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Paul A. Mayewski

Mark S. Twickler

Wm Berry Lyons

Mary Jo Spencer

Debra A. Meese

See next page for additional authors

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

By PAUL A. MAYEWSKI, MARK S. TWICKLER, WM BERRY LYONS, MARY JO SPENCER,

(Glacier Research Group, Institute for the Study of Earth, Oceans and Space (EOS), University of New Hampshire, Durham, New Hampshire 03824, U.S.A.)

DEBRA A. MEESE,

(Glacier Research Group, Institute for the Study of Earth, Oceans and Space (EOS), University of New Hampshire, Durham, New Hampshire 03824, U.S.A., and U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire 03755, U.S.A.)

ANTHONY J. GOW,

(U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire 03755, U.S.A.)

PIETER GROOTES,

(Quaternary Isotope Laboratory, University of Washington, Seattle, Washington 98195, U.S.A.)

TODD SOWERS,

(Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island 02882, U.S.A.)

M. SCOTT WATSON,

(Polar Ice Coring Office, University of Nebraska, Lincoln, Nebraska 68558, U.S.A.)

and ERIC SALTZMAN

(Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Miami, Florida 33149, U.S.A.)

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^-, SO_4^{2-}, MSA), and isotopic composition of trapped gases.

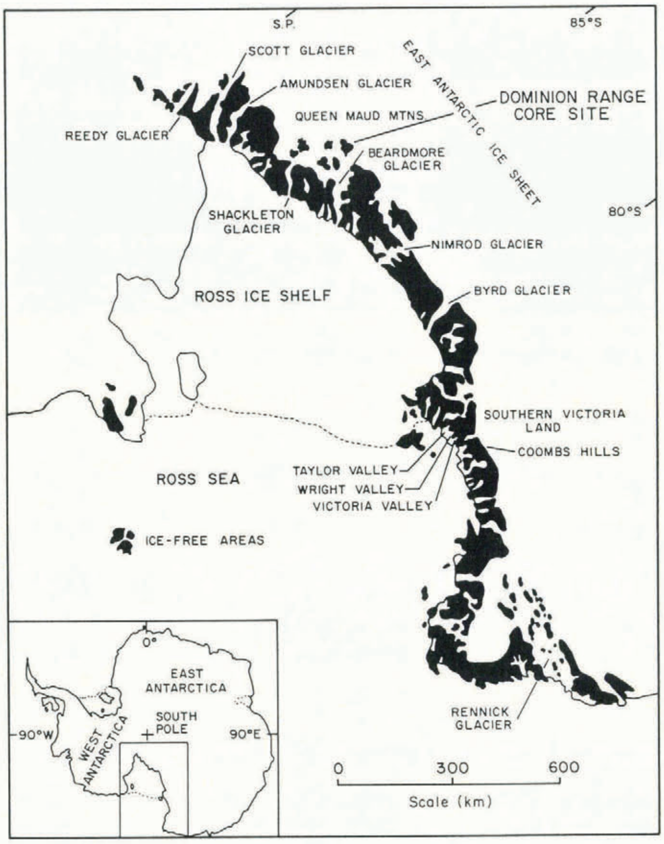

Fig. 1. Location map.

