A tephra chronostratigraphic framework for the Frontier Mountain blue ice field (northern Victoria Land, Antarctica)

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Summary Englacial tephra are chronostratigraphic markers of the Antarctic ice sheet. Structural, mineralogical, geochemical and geochronological data on selected samples allowed the reconstruction of a chronostratigraphic framework for the Frontier Mountain blue ice field – an important meteorite trap on the southeastern flank of Talos Dome in Victoria Land. The stratigraphic thickness of the ice succession is ~1150 m. The ^{40}Ar-^{39}Ar age of one layer close to the stratigraphic bottom is 100±5 ka and constrains the maximum age of the bulk of Frontier Mountain blue ice. This work lays the foundations for a detailed investigation of ~100 ka of explosive volcanism in Victoria Land. Furthermore, in light of the ongoing ice core drilling project at Talos Dome, the Frontier Mountain ice succession may become important for establishing regional correlations, for sampling and dating key tephra layers, and for selecting ice successions for high-resolution studies of past atmospheric chemistry and fall out.

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Introduction

Blue ice fields are peculiar features of the Antarctic plateau: extending for tens to thousands of km^2, they account for 1% of the surface of the Antarctic continent (Bintanja, 1999). They are characterized by negative surface mass-balance, inducing exhumation of deep ice. Blue ice fields are of great interest for the scientific community since they bear extraordinary meteorite concentrations (e.g., Cassidy et al. 1992; Harvey 2003); they are also of potential interest because they represent natural "windows" into relatively old ice of the Antarctic ice sheet, thus offering easy access to paleoenvironmental records which are complementary to those from ice cores (Bintanja, 1999). The reconstruction of the chronostratigraphy of the ice cropping out in blue ice fields represents, however, the first requirement for their use as archives of the past atmospheric chemistry and fall out.

Tephra layers occur embedded in the Antarctic ice sheet. They are commonly found in ice-cores (e.g., Dunbar et al., 2003; Narcisi et al., 2006, and references therein) and blue ice fields (e.g., Perchiazzi et al., 1999, and references therein). Tephra layers are isochronous planes of the Antarctic ice sheet, correlated across wide distances (Smellie, 1999), possibly up to hundreds kilometres, or more. As such, they have long been regarded as potential chronostratigraphic markers of the Antarctic ice sheet, possibly enabling reconstruction of ice successions up to a regional scale and providing independent age constraints for glaciological modelling of core timescales.

We present a structural, morphometrical, geochemical and ^{40}Ar/^{39}Ar geochronological study of selected tephra layers from the Frontier Mountain blue ice field – a well-known meteorite trap in northern Victoria Land (Delisle et al., 1989; Folco et al., 2002). Tephra layers were mapped and sampled during the 1995, 1997, 1999 and 2001 Antarctic Campaigns of the Italian *Programma Nazionale delle Ricerche in Antartide*, PNRA. This work provides the overall structure of the ice body in the area, along with a framework of the ice stratigraphy and a maximum age for the reconstructed ice succession. Implications for regional-scale stratigraphic correlations and meteorite trapping mechanism are also discussed.

Glaciological Outline

Several PNRA field campaigns have been carried out at the Frontier Mountain blue ice field to study the meteorite concentration mechanism, and many glaciological data are available (Folco et al., 2002). Frontier Mountain (~72°59' S, 160°20' E) is a nunatak within the Transantarctic Mountains, located at the edge of the polar plateau (Outback Nunataks region) in the inland catchment of the upper Rennick Glacier (Fig. 1a). It is a 9 km long and 2804 m high, NW-SW trending ridge built up by granitoids, pegmatites and aplites of the Granite Harbour intrusive complex (Gunn and Warren, 1962), which rises for ~600 m above the ~2200 m regional ice level. On its regional northeastward flow from the Polar Plateau towards the outlet Rennick Glacier, ice flows past both ends of Frontier Mountain at velocities in excess of 1 m yr^{-1}. Downstream of Frontier Mountain, turbulent south-southwesterly katabatic winds form a ~40 km^2 blue ice area which undergoes relatively high ablation (avg. 6.5±2 cm yr^{-1}). The ice removed by ablation is replenished by ice from the Polar Plateau which flows around both ends of the mountain. The two ice flows meet along a shallow (less than few tens of meters below the average altitude of the blue ice field of ~2070 m), east-west trending, curvilinear ice depression. As such, the overall topography of the blue ice field can be described as a shallow, east-west trending ice valley whose flanks are the fronts of the southern and northern ice flows. The ice depression runs over a shallow (~100-200 m below ice surface) sub-ice bedrock crest. Horizontal velocities of the ice decrease to <10 cm yr^{-1} on approaching the submerged obstacle, giving rise to a meteorite stranding surface. An ice divide located 15-20 km due west of Frontier Mountain on the southeastern flank of Talos Dome (72°47'14" S, 159°04'2" E; 2318 m WGS84 elevation; ~60 km due north-west of Frontier Mountain; Frezzotti et al., 2004) limits the drainage area of the Frontier Mountain ice field.

