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THE DOMINION RANGE ICE CORE, QUEEN MAUD MOUNTAINS, ANTARCTICA – GENERAL SITE AND CORE CHARACTERISTICS WITH IMPLICATIONS

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ABSTRACT. The Transantarctic Mountains of East Antarctica provide a new milieu for retrieval of ice-core records. We report here on the initial findings from the first of these records, the Dominion Range ice-core record. Sites such as the Dominion Range are valuable for the recovery of records detailing climate change, volcanic activity, and changes in the chemistry of the atmosphere. The unique geographic location of this site and a relatively low accumulation rate combine to provide a relatively long record of change for this potentially sensitive climatic region. As such, information concerning the site and general core characteristics are presented, including ice surface, ice thickness, bore-hole temperature, mean annual net accumulation, crystal size, crystal fabric, oxygen-isotope composition, and examples of ice chemistry and isotopic composition of trapped gases.

INTRODUCTION

Localized accumulation basins in the Transantarctic Mountains, fed completely by precipitation on to the site, provide a new avenue for Antarctic ice-core research. These sites are valuable for the recovery of records detailing climatic change, volcanic activity, and changes in atmospheric chemistry for periods extending well into the last glacial period. Since these sites are located within the transitional zone between plateau ice and ocean-ice shelf, they could provide some of the most climatically sensitive records available from Antarctica. Furthermore, unlike those ice cores retrieved from the interior of Antarctica, there are terrestrial records from nearby sites that can be used for comparison (e.g. Denton and others, 1971; Drewry, 1980; Stuiver and others, 1981; Mayewski and Goldthwait, 1985).

The Dominion Range (Fig. 1) is the first in a series of planned Transantarctic Mountains ice-core sites (Fig. 1). The Dominion Range is located along the edge of the East Antarctic ice sheet, approximately 500 km from the South Pole and 120 km from the Ross Ice Shelf, at the confluence of Beardmore and Mill Glaciers (Fig. 2). These glaciers, along with several other outlet glaciers in the Queen Maud Mountains (sub-sector of the Transantarctic Mountains), drain the Titan Dome area of the East Antarctic ice sheet. Approximately half of the Dominion Range (Fig. 2) is ice-free and the average elevation of the range is 2700 m.

Between 20 November and 14 December 1984, a tent camp was operated in the Dominion Range. Due to logistic restraints, all aspects of the study, including reconnaissance, site characterization, and recovery of a 201 m core were undertaken in the same field season. In this paper we present the results of site and core characterization, specifically ice surface and ice thickness, bore-hole temperature, mean annual net accumulation, crystal size, crystal fabric, oxygen-isotope composition, and examples of ice chemistry (Cl-, SO₄²⁻, MSA), and isotopic composition of trapped gases.
ICE-SURFACE AND ICE-THICKNESS MEASUREMENTS

The early part of the field season was devoted to establishing an optimum site for recovery of an ice core (Fig. 2). Maps, visual observations of ice-surface topography, and the presence of bedrock ridges all validated initial estimates that the Dominion Range ice cover is either entirely separated from or only minimally connected to the East Antarctic ice sheet and hence the site is a catchment for local precipitation. Exposed bedrock ridges flanking the Dominion Range are cavernously weathered. Comparison of the degree of cavernous weathering with that examined in the general region of the Queen Maud Mountains by Mayewski and Goldthwait (1985) suggests that ice has not topped these ridges for at least several tens of thousands of years.

Based on an examination of USGS (1:250,000) topographic maps and a radio echo-sounding survey conducted in the field, the Dominion Range ice mass is divisible into three major drainage basins, referred to as A, B, and C (Fig. 2). The radio-echo survey employed a mono-pulse system (after Watts and Isherwood, 1978) and was centered primarily over drainage basin C. It included measurements at 42 stations, ten of which were occupied at least twice to test instrument reproducibility, which proved to be less than the error inherent in reading the oscilloscope. Final ice-thickness measurements were determined using Watts and Isherwood's (1978) relationship with adjustments for density made using measurements from the core. Crevassed areas in the southern section of basin C, lower Vandament Glacier, prevented the recovery of useful radio echo-sounding data from this area.

