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Last glacial tephra layers in the Talos Dome ice core (peripheral East Antarctic Plateau), with implications for chronostratigraphic correlations and regional volcanic history

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A B S T R A C T

Tephra isochrons offer considerable potential for correlating diverse palaeoarchives and highlighting regional climatic differences. They are especially useful when applied to polar ice records encompassing the last glacial, as these clearly portray the pronounced millennial-scale climate variability that characterised this period. Here we present the continuous record of primary fallout tephra layers in the East Antarctic Talos Dome ice core (72°49′S, 159°11′E), developed upon examination of the core sections spanning the glacial period 16.5 to 71 ka. A total of ca. 45 discrete tephra deposits precisely positioned stratigraphically relative to the temperature record for the core and dated using the AICC2012 timescale, were identified. Quantitative grain size, particle morphology, major and trace element composition using Coulter Counter, SEM, EPMA-WDS, and LA-ICP-MS analytical methods were studied as diagnostic features for tephra characterisation. The tephrostratigraphic framework provides a reference for future precise comparison between ice and sediment sequences across the Antarctic continent. Indeed, several potential markers characterised by distinct volcanic glass geochemistry and/or particular stratigraphic location (e.g., a 17.6-ka ash layer deposited during the well-known major acidity event) are now available for the direct linkage of palaeoclimatic archives. The Talos Dome tephra sequence, dominated by mid-distal pyroclastic products from the nearby Northern Victoria Land volcanoes, also represents the most comprehensive and best time-constrained record of regional Antarctic volcanism yet developed. It documents nearly continuous sustained explosive activity during the considered time interval and, combined with previous ice-core tephra results for the last and the current interglacial periods, suggests progressive compositional shift through time.

1. Introduction

A few decades after the pioneering work of S. Thorarinsson (1981), and particularly with the advent of analytical techniques for the characterisation of fine-grained single volcanic particles, tephra studies have become one of the most powerful tools in Quaternary research (Lowe, 2011, and references therein). Due to virtually instantaneous deposition of volcanic ash, and especially when the material exhibits distinctive features and regionally extensive distribution far beyond the volcanic edifice, this method has unique capabilities to establish accurate correlations between diverse and distant archives and to improve the chronology of past environmental changes. In addition to chronostratigraphic tasks, the tephra approach provides important constraints on frequency, style and composition of past volcanic activity that are essential for predicting future volcanic hazards, particularly in contexts as glaciated regions where pyroclastic deposits in the source area may not be available (Ponomareva et al., 2015, and references therein; Smellie, 1999).

Polar ice sequences hold valuable information on past climates and volcanism (Robock, 2000; Sigl et al., 2015). TALDICE (72°49′S, 159°11′E; 2315 m), the long ice core drilled at Talos Dome with the aim of documenting the regional variability of Antarctic palaeoclimate, preserves a significant tephra archive due to its mid-distal location relative to regional explosive volcanism, overall good quality of the core and unmodified stratigraphic order, and robust

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independent dating of tephras and of various proxies for past changes (Fig. 1). The high accumulation rate of this East Antarctic core site (~80 mm water equivalent per year) relative to more inland locations of the Plateau provides an ideal location for developing a well-resolved record of primary fallout. Earlier studies have focused on the Holocene (Narcisi et al., 2001, 2012) and the Eemian interglacial section (Narcisi et al., 2016) and preliminary findings of the 70 ka volcanic record have also been reported (Narcisi et al., 2010a). These studies have shown the potential of this core for developing a tephrostratotype record for the Ross Sea sector of the Antarctic region. Northern Victoria Land volcanoes, located within a radius of ~250 km from Talos Dome (Fig. 1c) and associated with the active West Antarctic Rift System, are the major tephra contributors. These volcanoes were the site of volcanic activity of alkaline character over Quaternary times (Wörner, 1999).

This paper presents the inventory of tephra layers deposited in the last glacial between 17 and 64 ka BP. This is a period characterised by strong millennial-scale climate variability identified worldwide including polar ice sheets from both hemispheres (Blunier and Brook, 2001; Wolff et al., 2010). Specifically, the Antarctic temperature record appears punctuated by several warm events named Antarctic Isotope Maxima (AIM) that are obviously coupled with the Greenland Dansgaard-Oeschger events by the “bipolar see-saw” mechanism (EPICA Community Members, 2006; Landais et al., 2015; WAIS Divide Project Members, 2015). Important regional differences notwithstanding, this temperature pattern is clearly recorded also in the Talos Dome ice core as a direct response to the Greenlandic record (Stenni et al., 2011; Buiron et al., 2012) (Fig. 1). As such, the TALDICE tephra record of this critical period is of interest, given the prospects for identifying well-constrained tephra markers for confident stratigraphic correlations. The ultimate goal of tephra investigations is the independent alignment of diverse palaeoclimatic records in order to compare the expression of the rapid climatic events in different sectors of the Antarctic region. The tephra approach was already successfully employed to link last glacial proxy signals in Greenland ice cores and in Atlantic marine sediments (e.g. Davies et al., 2010). Moreover, since the available information for the activity of the local Antarctic volcanoes is very fragmentary for the investigated time period (e.g. Kyle, 1982), the present study aims to add to palaeovolcanic knowledge through an accurate temporal and compositional perspective.

