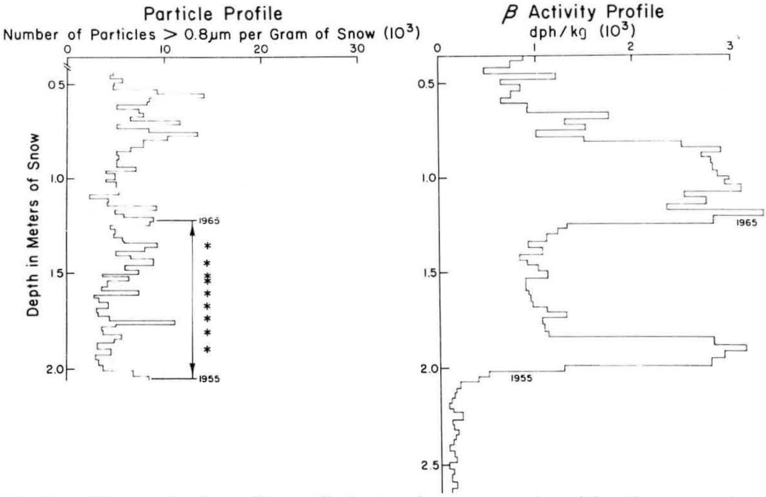


Fig. 2 Pit samples from Dome C, Antarctica were analysed for the concentration of particles with diameters >0.80 μm per 1000 μl sample and for the total β activity (Laboratoire de Glaciologie). The β activity peaks are used to determine the 1955 and 1965 horizons. The particle concentration variations (left profile) exhibit 10 peaks in this 10-year interval.

associated particulate material is removed or never deposited at the sampling site (Gow, 1965), an underestimation of the age in subsequent layers results.

In an attempt to reduce these errors, both minimum and maximum estimates of the annual layer separation (a_i) are obtained. Minimum a_i values are determined by counting every microparticle concentration peak as an annual feature. On the other hand, the maximum a_i values are derived by counting only those microparticle concentration peaks which conform to a predetermined set of criteria (Thompson, 1979). Basically concentration peaks must consist of two or more samples and the background separating these peaks must consist of at least two samples in which concentrations are approximately 60% or less of the smaller adjacent peak. Thus, by using only the best defined peaks, spurious increases in microparticle concentration are not mistaken for annual features. However, any disrupted annual microparticle concentration cycle which appears as a single sample is erroneously disregarded.

Figure 3 illustrates the concentration variations in small particles (0.63 µm ≤ diameter ≤ 0.80 µm) per 500 µl sample for five sections in the upper 500 m of the core (Holocene or post glacial strata) and similarly, Fig 4. illustrates the small particle concentrations for five sections between 500 and 900 m (end of the last glaciation). The insert at the bottom of Fig. 4 presents the maximum a_i estimate for each of these 10 sections (Figs. 3 and 4) based upon the best defined peaks. These a_i estimates compare favourably with the current estimate of net

