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The last interglacial as represented in the glaciochemical record from Mount Moulton Blue Ice Area, West Antarctica

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ABSTRACT

Understanding climate during the last interglacial is critical for understanding how modern climate change differs from purely naturally forced climate change. Here we present the first high-resolution ice core record of the last interglacial and transition to the subsequent glacial period from Antarctica and the first glaciochemical record for this period from West Antarctica. Samples were collected from a horizontal ice trench in the Mt. Moulton Blue Ice Area (BIA) in West Antarctica and analyzed for their soluble major anions (Cl^-, NO_3^-, SO_4^{2-}), major and trace elements (Na, Mg, Ca, Sr, Cd, Cs, Ba, La, Ce, Pr, Pb, Bi, U, As, Al, S, Ti, V, Cr, Mn, Fe, Co, Cu, Zn) and water hydrogen isotopes (δD). The last interglacial is characterized by warmer temperatures (δD), weakened atmospheric circulation (dust elements, seasalts aerosols), decreased sea ice extent (Na, $nssSO_4^{2-}$) and decreased oceanic productivity ($nssSO_4^{2-}$). A combined examination of Mt. Moulton seasalts, dust, $nssSO_4^{2-}$ and δD records indicates that the last interglacial was extremely stable compared to glacial age climate events and it ended through a long period of gradual cooling unlike that projected for future Holocene climate.

1. Introduction

The last interglacial (also known as the Eemian in Europe or marine isotope stage 5e) is the most recent analog for the present (Holocene) interglacial and therefore the most recent analog for a purely naturally forced interglacial. It is characterized by a diminution of ice sheets and establishment of biotic assemblages similar to those of the Holocene (Van Kolfschoten et al., 2003). It appears that global temperatures during the last interglacial were on average ~1.5 °C higher than today (Turney and Jones, 2010). Temperature reconstructions for East Antarctica suggest that the peak temperature during the last interglacial was higher than late Holocene values by about 3–4.5 °C (Petit et al., 1999; Watanabe et al., 2003; Kawamura et al., 2007; Jouzel et al., 2007). Global sea level was at least 3 m, and very likely more than 6.6 m, higher than at present as a result of disintegration of the West Antarctic and Greenland ice sheets (Cuffey and Marshall, 2000; Kopp et al., 2009). CO_2 concentrations in the atmosphere were briefly higher than those during the pre-industrial Holocene (Petit, 1999).

Published records suggest differences in timing, duration and stability for the last interglacial (Winograd et al., 1997; Adams et al., 1999; Kukla et al., 2002). Only five ice core records fully cover the last interglacial and these come from East Antarctica (Petit et al., 1999; Steig et al., 2000; Grootes et al., 2001; EPICA Community Members, 2006; Jouzel et al., 2007; Kawamura et al., 2007). However the climate during the last interglacial in West Antarctica is of special interest, since the West Antarctic Ice Sheet (WAIS) most likely contributed to sea level rise above that of the present during the peak of the last interglacial (Overpeck et al., 2006). The WAIS is the largest potential source of the up to 1.4 m potential sea level rise projected as a consequence of warming by 2100 (ACCE (Antarctic Climate Change and the Environment), 2009) making understanding of the last interglacial climate in this region of particular significance. In this work we present the first glaciochemical record of the last interglacial and transition to the subsequent glacial period from West Antarctica. Rather than using a standard vertical ice core we used samples collected from a horizontal ice trench in the Mt. Moulton BIA. The record is high resolution and contains a suite of 27 measurements, including major anions, major and trace elements.

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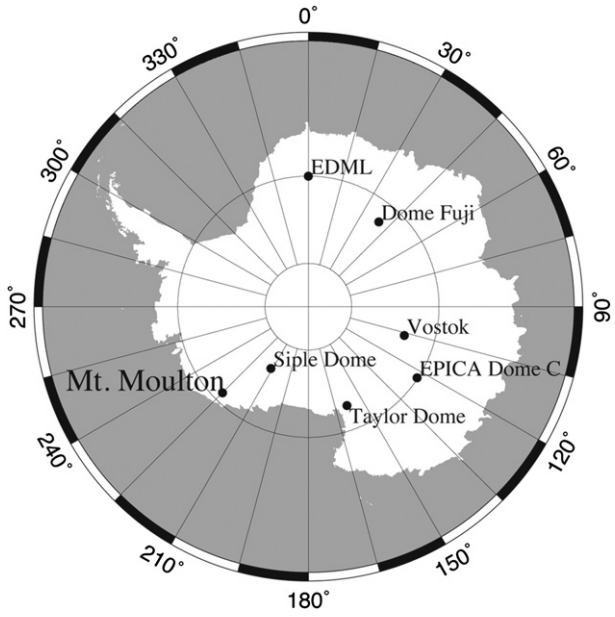

Fig. 1. Location of Mt. Moulton in West Antarctica. Also shown are locations of the Vostok, EPICA Dome C, EDML, Dome Fuji and Taylor Dome deep ice core sites in East Antarctica.

