

MICROPARTICLE ANALYSIS OF THE ROSS ICE SHELF Q-13 CORE AND PRELIMINARY RESULTS FROM THE J-9 CORE*

by

Ellen Mosley-Thompson

(Institute of Polar Studies, Ohio State University, Columbus, Ohio 43210, U.S.A.)

and Lonnie G. Thompson

(Institute of Polar Studies and Department of Geology and Mineralogy, Ohio State University, Columbus, Ohio 43210, U.S.A.)

ABSTRACT

The concentration and size distribution of microparticles are measured on the Ross Ice Shelf at three sites: Q-13, base camp, and J-9. Results from the analysis of 2 611 samples representing the 100 m core from site Q-13 are presented. Increasing particle concentrations since 1800 are interpreted as a reflection of the gradual movement of the Q-13 drill site northward toward the Ross Sea under greater influence of the dissipating cyclonic storms in the Ross embayment. A substantial increase in particle concentrations found between 1920-40 may reflect an increase in the frequency and/or intensity of cyclonic storms dissipating in the Ross Sea. This is under investigation. Preliminary microparticle analyses of a small portion of each of 39 sections from the 416 m J-9 core indicate a substantial increase in particle concentrations between 250 and 350 m, possibly signaling the presence of late glacial, or Wisconsin, ice.

INTRODUCTION

The Ross Ice Shelf Project (RISP) began during the 1973-74 austral summer with the establishment of a base camp (~82°30'S, 166°W) on 14 December 1973. RISP is an interdisciplinary program composed of glaciological, geophysical, and oceanographic investigations. The primary glaciological objectives are to measure snow accumulation, ice strain-rates, 10 m temperatures, ice thicknesses, and ice velocities. This information is necessary to interpret data from the bore holes and ice cores drilled in the Ross Ice Shelf.

Microparticle concentration and size distribution have been measured in samples from three sites on the Ross Ice Shelf. The analytical aspects of the Coulter counter technique are described by Thompson (1977). The physical dissimilarity of firn and ice demands separate methods for sample cutting and cleaning as firn is more easily contaminated and requires special handling (Mosley-Thompson 1980).

One objective of these analyses is to examine the temporal variability in particulate deposition on the Ross Ice Shelf over two time scales: the last 400 a contained in the Q-13 core, and over many millennia contained in the J-9 core. A second objective is to determine if a seasonal cycle in microparticle deposition exists, and to test the use of microparticle concentration variations for dating ice stratigraphy on the Ross Ice Shelf. Clausen and others (1979) suggest that conditions on the Ross Ice Shelf are less favorable for a seasonal pattern of dust deposition and that the fallout from nearby volcanoes may mask the possible seasonal pattern in the sparse deposition. Scanning electron-microscope examination of the material in the Q-13 core does not indicate a great abundance of fresh volcanic fragments and the predominance of clay particles suggests that airfall from Mt Erebus is not a major contributor to the insoluble particulates.

100 m CORE FROM SITE Q-13

A 100 m core was drilled during the 1977-78 austral summer on the Ross Ice Shelf at site Q-13 (78°57'S, 179°55'E) (for map see figure 1 in Thompson and Mosley-Thompson 1982). 2 611 samples representing the entire 100 m length (77 m water equivalent) were analyzed for micro-particle concentration and size distribution. The sample size at the top was 55 mm firn (21 mm water: $\rho = 388 \text{ kg m}^{-3}$) decreasing to 30 mm firn (27 mm water: $\rho = 920 \text{ kg m}^{-3}$) at the bottom. These sample sizes, coupled with the estimated annual accumulation of 160-190 mm water, provide a resolution of between 7 and 9 samples per average annual accumulation increment.

The Ross Ice Shelf is ~330 m thick at Q-13 and the ice moves approximately 900 m a^{-1} from the south-east corner of the ice shelf (Jezek unpublished). Flow-line maps based upon intensity variations of the bottom echo (Bentley and others 1979) indicate that ice at Q-13 has come from the vicinity

*Contribution No.414 of the Institute of Polar Studies, Ohio State University, Columbus, Ohio 43210, U.S.A.