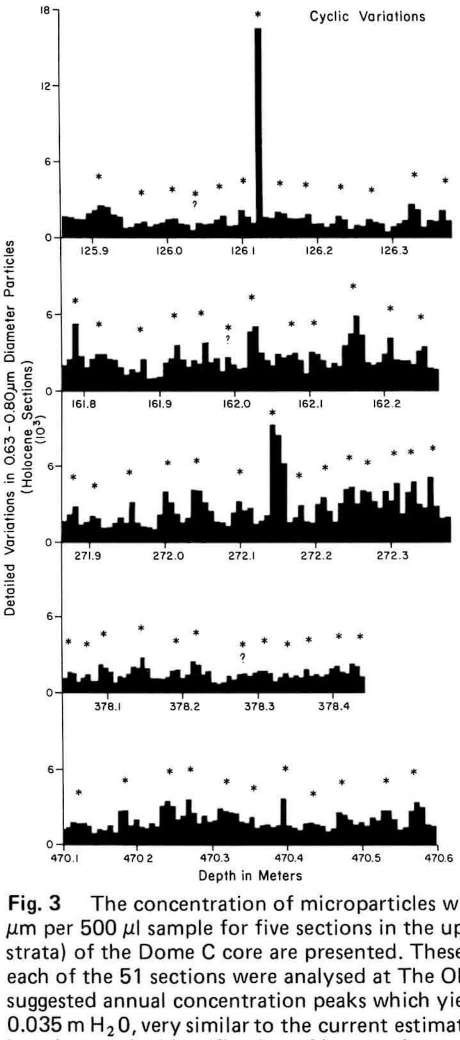
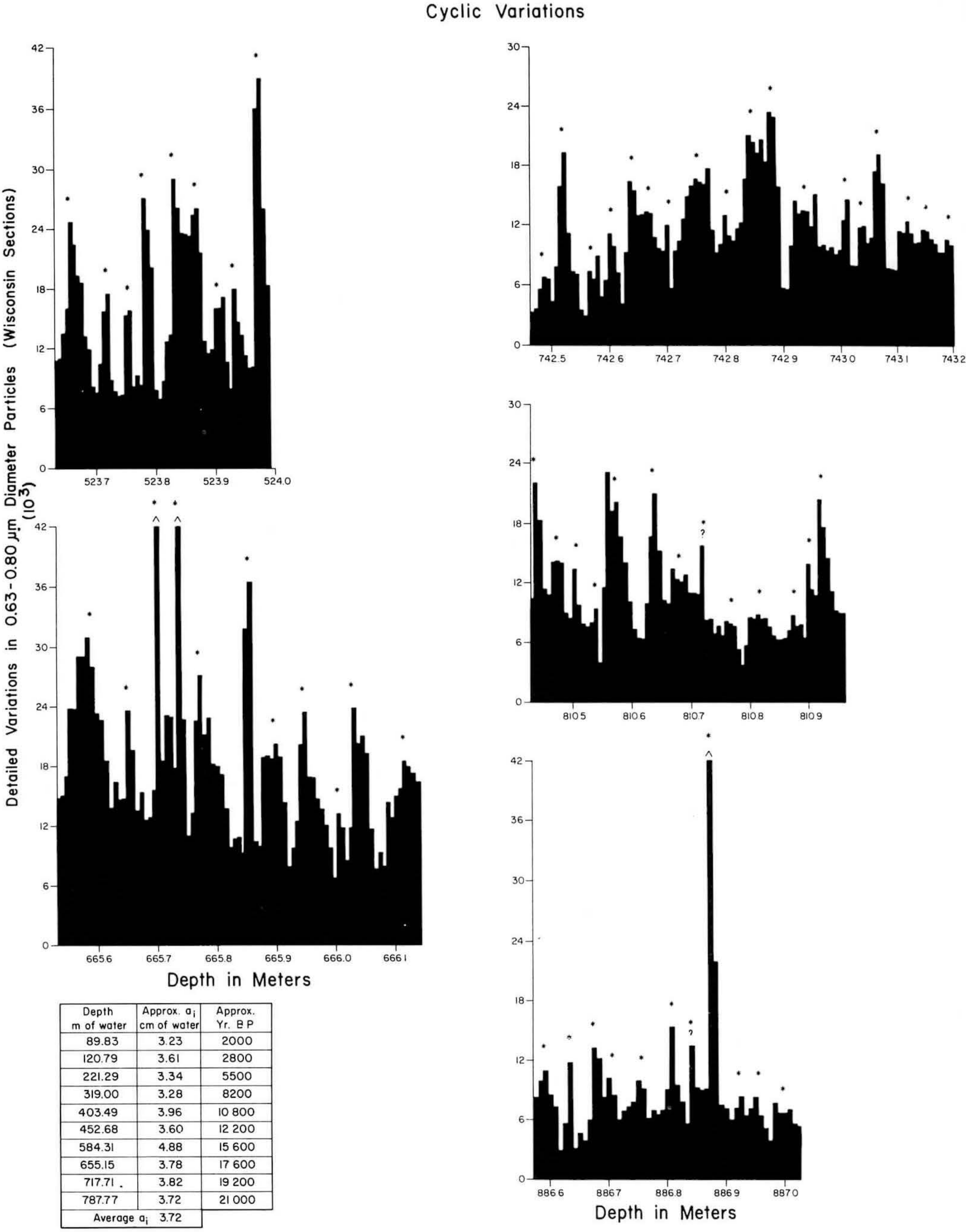


Fig. 3 The concentration of microparticles with diameters between 0.63 and 0.80 µm per 500 µl sample for five sections in the upper 500 m (Holocene or post glacial strata) of the Dome C core are presented. These profiles illustrate the detail in which each of the 51 sections were analysed at The Ohio State University. The stars indicate suggested annual concentration peaks which yield an average peak separation of 0.035 m H_2O, very similar to the current estimate of 0.032 m H_2O (Petit *et al.*, in press) based upon the identification of known time stratigraphic horizons (total β activity). The ? indicates questionable peaks.