2. Methodology

Mt. Moulton BIA is located in the Flood Range of Marie Byrd Land in West Antarctica (76°4′S, 134°42′W) at an elevation of 2820 m above sea level (Figs. 1 and 2). The BIA formed on the southern shoulder of Mt. Moulton as a result of a nunatak (Prahl Crags) obstructing ice flow from the summit (Dunbar et al., 2008). The ~600 m of exposed ice contains more than 40 volcanic tephra layers distributed over the last ~500 ka. The geochemical composition of the tephra layers suggests that most of them were derived from Mt. Berlin, located 20 km from Mt. Moulton (Wilch et al., 1999; Dunbar et al., 2008).

Forty-two meters of the Mt. Moulton ice trench were melted using the University of Maine continuous melting system (Osterberg et al., 2006) at a sample resolution of ~0.8–1 cm. There are three gaps in the melted section totaling 1.62m. Each block of ice (~50 cm length) extracted from the horizontal trench was cut into 3.5 × 3.5 cm sections. The ends of each ice block were scraped using a clean ceramic knife before melting to prevent contamination. Samples were collected from the inner and outer parts of the samples. To avoid contamination only the inner portion of each sample was used for major anion and trace element analysis. The meltwater from the potentially contaminated outer part was collected for stable isotope analysis.

All 3795 samples were analyzed for their soluble major anion content (Cl^-, NO_3^-, SO_4^{2-}) by ion chromatography (IC) and for major and trace elements (Na, Mg, Ca, Sr, Cd, Cs, Ba, La, Ce, Pr, Pb, Bi, U, As, Al, S, Ti, V, Cr, Mn, Fe, Co, Cu, Zn) by inductively coupled plasma sector field mass spectrometry (ICP-MS). Major anions were analyzed on a Dionex DX-500 ion chromatograph coupled to a Gilson autosampler, and concentrations are reported in ug/L (ppb). Major and trace elements analyses were performed with the UMaine Thermo Electron Element2 ICP-MS coupled to a Cetac Model ASX- 260 autosampler. Concentrations are reported in ug/L (ppb), ng/L (ppt) and pg/L (ppq). The ICP-MS samples were acidified to 1% with double-distilled HNO3 under a class-100 High Efficiency Particle Air (HEPA) clean bench and allowed to react with the acid for approximately 1 week before being frozen. Approximately every fifth sample (713 total) was analyzed for δD by isotope ratio mass spectrometry (IRMS) using a Micromass Isoprime mass spectrometer. Data are reported in delta (δ) notation relative to standard mean ocean water (SMOW).

The sampled section contains several englacial tephra layers, three of them have been dated by $^{40}Ar/^{39}Ar$ radiometric dates: BIT-158 (104.9 ± 0.6 ka), BIT-160 (118.1 ± 1.3 ka) and BIT-162

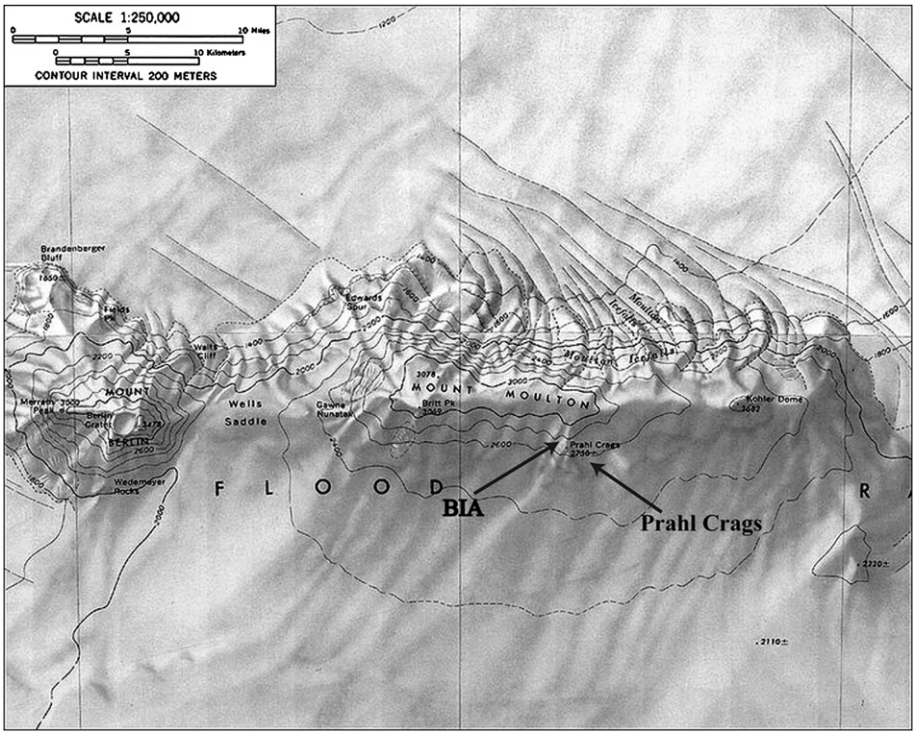

Fig. 2. U.S. Geological Survey topographic map of Mt. Moulton and Mt. Berlin. The locations of the Mt. Moulton BIA and rock outcrop of Prahl Crags are shown.