Drainage basin C surface topography (Fig. 3) is characterized by a general surface slope to the east, thus

![Fig. 1. Location map.](image)

![Fig. 2. Dominion Range location map.](image)

![Fig. 3. Drainage basin C ice surface.](image)
Fig. 4. Drainage basin C ice thicknesses.

Mean Crystal (mm²)

Mean Crystal Size as a Function of Depth

Fig. 5. Temperature, density (smoothed), and mean crystal size as a function of depth.

Fig. 6. Fabric point-scatter diagrams illustrating c-axis orientations at (A) 59.52 mbar, (B) 70.71 mbar, (C) 85.28 mbar, (D) 122.65 mbar, (E) 143.18 mbar, and (F) 190.00 mbar. Larger dots represent crystals that are greater than twice the average grain-size.

BORE-HOLE TEMPERATURE AND MEAN ANNUAL NET ACCUMULATION

Temperature measurements were made at 5 m intervals (Fig. 5) down the entire length of the bore hole using a thermometer system designed by L. Hansen (PICO). Twenty readings at 20 s intervals were made at each depth immediately following a 10 min equilibrium period. Instrument error is ±0.02°C based on duplicate measurements. The mean annual temperature, at 10 m depth, is -37.3°C, and the temperature at the base of the core, 201 mbar (m beneath surface), is -31.3°C. Radio echo-sounding results suggest that the glacier at this point is <230 m thick, hence there is little doubt that the base of this ice mass is frozen to the bed.

Mean annual net accumulation was determined by a combination of measurements, including total B-activity, 3H/Pb, 4C, seasonal signatures in anion chemistry, and volcanic horizons. Details concerning the dating of the core appear in Spencer and others (in press). We report here only the resultant mean annual net accumulation for the upper ~100 m of the core which is ~33 kg m⁻² a⁻¹.

The mean annual temperature and mean annual accumulation at this site are consistent with relationships presented by Gow (1968) for a survey of Antarctic sites.

CRYSTAL SIZE AND FABRIC

Horizontal and vertical thin sections were cut from core samples taken at depths of 59.5, 70.7, 85.3, 122.7, 143.2, and 190 mbar. Mean crystal size (Fig. 5) within each section was determined from measurements of the long and short axes of individual crystals. Fabrics (Fig. 6) were determined from measurements of c-axis orientations using a Rigby stage (Langway, 1938).

Mean crystal cross-section increased from ~7 mm² at 59.5 mbar to ~13 mm² at 70.7 mbar and then decreased progressively to ~2 mm² between 70.7 and 143.2 mbar before increasing to ~7 mm² at 190 mbar. Sections at 59.5 and

Majewski and others: Dominion Range ice core, Antarctica
70.7 mbar exhibited random fabrics. At 82.3 mbar, a weakly preferred orientation of c-axes is evident with local c-axis concentrations of 8% per 1% area of projection. By 122.7 mbar, c-axes group into two maxima located approximately 35° from the vertical. c-axis concentrations as high as 10% per 1% were observed. At 143.2 mbar, a girdle pattern appears with local c-axis concentrations as high as 12% per 1% area. A ring or small girdle fabric is present at 190 mbar.

The marked decrease in size of crystals between 70.7 and 143.2 mbar may indicate the onset of shearing. Moderate development of c-axis fabrics from the same depth interval might support a shearing process; however, a lack of tight single-pole fabrics would indicate that shearing is not yet a dominant process. Crystal coarsening at 190 mbar could signal the onset of recrystallization in the basal layers of ice. However, such a process would tend to be impeded by the generally low temperatures at the site. It was not possible to obtain azimuthally oriented core this, together with the limited observations of the texture and fabric of the ice, prevent us from developing a unique flow history for this part of the Dominion Range ice field. Notably, the quality of the ice core recovered deteriorated from whole to fractured core interspersed with whole sections from this depth downward. It was not possible in the field, however, to resolve whether the core quality was necessarily due to strained ice or problems with the cutters.