Depth m of water	Approx. a_i cm of water	Approx. Yr. B P
89.83	3.23	2000
120.79	3.61	2800
221.29	3.34	5500
319.00	3.28	8200
403.49	3.96	10 800
452.68	3.60	12 200
584.31	4.88	15 600
655.15	3.78	17 600
717.71	3.82	19 200
787.77	3.72	21 000
Average a_i	3.72	

Fig. 4 The concentration of microparticles with diameters between 0.63 and 0.80 µm per 500 µl sample for five sections in the lower 400 m (last glaciation) of the Dome C core are presented. These profiles illustrate the detail in which each of the 51 sections were analysed at The Ohio State University. The stars indicate suggested annual concentration peaks which yield an average peak separation of 0.039 m H_2O, higher than the current estimate. The ? indicates questionable peaks.

annual surface accumulation, 0.035 m a^{-1} ice (ρ = kg m^{-3}) or 0.032 m a^{-1} water (Petit *et al.*, in press), which is based upon identification of known total β activity horizons. These data support the hypothesis that these cyclical variations in microparticle concentration are annual.

Figure 5 presents the maximum and minimum a_i estimates for each of the 61 sections of the core analysed. The number on the bar connecting the estimates is the average number of particle concentration peaks upon which the two estimates are based. For all 61 sections the average minimum a_i is 0.028 m a^{-1} water and the maximum is 0.039 m a^{-1} water. These maximum and minimum a_i estimates may be employed to construct, respectively, both minimum and maximum time scales for the core by assuming that each of the 61 a_i values represents the core interval halfway between successive sections. The time interval (Δt) represented by the depth interval (Δh) is given by

$$\Delta t = \Delta h / a_i$$

assuming that a_i is representative over Δh. This procedure yields the two time scales presented in Fig. 6. The minimum estimated age for the bottom of the core is 22 000 years BP and the maximum estimated age is 30 000 years BP.

These maximum and minimum ages bracket the age of 27 000 years BP derived from Nye's (1957) model as presented by Lorius *et al.* (1979). Using an entirely different approach, Lorius *et al.* (1979) estimate the age at the bottom of the core to be 32 000 years BP. This older age for the bottom results from the