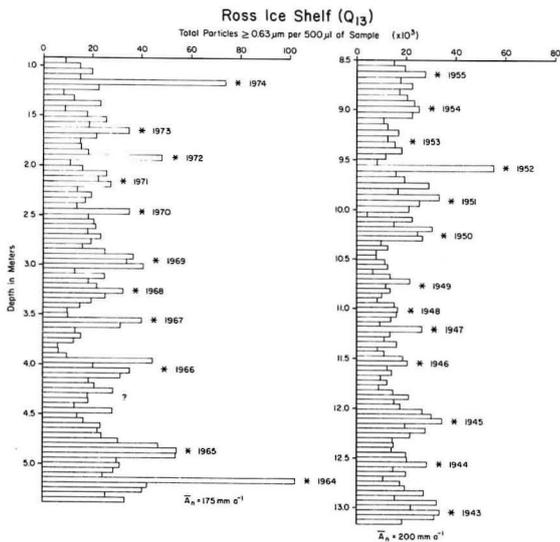


Fig.1. Total particle concentrations in two sections of the Q-13 core. Dates were assigned by counting the cyclical variations. \bar{A}_n is the average annual accumulation rate for each section.

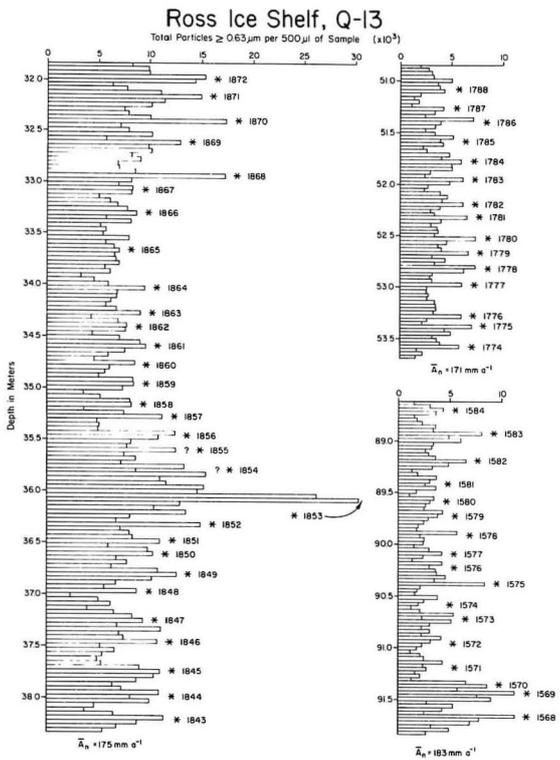


Fig.2. Total particle concentration in three sections of the Q-13 core. Dates were assigned by counting the cyclical variations in microparticle concentration. \bar{A}_n is the average annual accumulation rate for each section.

of West Antarctic ice streams A and B passing west of the Crary Ice Rise.

The detail of the microparticle record is illustrated by five representative sections (Figs.1 and 2). A tentative time scale is constructed by counting the best defined microparticle concentration peaks downward from the surface. A discussion of the problems inherent in the interpretation of microparticle stratigraphy is presented elsewhere (Mosley-Thompson and Thompson in press). There have been no surface

stratigraphic studies in the Q-13 area to provide confirmation that the well-preserved microparticle concentration cycles are annual.

One approach successfully employed in a previous study at the South Pole (Mosley-Thompson 1980) is to assume that the particle concentration peaks are annual, convert the vertical separation between successive peaks to water equivalent using the density profile, and construct an accumulation profile. A total of 454 peaks were counted and a corresponding accumulation record was constructed. A Fourier transformation of the data sequence and removal of periods less than 10 a was performed but no consistent trend was evident. Annual variability in net water accumulation (\bar{A}_n) was found to be quite high, ranging between a minimum of 100 mm a⁻¹ and a maximum of 260 mm a⁻¹. \bar{A}_n for the entire core is 168.8 mm a⁻¹, intermediate between the earlier estimates of 180 mm a⁻¹ by Crary and others (1962) and more recent estimates which fall between 120 and 160 mm a⁻¹ (Bentley and Jezek 1981).

