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Meteoritic and bedrock constraints on the glacial history of Frontier Mountain in northern Victoria Land, Antarctica

K.C. Welten [a,*], L. Folco [b], K. Nishiizumi [a], M.W. Caffee [c], A. Grimberg [d,e], M.M.M. Meier [d], F. Kober [d]

[a] Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA
[b] Museo Nazionale dell'Antartide, Università di Siena, Via Laterina 8, I-53100 Siena, Italy
[c] PRIME Lab, Purdue University, West Lafayette, IN 47907, USA
[d] Isotope Geology, ETH Zurich, CH-8092 Zurich, Switzerland
[e] Institute of Physics, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland

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ABSTRACT

In 2001, a small H4 chondrite, Frontier Mountain (FRO) 01149, was found on a glacially eroded surface near the top of Frontier Mountain, Antarctica, about 600 m above the present ice level. The metal and sulphides are almost completely oxidized due to terrestrial weathering. We used a chemical leaching procedure to remove weathering products, which contained atmospheric ^{10}Be and ^{36}Cl in a ratio similar to that found in Antarctic ice. The FRO 01149 meteorite has a terrestrial age of 3.0±0.3 Myr based on the concentrations of the cosmogenic radionuclides ^{10}Be, ^{26}Al and ^{36}Cl. This age implies that FRO 01149 is the oldest stony meteorite (fossil meteorites excluded) discovered on Earth. The noble gas cosmic ray exposure age of FRO 01149 is ~30 Myr. The meteorite thus belongs to the 33 Myr exposure age peak of H-chondrites.
The bedrock surface on which FRO 01149 was found has wet-based glacial erosional features recording a former high-stand of the East Antarctic ice sheet. This ice sheet evidently overrode the highest peaks (>2800 m a.s.l.) of the inland sector of the Transantarctic Mountains in northern Victoria Land. We argue that FRO 01149 was a local fall and that its survival on a glacially eroded bedrock surface constrains the age of the last overriding event to be older than ~3 Myr. The concentrations of in-situ produced cosmogenic ^{10}Be, ^{26}Al and ^{21}Ne in a glacially eroded bedrock sample taken from near the summit of Frontier Mountain yield a surface exposure age of 4.4 Myr and indicate that the bedrock was covered by several meters of snow. The exposure age is also consistent with bedrock exposure ages of other summit plateaus in northern Victoria Land.

1. Introduction

More than 30,000 meteorites have been found in Antarctica, mainly concentrated on blue ice fields bounded by the Transantarctic Mountains on one side and the Yamato, Sør Rondane and Grove Mountains on the other side. One of these meteorite stranding surfaces, on which more than 700 meteorites have been found, is Frontier Mountain (~72° 59′ S, ~160° 20′ E). The terrestrial ages of Frontier Mountain (FRO) meteorites are generally <200 kyr, with the exception of one meteorite having an age of ~530 kyr (Welten et al., 1999, 2001, 2006). Folco et al. (2002, 2006) recently reviewed the local glaciology and meteorite concentration mechanism operating at Frontier Mountain.

The chronological reconstruction of the Antarctic ice sheet is a key element in our understanding of global climatic changes from Late Tertiary to present. We show here that Antarctic meteorites can survive terrestrial weathering long enough to provide independent chronological constraints on the evolution of the Antarctic ice sheet. We discuss the terrestrial age of a FRO meteorite and surface exposure age of the bedrock surface.

2. Local geology and glaciology

Frontier Mountain (Fig. 1) is a ~9 km northwest–southeast trending ridge of the Outback Nunataks within the Transantarctic Mountains in northern Victoria Land (NVL). The mountain, culminating at 2804 m a.s.l., projects for as much as ~600 m above the ice sheet descending northeastward from the Polar Plateau toward the upper sector of the outlet Rennick Glacier, and represents one of the most inland and highest obstacles to the seaward flow of the East Antarctic Ice Sheet in NVL. The mountain is mainly ice-free and consists of felsic granitoids belonging to the Granite Harbour Intrusive Complex (Gunn and Warren, 1962). During a geomorphological survey in December 2001, a 1.5 g H4 chondrite, FRO 01149 (Fig. 2), was found on top of Frontier Mountain by a team of the Italian Programma Nazionale di Ricerche in Antartide (PNRA) (Ferraris et al., 2003). The meteorite was

* Corresponding author. Tel.: +1 510 643 1433; fax: +1 510 643 7629.
E-mail address: kcwelten@berkeley.edu (K.C. Welten).

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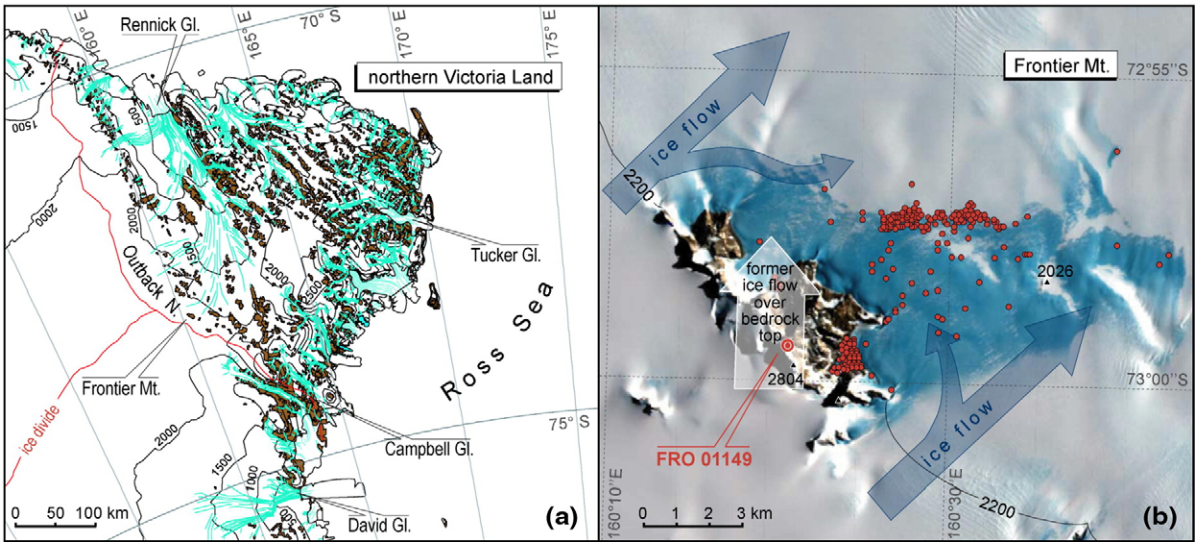