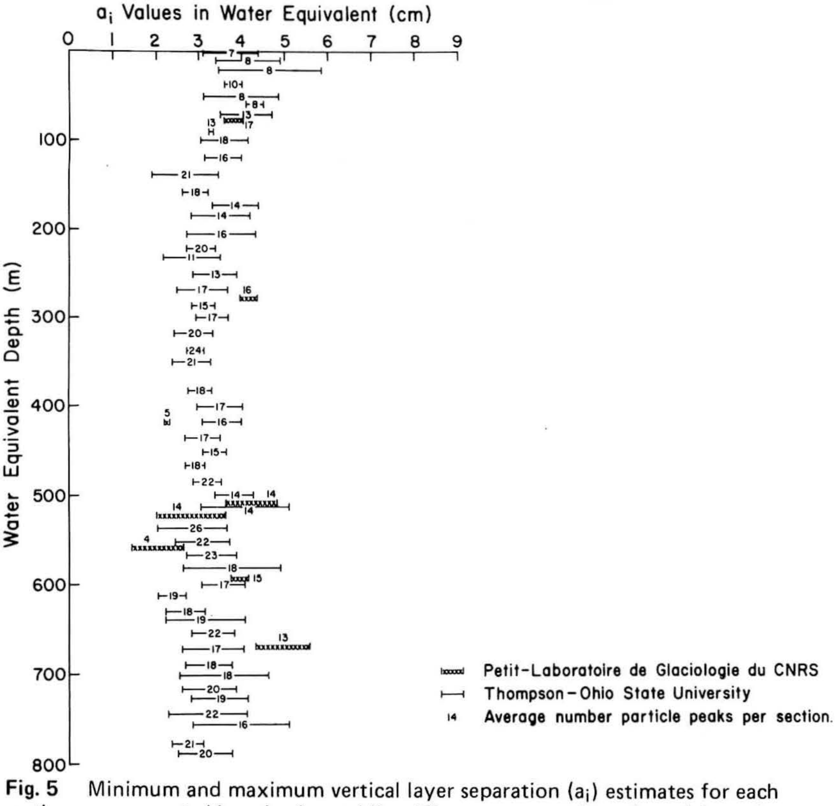


Fig. 5 Minimum and maximum vertical layer separation (a_i) estimates for each section are connected by a horizontal line. The average number of particle peaks upon which the a_i estimates are based is presented in association with each pair of a_i estimates.

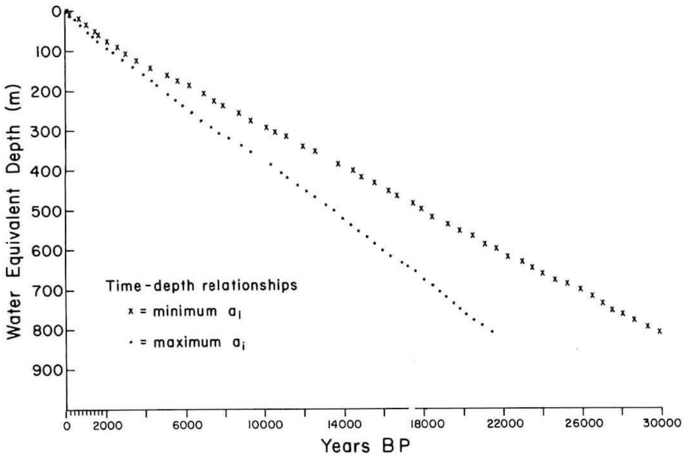


Fig. 6 The time-depth relationships for the Dome C core are based upon minimum and maximum a_i estimates from 51 sections processed at The Ohio State University. The minimum age for the bottom of the core is 22 000 years BP and the maximum age is 30 000 years BP.

assumption of lower accumulation rates at core depths greater than 381 m. Based upon the 61 sections of the Dome C core analysed, we found no consistent or substantial reduction in net surface accumulation (Fig. 5).

Although lower air temperatures during the last glacial stage may have reduced the amount of water vapour transported to the polar plateau, the greater baroclinic instability resulting from expanded ice shelves or a modest alteration in circulation patterns may have increased the net mass transport enough to offset the temperature effect upon precipitation. Any of these suggestions are purely speculation. In light of the many processes operating within the Antarctic meteorological regime, it cannot be assumed without additional substantiation, that lower temperatures as deduced by ^{18}O depletion resulted in a reduced accumulation. Additionally, the data from one core are insufficient to confirm or negate any regional trend in accumulation and other cores in the East Antarctica plateau region should help clarify these discrepancies.

CONCLUSION

An excellent temporal correspondence between the increase in microparticle concentration and more negative $\delta^{18}O$ ratios over millennial time intervals was found in the 905-m Dome C core. This relationship is similar to that found in both the Byrd station, Antarctica and the Camp Century, Greenland deep cores. In each of the 61 sections analysed, distinct cyclical variations in microparticle concentration were found. Evidence is presented which supports the annularity of this cycle. Additional surface and core investigations are required to confirm this.

The annual layer separation estimated from these cyclical concentration variations, in each core section, suggests that net annual surface accumulation was not substantially reduced near the end of the last glacial. In fact, accumulation appears to have remained reasonably constant (Fig. 5) over the entire time interval represented by the core.

These annual layer separation estimates were employed to construct both a maximum and minimum time scale for the core. Although this time scale is reasonable under the assumption of steady state conditions, it is not in close agreement with a time scale based upon an alternate approach (Lorius *et al.*, 1979). Hopefully, additional cores in the central Antarctic plateau region, as well as continued studies of the 905-m Dome C core, will provide a refined chronology and clarify some of the problems encountered in the interpretation of proxy data from deep ice cores.

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