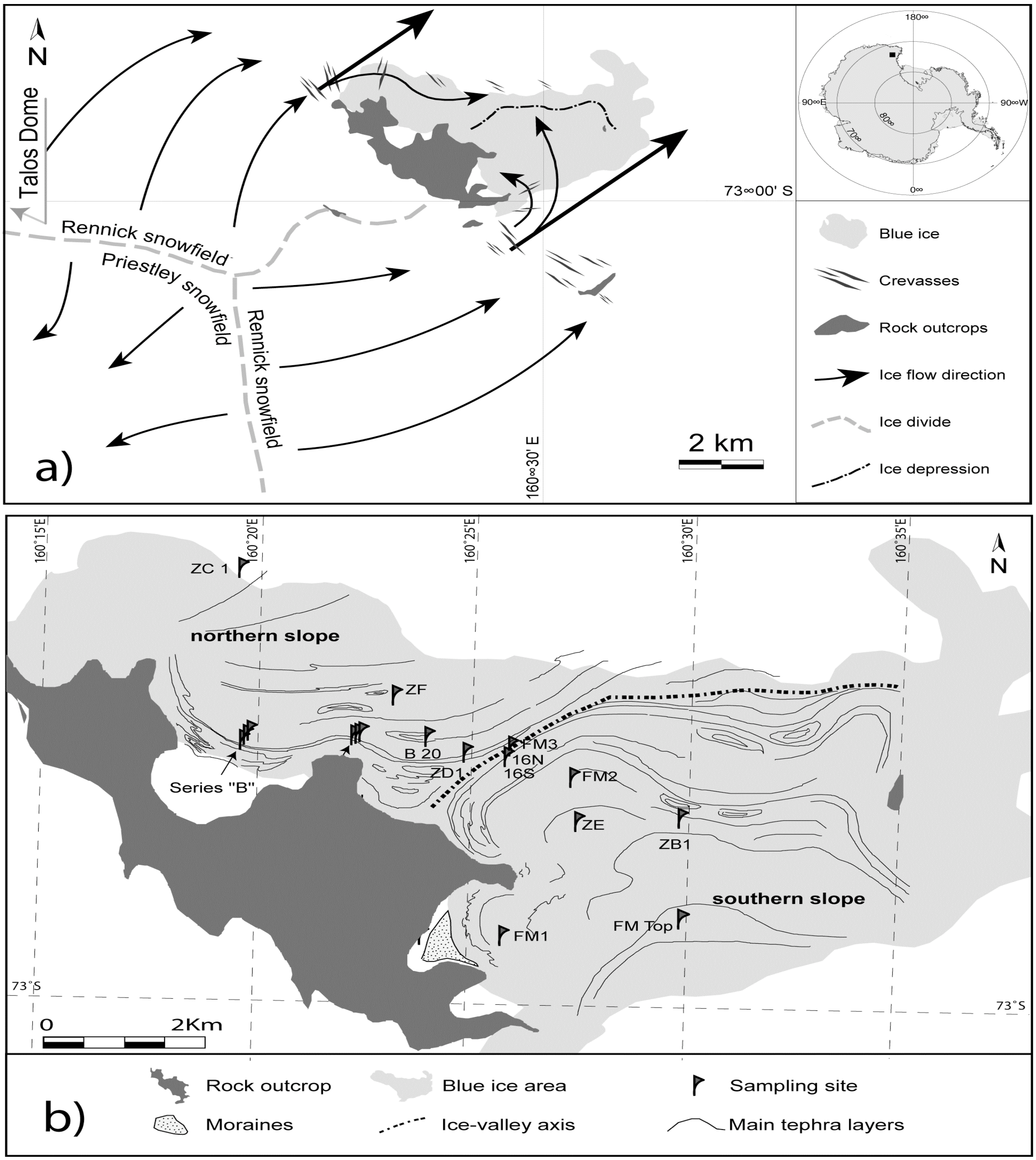

Figure 1. a) Location map of the Frontier Mountain blue-ice field in respect with main ice divides and local flow directions. b) Map of the Frontier Mountain blue-ice field, with sample locations, major tephra layers contours and indication of the sampling sites.

Tens of englacial tephra layers are exposed in the blue ice field, at the fronts of both the northern and southern ice flows (Fig. 1b). They crop out as cm-thick, dark, dusty bands which mark the surface of the ice field for up to several kilometres, highlighting the ice stratigraphy and deformation of the ice flows.

Discussion and summary

1) Structural, mineralogical, geochemical and geochronological data on englacial tephra layers (Fig. 1) allowed us to reconstruct a glacial chronostratigraphic framework of the Frontier Mountain blue ice field. To our knowledge, this is the first tephra chronostratigraphic reconstruction of an Antarctic blue ice area.
2) The geometry of the tens of tephra layers mapped in the field allowed us to define the overall structure of the two ice flows nourishing the Frontier Mountain blue ice field. In particular, both the ice flow from the south and the one from the north can be described as up-glacier monoclines (with severe deformation only at their fronts).
3) The mineralogical, morphometrical and geochemical analysis of 22 representative layers demonstrated that each layer has characteristic features which enable us to define coherent ice successions and establish stratigraphic correlations amongst the two ice flows. The calculated stratigraphic thickness of the ice succession cropping out at the Frontier Mountain blue ice is ~1150 m. This succession is entirely exposed at the surface of the northern flow; only the first ~1000 m of the succession crop out at the surface of the southern flow instead.
4) Two tephra layers were dated using the $^{40}Ar/^{39}Ar$ geochronological method. The age of one layer close to the stratigraphic bottom of the ice succession is 100±5 ka and constrains the maximum age of the bulk of Frontier Mountain blue ice. The age of the second layer at a depth of ~950 m in the stratigraphic succession indicates that >90% of the ice currently under ablation at Frontier Mountain is younger than 49±11 ka.