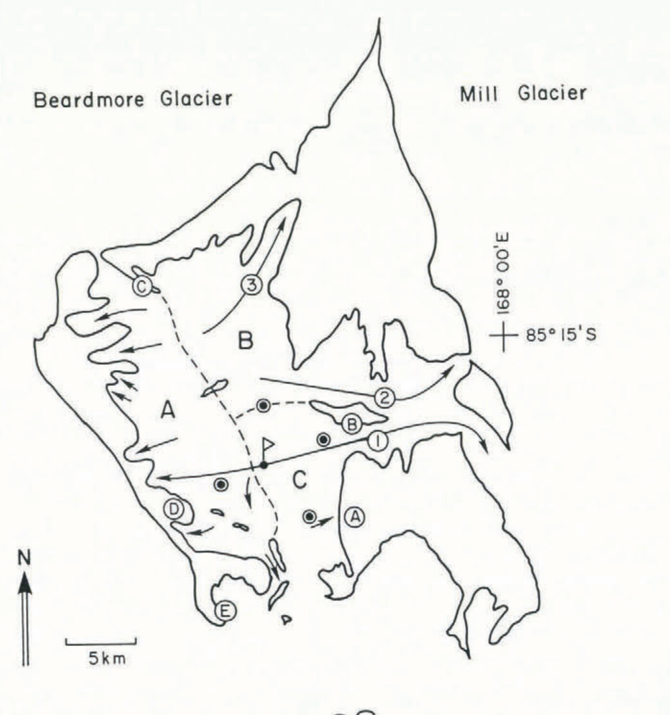

Fig. 2. Dominion Range location map.

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

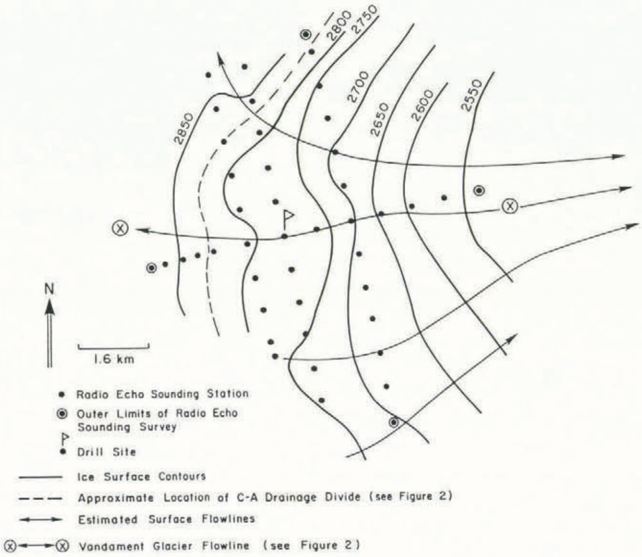

Fig. 3. Drainage basin C ice surface.

the major part of the drainage for C discharges through Vandament Glacier. Ice thicknesses in basin C (Fig. 4) range from ≅350 to <50 m with the thickest areas north of the drill site and in the Mount Tennant area. Thinner ice areas are found in the western part of the basin close to the C–A surface ice divide, and the remainder of the basin is characterized by ice depths most commonly in the range 200–300 m. The general gradient of the subglacial topography is east-south-east.

The core site (see Figs 2, 3, and 4) was chosen ≅1.7 km down-flow line from the C–A ice divide to minimize complications due to flow right on the divide and ≅1.7 km up-slope from the base camp to minimize the effects of any local chemical contamination from the camp. Although it cannot be demonstrated definitively with the data available, it appears that if any East Antarctic ice penetrates drainage basin C from the Mount Tennant area that this ice would be deflected eastward toward Vandament Glacier and hence away from the drill site. A comparison between ice-surface contours (Fig. 3) and ice-thickness contours

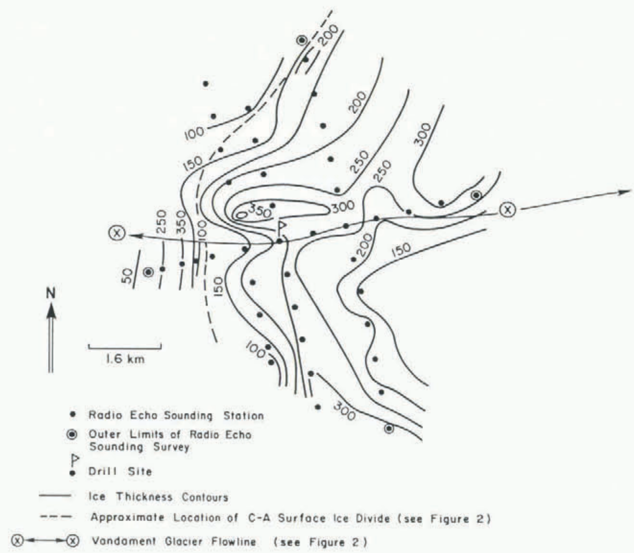

Fig. 4. Drainage basin C ice thicknesses.