Figure 3 illustrates the concentration of total particles (diameters >0.63 μm) per 500 μl of sample for the entire 100 m core, plotted in water equivalent depth. The dates assigned at each 5 m interval were obtained by counting apparent seasonal variations in particle concentration downward from the surface as discussed above. The Q-13 microparticle record for the last 450 a bears no resemblance to the only other detailed Antarctic microparticle

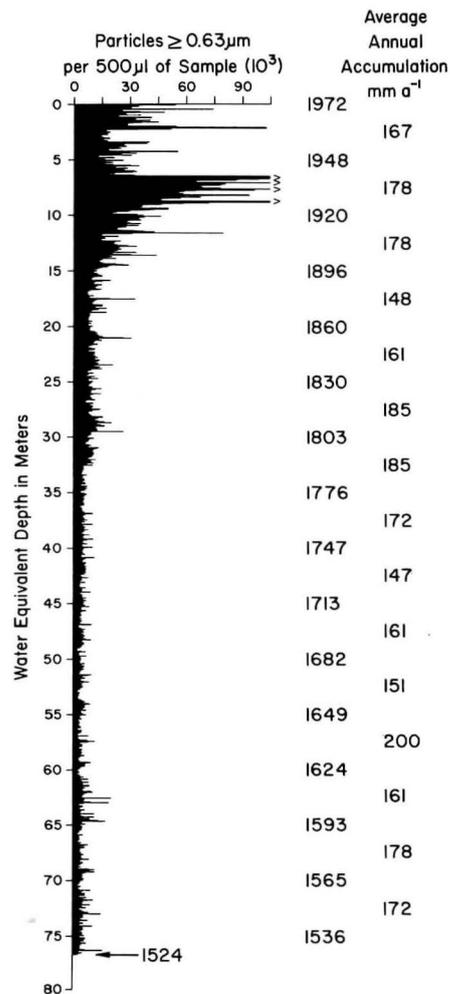


Fig.3. The concentration of total particles in 2 611 samples, representing the entire 100 m Q-13 core. Depth is in water equivalent. The estimated annual accumulation rate and data are included for each 5 m increment.

record, that from the South Pole (Mosley-Thompson 1980). Two prominent features of the Q-13 record are the gradual increase in concentrations since ~1800 and the very pronounced concentrations between 6.5 and 10 m (water equivalent) representing the period 1920-40 (Fig.3).

A gradual increase in particulate deposition begins around 1800, increasing by a factor of 4 by 1900 (Table I). Particulate concentrations increase rapidly after 1900 and by 1950 the concentrations are almost one order of magnitude greater than in 1730 (Table I). The ratios of concentrations in 1951 to 1730 show a small particle (0.63-0.80 μm) ratio of 8 and a large particle ($>5.0 \mu\text{m}$) ratio of 24, demonstrating that a much greater proportion of larger fragments are being deposited at the current Q-13 site than 220 a ago when the drill site was nearly 200 km further inland.

This general increase in particle concentration is attributed to the gradual northward movement of the deposition site. As the deposition site moves closer to the particle source, the exposed areas surrounding the Ross embayment, the number of particles deposited annually increases and larger fragments are more abundant (Table I).

TABLE I. RATIOS OF PARTICLE CONCENTRATIONS REPRESENTING FIVE TIME INTERVALS IN THE Q-13 ICE CORE

Estimated time horizons	0.63-0.80 μm	$>0.63 \mu\text{m}$	$>1.0 \mu\text{m}$	$>5.0 \mu\text{m}$
1900 1730	5.2	4.8	3.9	4.0
1951 1730	8.1	9.3	10.8	24.0
1940 1730	25.0	27.9	29.6	25.0
1927 1730	39.5	52.2	68.5	34.0
1951 1900	1.5	2.0	2.7	6.0

Thompson and Mosley-Thompson (1982) report that the current annual particle deposition rate is $\approx 150 \times 10^7$ particles m^{-2} at site J-9, which is ≈ 500 km from the Ross Sea. This contrasts sharply with the $\approx 800 \times 10^7$ particles m^{-2} deposited at Q-13 today. It is interesting that no general trend in estimated net accumulation was found. Such a trend would be in keeping with the spatial distribution of accumulation reported by Clausen and others (1979) and would be expected as the site moves closer to the moisture source. This is under investigation.