5) Particle size and compositional data relate the 22 sampled layers to source volcanoes within the Cenozoic alkaline magmatism associated with the West Antarctic Rift System (e.g., Lemasurier and Thomson, 1990). In particular, the relatively large particle size (up to several tens of microns) indicates a proximal source (Lisitzin, 1996). Geochemical and geochronological data match literature data for the Mount Melbourne, Mount Rittmann and The Pleiades lavas, suggesting that these three emission centers (amongst the closest centers to Frontier Mountain, within a ~250 km radius) are the best candidate source volcanoes. Note the possible correlation between the 49±11 ka old 16S tephra layer and a 48±2 ka trachytic eruption from The Pleiades (sample #25702; see Kyle, 1982, and Esser and Kyle, 2002). The chronostratigraphic framework of the Frontier Mountain blue ice field here reported lays the foundations for a detailed reconstruction of ~100 kyr of explosive volcanism in northern Victoria Land.
6) In light of the ongoing ice core drilling project at Talos Dome (Frezzotti et al., 2004), the Frontier Mountain ice succession may become important for establishing regional-scale correlations from snow accumulation to ablation zones in the Rennick Glacier area, for calibrating time-depth profiles of the ice sheet through sampling and dating of key tephra layers, and for high-resolution past atmospheric chemistry and fall out through sampling of selected ice successions. In particular, the succession around the last interglacial-glacial-interglacial transition are currently of great scientific interests for paleoclimatic studies.
7) The fact that the age of the Frontier Mountain blue ice overlaps with terrestrial ages of meteorites found thereon (up to 140±30 ka; Welten et al. 2006: Folco et al., 2006) is consistent with a mechanism of exhumation of meteorites in the blue ice field by ablation after englacial transport from snow accumulation areas (e.g., Cassidy et al., 1992; Folco et al., 2002).

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