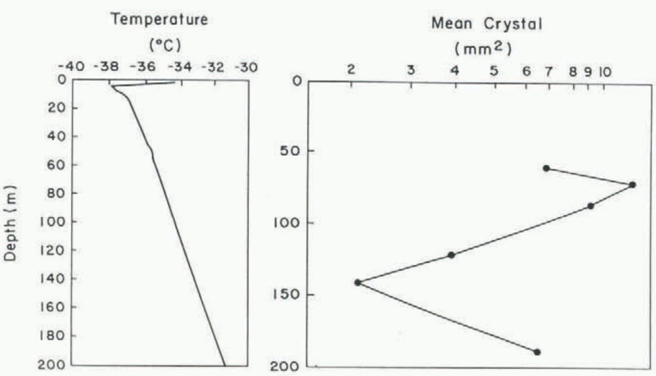

Fig. 5. Temperature, density (smoothed), and mean crystal size as a function of depth.

(Fig. 4) in the area of the Vandament Glacier flow line suggests that the ice in this area must be strained.

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 thermistor 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 β-activity, ^{210}Pb, ^{14}C, 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 ≈35 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 Rigsby stage (Langway, 1958).

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

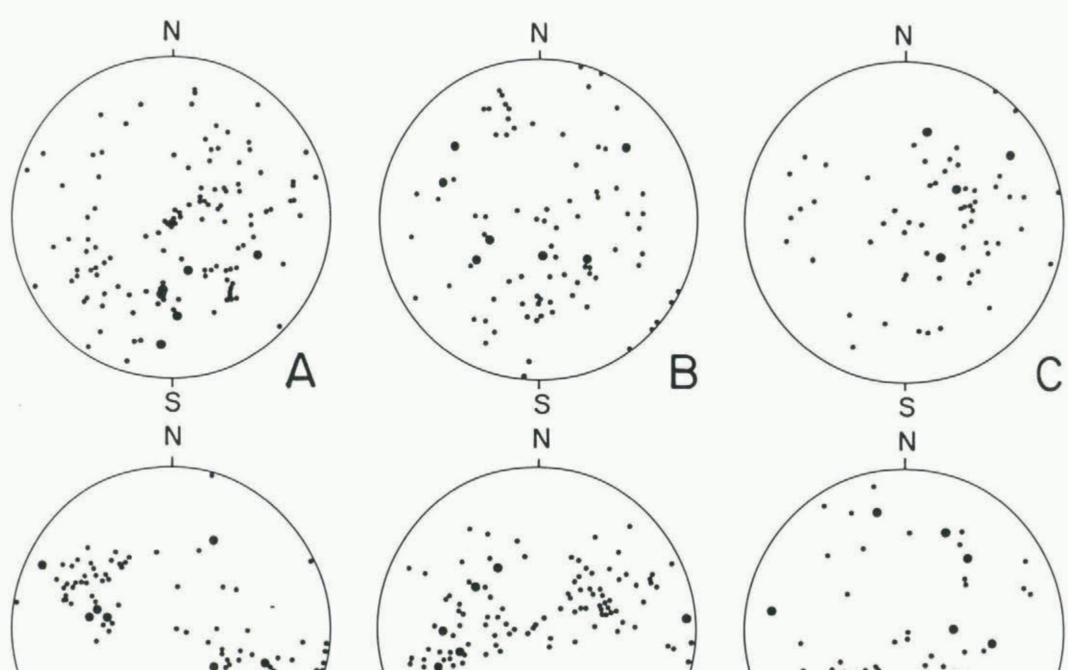

Fig. 6. Fabric point-scatter diagrams illustrating c-axis orientations at (A) 59.52 mbar, (B) 70.71 mbar, (C) 85.28 mbar, (D) 122.65 mbar, (E) 143.18 mbar, and (F) 190.00 mbar. Larger dots represent crystals that are greater than twice the average grain-size.

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 and 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 $\delta^{18}O_{ICE}$ 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. $\delta^{18}O_{ICE}$ is defined here as being equal to $((^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{SMOW})/(^{18}O/^{16}O)_{SMOW}$ and SMOW is Standard Mean Ocean Water. $\delta^{18}O_{ICE}$ for 50 cm averages of the data appear in Figure 7.