Much of the material deposited at Q-13 today appears to be locally derived, and is probably transported in association with the cyclonic storm systems which move into the Ross Sea. Carleton (1981) reports that cyclogenesis in the southern hemisphere winter tends to occur over middle latitudes, with maturity and decay (cyclolysis) occurring at higher latitudes. This is the same pattern as reported by Streten and Troup (1973) and Streten and Wells (1977) for other seasons. Cyclone frequency is 2.5 times greater during winter than summer (Carleton 1981) and, by late winter/early spring (September), cyclolysis reaches a maximum in response to the intensified circumpolar trough. The mean distribution of dissipating vortices for five winters shows a maximum over the Ross Sea (Carleton 1979). As these dissipating storms move onto the Ross Ice Shelf, they transport very small ($<1.0 \mu\text{m}$) particles from mid-

latitudes as well as local Antarctic material entrained from exposed areas along the eastern margin of the Ross embayment.

The very substantial increase in particle concentrations between 1920 and 1940 is quite intriguing. Size distribution data indicate that the material is locally derived and consists of great quantities of large ($>1.0 \mu\text{m}$) fragments. Very pronounced broad peaks are centered at 1927, 1934, 1938, and 1940, and are associated with modest accumulation increases. Scanning electron-microscope examination of the particles in the 1927 and 1940 peaks reveals many large ($>50 \mu\text{m}$) fragments and very few fresh volcanic glass shards, which might be expected if direct air fall from Mt Erebus were the source. The ratio of particle concentrations in the 1940 and 1927 peaks to that in 1730 (Table I) provide strong evidence that local sources contributed greatly to the total particulate mass.

Interestingly, conductivity measurements on liquid samples from a 44 m core from Windless Bight, near Ross Island, show a number of moderately elevated conductivity peaks between 1922 and 1940 (J Palais personal communication). The core was dated by assuming steady-state conditions and a constant accumulation rate of 200 mm a^{-1} water. Palais reports a 0.1 m thick dust band at 18.51-18.61 m (≈ 1929) in the core. Preliminary indications are that the conductivity increases are associated with enhanced concentrations of sea salts. More detailed comparisons between the Windless Bight and Q-13 cores will be pursued.

We propose that the most viable mechanism to account for the transport of the great quantity of poorly sorted material to site Q-13 is either an increase in the annual frequency of storms entering the Ross Sea or deeper penetration of the depressions onto the Ross Ice Shelf. Analysis of the long records of sea-level pressures and temperatures in New Zealand and Australia could reveal whether anomalous conditions characterize the 1920-40 period. Certainly under conditions of greater baroclinic instability, deeper depressions could be generated over the southern oceans resulting in deeper penetration into the Ross Sea during a longer dissipation stage.

BASE CAMP SHALLOW CORE STUDIES

In 1973-74, thirty-six 10 m cores were recovered in the south-eastern part of the Ross Ice Shelf (Clausen and others 1979). Three cores drilled at base camp on January 29, 1974 were shipped to The Ohio State University for microparticle analysis. One core was analyzed in October 1974 using a Coulter counter model T in the clean room at the Institute of Polar Studies. In November 1974, the old room was replaced with a commercial Class 100 clean room and a new Coulter counter model TA II was installed. In July 1975, the remaining two cores were analyzed in the new microparticle facility. The size ranges measured by the two counters are not comparable and, thus, only the latter two cores are discussed (Fig.4).

Cyclical variations in particle concentration appear fairly well preserved in these cores, which provide the only information about the spatial variability of microparticle concentrations and the preservation of concentration variations in the stratigraphy on the Ross Ice Shelf. Previous microparticle studies (Mosley-Thompson 1980, Thompson and others 1981) have illustrated the importance of detailed pit and shallow core work for the proper assessment of stratigraphic records from deeper cores.

The first estimates of annual accumulation patterns in the base camp and J-9 area were derived from stratigraphic studies in shallow pits along traverse routes and were reported as 158 mm water a^{-1} (Crary and others 1962). More recently the use of total β activity to identify time-stratigraphic horizons (Clausen and others 1979) reveals that accumulation in the J-9 and base camp areas is approximately 81

and 90 mm a⁻¹ (water equivalent), respectively. Herron and Langway (1979) found that Na concentrations exhibit a seasonal variation, thus providing a method for dating. At site J-9, an accumulation rate of 90 mm a⁻¹ was determined by counting Na concentration peaks with depth. Molenaar and Warburton (1979) report a personal communication from C Cornish that radiometric (β) dating of 5 m cores at site J-9 yielded an average annual accumulation of 97 mm a⁻¹. In view of the correspondence among these three independent studies, it is assumed here that the average annual accumulation in the J-9 region of the Ross Ice Shelf is 80 to 100 mm a⁻¹.