OXYGEN ISOTOPES OF ICE

A continuous \( ^{18}O_{\text{ice}} \) profile was obtained for the ice core using 25 cm increments for most of the core and 2-3 cm samples in the sections studied for ice chemistry. \( ^{18}O_{\text{ice}} \) is defined here as being equal to \( \left( \frac{^{18}O/^{16}O}{^{18}O/^{16}O}_{\text{SMOW}} \right) \) and \( ^{18}O_{\text{SMOW}} \) is Standard Mean Ocean Water. \( ^{18}O_{\text{ice}} \) for 50 cm averages of the data appear in Figure 7.

Fig. 7. \( ^{18}O_{\text{ice}} \) measurements down-core (50 cm averages).

For the upper \( \approx 100 \) m of the core there appears to be a small trend toward less negative \( ^{18}O_{\text{ice}} \) values with depth. The sections below \( \approx 100 \) m are significantly lighter and are marked by a drop of \( \approx 10 \% \) from \( \approx 100 \) to 145 mbar followed by a rise of \( \approx 2-3 \% \). The \( \approx 5 \% \) marked drop is similar to the glacial/interglacial \( 6 \) changes of 5.4% and about \( 5 \% \) observed at Dome C (Lorius and others, 1979) and at Vostok (Lorius and others, 1985), respectively.

ICE CHEMISTRY

While details of the distribution of major chemical species in the core are left to other papers (e.g. Spencer and others, in press), it is worth mentioning the marked difference in the distribution of C1 and SO\( ^{2} \) in the upper half of the core (2 and 3 cm sampling interval) and one of the few intact sections that could be analyzed from the lower half of the core at 138.0-138.4 mbar (2 cm sampling interval). Marine aerosols and volcanic activity represent the primary sources for both C1 and SO\( ^{2} \) to the ice sheet on sheet. While volcanic source inputs would be expected to be randomly distributed in the record, differences in marine source input would result in trends in the data series that probably reflect changes in air-mass circulation and/or oceanic relationships. Averaged values of C1 (\( \approx 250 \) ppm) and SO\( ^{2} \) (\( \approx 300 \) ppb) in the 138.0-138.4 m section are two to three times those in the upper half of the core. The contrast between lower-level ice, as represented by the 138.0-138.4 m section, and the upper \( \approx 100 \) m of ice is striking. Although the higher SO\( ^{2} \) and C1 concentrations in the deeper sections could coincidentally be the result of the volcanic events in the upper half of the core is as high in concentration as or as broad in time span. We conclude, therefore, that the deeper section marks a period which differs from upper sections either in marine source intensity, in transport pathway, and/or for some unknown reason.

The upper and lower sections of the core also appear to differ in their concentration of methanesulfonic acid (MSA). MSA is a constituent of marine aerosols which is formed as a result of the atmospheric oxidation of DMS. Variations in MSA concentration in the core reflect changes in the flux of DMS from the oceans, in the patterns of aeolian transport, and/or in precipitation rate (Saigne and Legrand, 1987). A noticeable difference was, however, observed between the four samples measured from an upper section of the core (29-30 mbar; MSA conc. = 2.2 \( \pm \) 0.2) and five samples measured from a lower core section (138-139 mbar; MSA conc. = 5.7 \( \pm \) 1.0).

ISOPTIC COMPOSITION OF TRAPPED GASES

The isotopic composition of trapped O\( _{2} \) and N\( \_2 \)O in two sections of the Dominion Range core appear in Table I. The isotopic composition of the 83 mbar samples was similar to the isotopic composition of Recent (<1500 a.n.p.) samples of ice from five different cores taken from Antarctica and Greenland (paper in preparation by T. Sowers and others). The isotopic composition of the 139 mbar samples had \( ^{18}O_{\text{ATM}(O_2)} \) values which were enriched, compared to Recent ice samples, by 1.0 \( \pm \) 0.136.