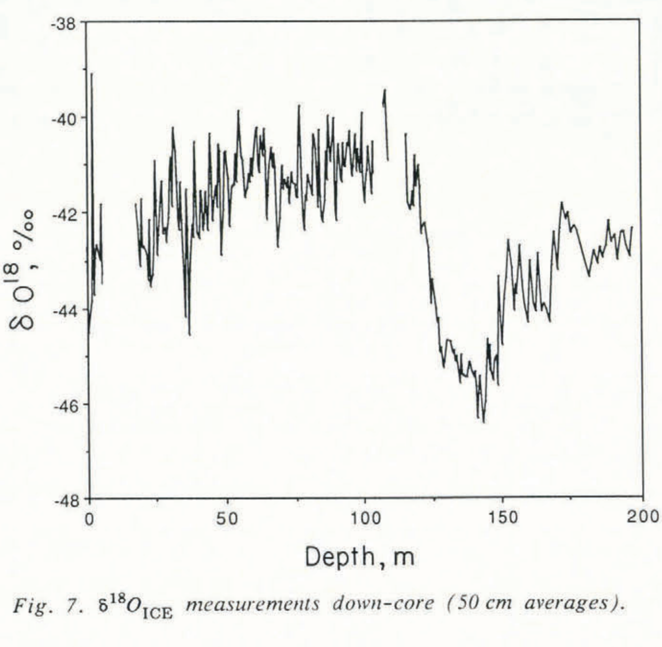

Fig. 7. $\delta^{18}O_{ICE}$ *measurements down-core (50 cm averages).*

For the upper ≈100 m of the core there appears to be a small trend toward less negative $\delta^{18}O_{ICE}$ values with depth. The sections below ≈100 m are significantly lighter and are marked by a drop of ≈5‰ from ≈100 to 145 mbar followed by a rise of ≈2–3‰. The ≈5.0‰ marked drop is similar to the glacial/interglacial δ 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 Cl^- and SO_4^{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 Cl^- and SO_4^{2-} to the Antarctic ice 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 ocean/ice relationships. Average values of Cl^- (≈250 ppb) and SO_4^{2-} (≈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 ≈100 m of ice is striking. Although the higher SO_4^{2-} and Cl^- concentrations in the deeper sections could coincidently be a volcanic layer, none of the volcanic events in the upper half of the core is as high in concentration 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 ± 0.2) and five samples measured from a lower core section (138–139 mbar; MSA conc. = 5.7 ± 1.0).

ISOTOPIC COMPOSITION OF TRAPPED GASES

The isotopic composition of trapped O_2 and N_2 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 B.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 $\delta^{18}O_{ATM(O_2)}$ values which were enriched, compared to Recent ice samples, by 1.0 ± 0.13‰.

During the transition from glacial to interglacial periods, isotopically light melt water from glaciers was introduced to the oceans, resulting in a decrease in the $\delta^{18}O_{water}$ of sea-water (where $\delta^{18}O_{water} = ((H_2{}^{18}O/H_2{}^{16}O)_{water}/(H_2{}^{18}O/H_2{}^{16}O_{SMOW}) - 1)10^3$). Photosynthesizing organisms utilized the isotopically depleted melt water to form O_2 which was mixed into the paleoatmospheric O_2 reservoir causing the $\delta^{18}O_{ATM(O_2)}$ of air to fall (where $\delta^{18}O_{ATM(O_2)} = ((^{18}O^{16}O)/(^{16}O_2)_{paleo\text{-}air}/(((^{18}O^{16}O)/(^{16}O_2)_{present\text{-}day\ atmosphere}) - 1)10^3$). 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 sea-water over the past 20 000 years (Bender and others, 1985). Since the $\delta^{18}O_{ATM(O_2)}$ 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 ice show that the trapped gases are enriched in both ^{18}O and ^{15}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 has a very long residence time, the $\delta^{15}N$ of the atmospheric N_2 is believed to have been constant for the last 10^6 years (where $\delta^{15}N_{ATM(N_2)} = ((^{14}N^{15}N/^{14}N_2)_{paleo\text{-}air}/((^{14}N^{15}N/^{14}N_2)_{present\text{-}day\ air} - 1)10^3$). Given this constancy, and the observed $\delta^{15}N$–$\delta^{18}O$ relationship for gases trapped in modern ice, one can use the fractionation of the N_2 trapped in ice to determine the $\delta^{18}O_{ATM(O_2)}$ of past atmospheres using the following equation:

$$\delta^{18}O_{ATM(O_2)} = \delta^{18}O_{ICE(O_2)} - (1.95(\delta^{15}N_{ICE(N_2)}) + 0.08‰).$$