The following discussion assumes that microparticle concentrations exhibit a seasonal cycle of deposition. Microparticle work on the Ross Ice Shelf is insufficient, as the following discussion illustrates. Figure 4 presents the concentration of microparticles with diameters >0.63 μm (C) in the two base camp cores. The asterisks denote C peaks which conform to the standard criteria for well-defined peaks established from East Antarctic surface studies (Thompson and others 1981, Mosley-Thompson and Thompson in press). A well-defined peak (*) must consist of two or more samples and be separated from adjacent peaks by a distinct minimum on each side.

An alternative method is to count each microparticle concentration peak as an annual feature and estimate accumulation. The full circles (●) designate the peaks counted in this fashion. Using the density measurements from a 100 m core drilled in 1974 at J-9, the average annual water accumulation for each interpretation is calculated and shown at the bottom in Figure 4.

The counting of all microparticle peaks yields an estimate of 94 mm a⁻¹ water equivalent, in excellent agreement with data obtained by radiometric dating. One reason that each particle concentration peak should be counted may be the large sample size (40-50 mm) analyzed. Generally, 6 to 10 samples per

average accumulation increment is required for clear resolution of a seasonal cycle. In 1975, when these analyses were conducted, accumulation was thought to be nearly 150 mm a⁻¹ (water) or 440 mm (surface $\rho \approx 340 \text{ kg m}^{-3}$) of snow which, coupled with the sample size, gives 9 to 10 samples per average year. However, since accumulation is now known to be 90 mm a⁻¹ or 264 mm of snow, the 50 mm sample size gives only 5 samples per average accumulation increment, a resolution too coarse to result in well-defined peaks and minima. The degree of post-depositional disruption of the snow and associated particulate material on the Ross Ice Shelf has not been assessed, but is essential for proper interpretation of the stratigraphic records.

PRELIMINARY RESULTS FROM THE 416-m CORE AT J-9

A 416 m core was drilled in 1977-78 through the Ross Ice Shelf at site J-9 (82°22.5'S, 168°40'W) (Zotikov and others 1979). Recently, thirty-nine 1 m sections of the core were obtained for microparticle analysis. Approximately the top 0.2 m of each of the 39 sections have been analyzed for microparticle concentration and size distribution. Figure 5 illustrates the average concentration of small particles (0.63-0.80 μm) and total particles (>0.63 μm) in each of the 39 sections.

The top three samples between 36 and 44 m were contaminated by the drilling fluid. This was confirmed by microscopic examination of the particles. Pore close-off ($\rho = 820 \text{ kg m}^{-3}$) was reached at 44 m. Below pore close-off, ice samples are less subject to contamination and easier to clean prior to analysis.

Particle concentrations below 45 and above 250 m are very low, averaging roughly 5 000 particles

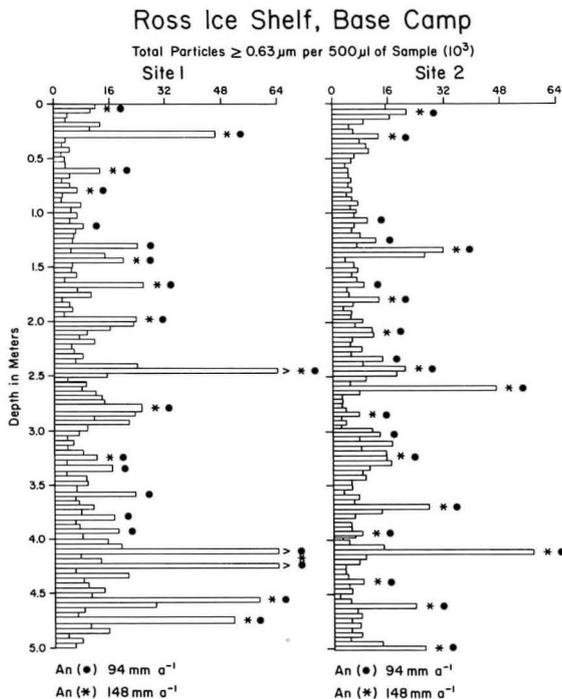


Fig.4. Concentration of total particles with diameters >0.63 μm 500 μl^{-1} sample in two cores drilled at base camp on the Ross Ice Shelf. Asterisks mark well-defined microparticle concentration peaks (see text) while dots mark each microparticle peak. \bar{A}_n is the estimated average annual accumulation rate in mm of water.