During the transition from glacial to interglacial periods, isotopically light water from glaciers was introduced to the oceans, resulting in a decrease in the \( ^{18}O_{\text{water}} \) of sea-water (where \( ^{18}O_{\text{water}} \) = \( (H/^{18}O/H/^{16}O/^{18}O_{\text{SMOW}} - 1)^{10} \)). Photosynthesizing organisms utilized the isotopically depleted melt water to form O\( _{2} \) which was mixed into the paleoatmospheric O\( _{2} \) reservoir causing the \( ^{18}O_{\text{ATM}(O_2)} \) of air to fall (where \( ^{18}O_{\text{ATM}(O_2)} \) = \( (^{18}O/^{16}O)/(^{18}O/^{16}O)_{\text{present-day atmosphere}} - 1)^{10} \)). Studies of the trapped gases in the Dome C core have shown that the isotopic composition of O\( _{2} \) trapped in the ice tracks the isotopic composition of seawater over the past 20000 years (Bender and others, 1985). Since the \( ^{18}O_{\text{ATM}(O_2)} \) is constant throughout the atmosphere, one can use the composition of the O\( _{2} \) in the ice as a chronologic tool. We have used this tool to estimate the ages of two samples from the Dominion Range core.

Analysis of Recent samples of O\( _{2} \) show that the trapped gases are enriched in both \( ^{18}O \) and \( ^{18}N \), relative to the contemporaneous atmosphere (paper in preparation by T. Sowers and others). The enrichment is probably the result of isotopic fractionation as the bubbles are sealed. Because atmospheric N\( \_2 \)O has a very long residence time, the \( ^{15}N \) of the atmospheric N\( \_2 \)O is believed to have been constant for the last 10,000 years (where \( ^{18}O_{\text{ATM}(O_2)} = (\frac{(^{14}N_{\text{water}})(^{18}O/^{16}O)_{\text{present-day atmosphere}}}{(^{14}N/^{16}O)_\text{air}} - 1)^{10} \)). Given this constancy, and the observed \( ^{8}O-^{8}N \) relationship for gases trapped in modern ice, one can use the fractionation of the N\( \_2 \)O trapped in ice to determine the \( ^{18}O_{\text{ATM}(O_2)} \) of past atmospheres using the following equation:

\[
^{18}O_{\text{ATM}(O_2)} = \frac{^{18}O_{\text{ice}}}{^{18}O_{\text{ice}} + 2} - 1
\]

\[
^{18}O_{\text{ice}} = (1.95(6\%\text{iceN}_{\text{ice}} + 0.089)\text{meas.})
\]
TABLE I. ISOTOPIC COMPOSITION OF TRAPPED GASES IN DOMINION RANGE ICE

| TABLE 1. ISOTOPIC COMPOSITION OF TRAPPED GASES IN DOMINION RANGE ICE |
|---------------------------------|-----------------|-----------------|
| &delta;15N_{ICE(N_2)} | &delta;18O_{ICE(O_2)} | &delta;18O_{ATM(O_2)} |
| 83 mbar sample (n = 2) | 0.17‰ | ±0.01‰ | 0.37‰ | ±0.02‰ | 1.00‰ | ±0.13‰ |
| 139 mbar sample (n = 7) | 0.13‰ | ±0.05‰ | 1.35‰ | ±0.02‰ | 1.00‰ | ±0.13‰ |

* Reported data have been corrected for the isotopic dependence on the elemental composition (paper in preparation by A.B. Kidson and others). The data are reported relative to present-day-air, &delta;15N.

† Isotopic composition of the contemporaneous atmosphere from which the trapped gases were derived, also reported relative to present-day-air.

SUMMARY AND CONCLUSIONS

The Dominion Range ice-core site is characterized by a mean annual temperature of −37.3°C and a core-base temperature of −31.3°C which is probably close to the basal ice temperature. The mean annual net accumulation is 35 kg m⁻² a⁻¹.

Dominion Range ice is divisible into three main drainage systems and a site close to the ice divide between two of these drainage systems was chosen for the recovery of a 201 m core. Differences between ice-surface and subglacial gradients in the area of the drill site suggest that some amount of lateral strain is imposed on the ice column. The difference in &delta;18O_{ICE(O_2)} to &delta;18O_{ATM(O_2)} values will shift the inferred &delta;18O_{ATM(O_2)} record closer to the present-day air. By converting the 139 mbar core, one would increase the age of the Dominion Range 139 mbar sample.

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