TABLE I. ISOTOPIC COMPOSITION OF TRAPPED GASES IN DOMINION RANGE ICE

	$\delta^{15}N_{ICE(N_2)}$*	$\delta^{18}O_{ICE(O_2)}$*	$\delta^{18}O_{ATM(O_2)}$†
83 mbar sample (n = 2)			
Average	0.17‰	0.37‰	−0.07‰
std. dev.	±0.01‰	±0.02‰	±0.01‰
139 mbar sample (n = 7)			
Average	0.13‰	1.35‰	1.00‰
std. dev.	±0.05‰	±0.02‰	±0.13‰

* Reported data have been corrrected for the isotopic dependence on the elemental composition (paper in preparation by A.B. Kiddon and others). The data are reported relative to present-day-air, δ^{15}N.

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

Knowing the $\delta^{18}O_{ATM(O_2)}$, one can estimate the age of an unknown trapped gas sample by comparing the measured $\delta^{18}O_{ATM(O_2)}$ value with the down-core record of $\delta^{18}O_{ATM(O_2)}$ measured in the Dome C core (Bender and others, 1985). Using this $\delta^{18}O_{ICE(O_2)}$ curve, we assign an ice age for the 139 mbar sample of >10 ka B.P. This age is expressed as a lower limit for two reasons. First, ice is older than the age of the trapped air (Schwander and Stauffer, 1984). Secondly, the $\delta^{18}O_{ICE(O_2)}$ values for the Dome C record were not converted to $\delta^{18}O_{ATM(O_2)}$ due to lack of $\delta^{15}N_{ICE(N_2)}$ measurements. Converting the Dome C $\delta^{18}O_{ICE(O_2)}$ to $\delta^{18}O_{ATM(O_2)}$ values will shift the inferred $\delta^{18}O_{ATM(O_2)}$ record closer to the present-day air. By converting the Dome C $\delta^{18}O_{ICE(O_2)}$, one would increase the age of the Dominion Range 139 mbar samples.

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 $\delta^{18}O_{ICE}$ noted from ≈100 to ≈145 mbar in the Dominion Range core is similar to the glacial/interglacial δ changes observed at Dome C and Vostok. Measurement of $\delta^{18}O_{ICE(O_2)}$ and $\delta^{15}N_{ICE(N_2)}$ of trapped gases indicates that ice at 139 mbar has an age >10 ka B.P.

If, as inferred from the measurements of $\delta^{18}O_{ICE}$, $\delta^{18}O_{ICE(O_2)}$, and $\delta^{15}N_{ICE(N_2)}$, the upper approximately half of the core column is Holocene in age and the ice below is glacial, then differences in both crystal size and chemical concentration discussed in this text may be more uniquely defined. While decreases in crystal size in the lower ice may be due partly to shear, they may also simply reflect the cooler temperature of formation present during the glacial period as observed at Dome C (Duval and Lorius, 1980). Furthermore, increases in Cl^- and SO_4^{2-} concentrations may be consistent with increases from Holocene to glacial age as measured from the Byrd core (Ragone and Finelli, 1972; Cragin and others, 1977) and Vostok core (Angelis and others, 1984), and the trend in MSA concentration is similar to that observed from Holocene to glacial ice measured at Dome C by Saigne and Legrand (1987).

The Dominion Range ice core provides relatively easy access to the Holocene record in a site that is potentially climatically sensitive. Were the quality of the lower half of the core better, it could also provide a view through the interglacial/glacial transition and into the last glacial period. Future papers will document details of the Holocene signal in this region.

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