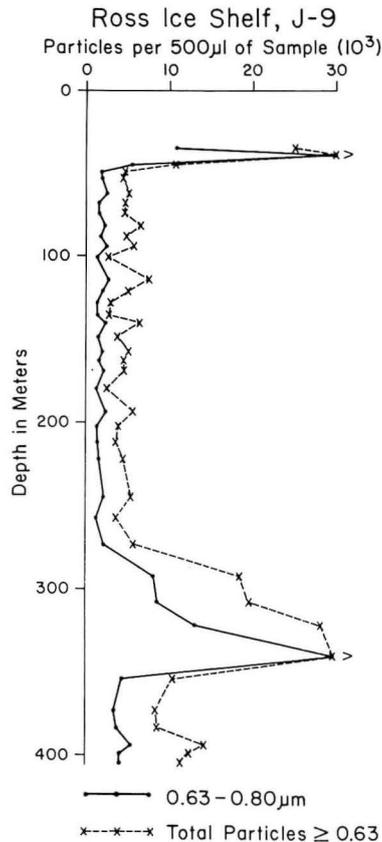


Fig.5. Preliminary results from the microparticle analysis of the upper 0.2 m of each of the thirty-nine 1 m sections of the 416 m core from site J-9 on the Ross Ice Shelf. The upper three sections are contaminated by drilling fluid. Pore close-off ($\rho = 820 \text{ kg m}^{-3}$) is at 45 m.

(>0.63 μm) per 500 μl sample. It is interesting to note that these low concentrations are quite similar to the concentrations found in the lower half of the Q-13 core (Fig.3). Below 250 m, total particle concentrations increase by a factor of 4 at 290 m and by a factor of more than 10 at 340 m. Below 350 m, concentrations decrease to roughly 10 000 particles per 500 μl sample, twice the concentrations between 50 and 250 m.

We propose that this substantial increase in particle concentration may signal the presence of ice deposited near the end of the last glacial stage, the Wisconsin. Thompson and Mosley-Thompson (1981) report that such increases in microparticle concentrations were found to characterize late glacial ice in three deep cores: the Byrd station and Dome C cores in Antarctica, and the Camp Century core in Greenland.

The analyses of the remaining sections of the J-9 core will include particle concentrations, size distributions, and microscopic examination. These microparticle data, coupled with the oxygen isotopic ratios, will indicate whether the ice between 250 and 350 m at J-9 was deposited in West Antarctica during the last glacial stage.

CONCLUSIONS

Microparticle analyses have been conducted for only three sites on Ross Ice Shelf: Q-13, base camp, and J-9. The data from Q-13 and base camp indicate a cycle in microparticle deposition which appears to be annual. Assuming these particle concentration peaks are annual, the estimated average annual accumulation near base camp is 94 mm water, consistent with radiometric dating estimates, but less than the results of pit stratigraphic studies. Using the same assumptions for the upper 5 m (water equivalent) of the Q-13 core, average annual accumulation was estimated to be 167 mm water, intermediate between radiometric dating estimates and pit stratigraphic measurement.

The microparticle analysis of the 100 m Q-13 core entailed 2 611 samples. A general trend of increasing particle concentration since 1800 is suggested to reflect gradual northward movement of the drill site closer to the Ross Sea. The bulk of the particulates are thought to be deposited in association with the dissipating cyclonic storms which move onto the Ross Ice Shelf. These storms can transport small particles from mid-latitudes as well as larger fragments from exposed areas along the eastern coast of the Ross embayment. The period between 1920 and 1940 in the core contains an order of magnitude increase in particle concentration in association with numerous very broad spikes in the particle profile. It is speculated that either deeper penetration or a greater frequency, of dissipating cyclones in the Ross Sea could account for the high particle concentrations and large fragments characterizing this 20 a period.