2. Materials and analytical techniques

This investigation focuses on the ice core sections between 800 and 1300 m depth (Fig. 1) that were drilled during the 2006-07 field season. 43 deposits were considered and characterised (Supplementary Table 1). The majority of studied layers were located during core logging and processing as visually distinguishable from clear embedding ice. Their macroscopic appearance, showing a wide range of colour and thickness, was routinely documented with pictures (Supplementary Fig. 1). A few volcanic horizons too faint to show up to the naked eye (<1 mm thick) were identified during Coulter Counter (CC) granulometric measurements for continental dust studies. These samples showed anomalous features either as mass concentration or as grain size values, compared to typical aeolian dust in East Antarctic ice (e.g. Albani et al., 2012; Narcisi et al., 2010a) and through subsequent microscopic observations they proved to contain significant concentrations of well-preserved glass shards. No systematic search for crypto-tephra deposits was carried out in the present study, but this is planned for the near future.

The ice core sub-samples containing tephra layers were processed for ash recovery following laboratory protocols suited for the typically low concentration of volcanic particles in Antarctic tephras as well as their fine grain size, and successfully employed in former ice-core studies (e.g. Delmonte et al., 2002; Narcisi et al.,

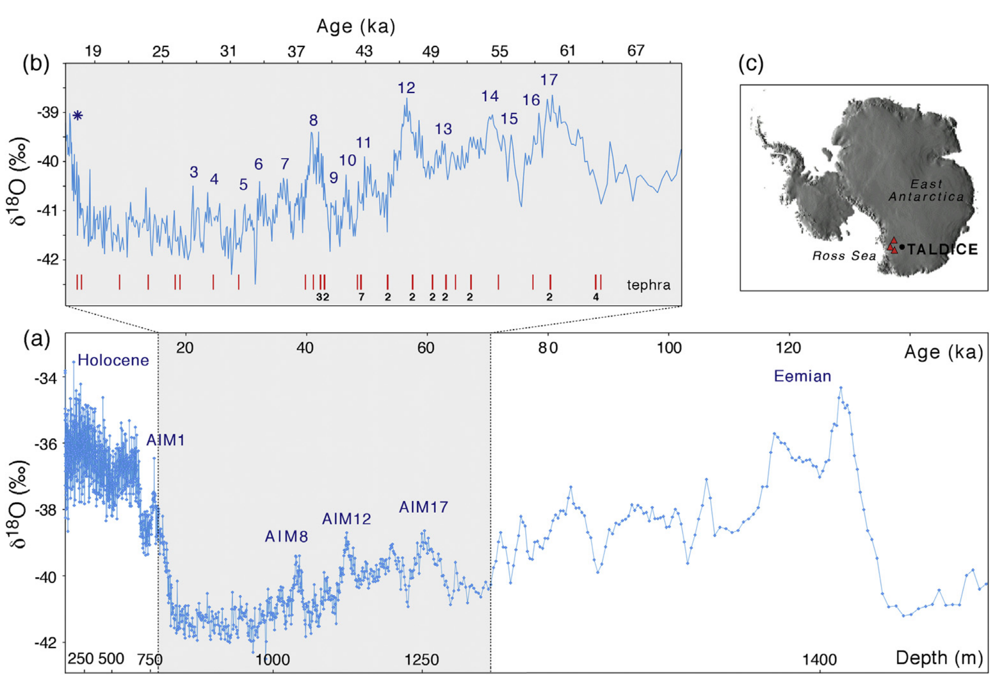

Fig. 1. (a) 1-m TALDICE stable isotope profile (Stenni et al., 2011) related to last glacial-interglacial climatic cycle vs. AICC2012 age (Veres et al., 2013) and depth, with the main climatic events indicated. Shading highlights the interval studied within this work. (b) Stratigraphic position of the tephra layers identified in this work (red bars, with indication of the number of closely timed horizons) relative to the $\delta^{18}O$ record vs. age. AIM climatic events (blue numbers) and the ‘fluoride main event’ (asterisk) are marked. (c) Satellite image of Antarctica with location of the ice core and local volcanoes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)