Fig. 1. a) Map of northern Victoria Land. Brown areas represent exposed bedrock. Blue lines show ice flow; red lines mark ice-divides. b) Map of the Frontier Mountain meteorite trap showing the recovery site of the FRO 01149 meteorite relative to other FRO meteorites (red dots) found on the blue ice.

found on a glacially eroded bedrock surface (Fig. 3) at an altitude of ~2775 m. A second search effort on top of Frontier Mountain in 2003 did not yield additional specimens, suggesting that this meteorite is a local fall rather than a specimen from a fossil meteorite stranding site or a member of a large shower. The bedrock surface shows the glacial marks of a past ice sheet overriding Frontier Mountain (Höfle, 1989). Here, decametric roches moutonnées are common mesoscale landforms, together with rare streamlined bedrock ridges with arcuate longitudinal profiles resembling miniature whalebacks (Fig. 3b); small-scale erosional forms are polishes, bearing striae and fission cracks (Fig. 3b–d). These landforms indicate glacial erosion produced by the abrasion of large amounts of debris transported within the basal ice of a fast-flowing, warm-based glacier of at least many tens of meters in thickness (Bennet and Glasser, 1996; Benn and Evans, 1998; James, 2003). Glacial striae and streamlined bedrock ridges trend north–south, the plucked lee sides of roches moutonées face northward and crescent gouges have southward dipping steep arcuate faces, thus recording a northward ice flow. The lack of a snow accumulation zone at the top of Frontier Mountain (Figs. 1 and 3) excludes the possibility that these landforms resulted from the dynamics of a local glacier. Geomorphological data from the FRO 01149 find site thus indicate that Frontier Mountain was overridden by the East Antarctic ice sheet in an overall northward direction during a past glaciation, in agreement with previous work (Delisle et al., 1989; Höfle, 1989). Glaciological features analogue to those observed at Frontier Mountain were found previously (Höfle, 1989) at the summit of the highest peaks in the Outback Nunataks (Fig. 1), including Roberts Butte (2828 m a.s.l.), Miller Butte (2610 m a.s.l.) and Mount Bower (2610 m a.s.l.), thereby indicating that the evidence of such a high ice stand of the East Antarctic ice sheet relative to bedrock is recorded at a regional scale. A bedrock exposure age of 2.3 ± 1.3 Myr was reported for Roberts Butte, while other peaks in NVL show exposure age >5 Myr, thus constraining the last overriding of the Outback Nunataks (Van der Wateren et al., 1996, 1999) to the late Miocene/early Pliocene.

3. Sample description and analytical methods

Although more than 50% of the surface of FRO 01149 is still covered with fusion crust, the meteorite shows almost complete oxidation of the metal and sulfides, corresponding to weathering degree W4 (Wlotzka, 1993). In this work we measured concentrations of the light noble gases, cosmogenic radionuclides ^{10}Be (half-life = 1.36×10^6 yr), ^{26}Al (7.05×10^5 yr), ^{36}Cl (3.01×10^5 yr) and ^{41}Ca (1.04×10^5 yr) in FRO 01149. We also measured in-situ produced cosmogenic nuclides ^{26}Al, ^{10}Be and ^{21}Ne in quartz from a glacially

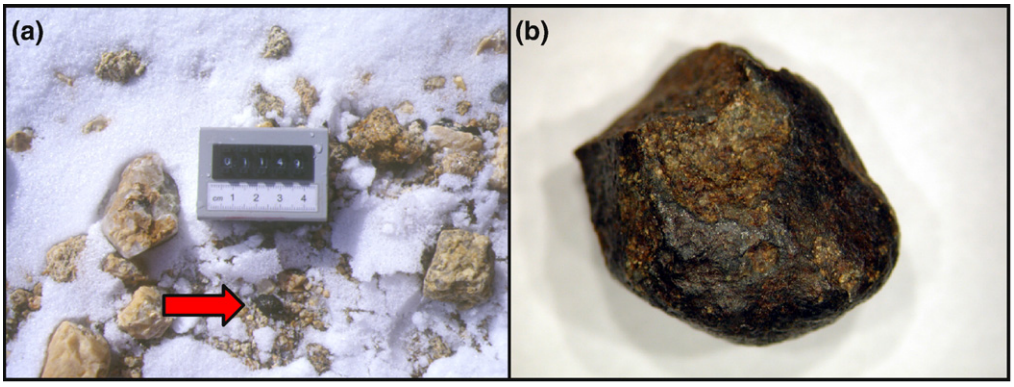

Fig. 2. Pictures of FRO 01149 H-chondrite as found in the field (a) and close-up (b). Picture b shows that FRO 01149, which measures 1.5 × 1 × 1 cm and is quite weathered, retained more than 50% of its fusion crust.