The preliminary analysis of small portions of 39 sections of the 416 m core from J-9 reveals a very substantial increase in particle concentration between 290 and 350 m. Analyses are continuing to determine whether this increase in particulate content signals the presence of late Wisconsin ice deposited in West Antarctica or a drastic change in the microparticle depositional regime.

ACKNOWLEDGEMENTS

The authors wish to express appreciation to D Bromwich, A Carleton, J Rogers, P Kyle, and J Palais for valuable discussions. We thank J Palais for providing unpublished data, R Tope for illustrating the manuscript, and J Cothran for typing it. This work was supported by US National Science Foundation grant DPP-7719371A02. The microparticle data from the Q-13 core will be furnished to World Data Center A for Glaciology, where they will be available upon request.

REFERENCES

- Bentley C R, Jezek K C In press. RISS, RISP and RIGGS: post-IGY glaciological investigations on the Ross Ice Shelf in the U.S. program. *Journal of the Royal Society of New Zealand*
- Bentley C R, Clough J W, Jezek K C, Shabtaie S 1979 Ice-thickness patterns and the dynamics of the Ross Ice Shelf, Antarctica. *Journal of Glaciology* 24(90): 287-294
- Carleton A M 1979 A synoptic climatology of satellite-observed extra-tropical cyclone activity for the southern hemisphere winter. *Archiv für Meteorologie, Geophysik und Bioklimatologie* Ser B 27(4): 265-279
- Carleton A M 1981 Monthly variability of satellite-derived cyclone activity for the southern hemisphere winter. *Journal of Climatology* 1(1): 21-38
- Clausen H B, Dansgaard W, Nielsen J O, Clough J W 1979 Surface accumulation on Ross Ice Shelf. *Antarctic Journal of the United States* 14(5): 68-72
- Crary A P, Robinson E S, Bennett H F, Boyd W W Jr 1962 Glaciological regime of the Ross Ice Shelf. *Journal of Geophysical Research* 67(7): 2791-2807
- Herron M M, Langway C C Jr 1979 Dating of Ross Ice Shelf cores by chemical analysis. *Journal of Glaciology* 24(90): 345-357
- Jezek K C Unpublished. Radar investigations of the Ross Ice Shelf, Antarctica. (PhD thesis, University of Wisconsin-Madison, 1980)
- Molenaar J V, Warburton J A 1979 Temporal variations and correlations in chemistry of snow on Ross Ice Shelf. *Antarctic Journal of the United States* 14(5): 72-74
- Mosley-Thompson E 1980 911 years of microparticle deposition at the South Pole: a climatic interpretation. *Ohio State University. Institute of Polar Studies. Report 73*
- Mosley-Thompson E, Thompson L In press. Nine centuries of microparticle deposition at the South Pole. *Quaternary Research*
- Streten N A, Troup A J 1973 A synoptic climatology of satellite observed cloud vortices over the southern hemisphere. *Quarterly Journal of the Royal Meteorological Society* 99(1): 56-72
- Streten N A, Wells N C 1977 Atmospheric and oceanic circulation at high latitudes of the south Atlantic and the southwest Indian oceans. *Deep-Sea Research* 24(8): 791-793
- Thompson L G 1977 Microparticles, ice sheets and climate. *Ohio State University. Institute of Polar Studies. Report 64*
- Thompson L G, Mosley-Thompson E 1981 Microparticle concentration variations linked with climatic change: evidence from polar ice cores. *Science* 212(4496): 812-815
- Thompson L G, Mosley-Thompson E 1982 Spatial distribution of microparticles within Antarctic snow-fall. *Annals of Glaciology* 3: 300-306
- Thompson L G, Mosley-Thompson E, Petit J R 1981 Glaciological interpretation of microparticle concentrations from the French 905-m Dome C, Antarctica core. *International Association of Hydrological Sciences Publication* 131 (Symposium at Canberra 1979 - Sea level, ice and climatic change): 227-234
- Zotikov I A, Zagorodnov V S, Raikovskiy J V 1979 Core drilling through Ross Ice Shelf. *Antarctic Journal of the United States* 14(5): 63-64