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A 16,000-yr tephra framework for the Antarctic ice sheet: a contribution from the new Talos Dome core

Biancamaria Narcisi [a,*], Jean Robert Petit [b], Barbara Delmonte [c], Claudio Scarchilli [a], Barbara Stenni [d]

[a] ENEA, C.R. Casaccia, 00123 Roma, Italy
[b] LGGE, CNRS-UJF, Grenoble, France
[c] DISAT, Univ. Studi Milano-Bicocca, Milano, Italy
[d] Department of Mathematics and Geosciences, Univ. Trieste, Trieste, Italy

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A B S T R A C T

A detailed tephra record for the last 16,000 years of the TALDICE ice core drilled at Talos Dome (East Antarctica, Pacific/Ross Sea sector) is documented. Traces of 26 different explosive volcanic eruptions, dated by ice core chronology and framed within the climate ($\delta^{18}O$) record for the core, have been identified. Glass major element composition and grain size data indicate that all prominent tephra layers derive from Antarctic volcanic activity and likely originated in proximal volcanoes of the Melbourne Volcanic Province (Northern Victoria Land). Two other Antarctic horizons may have originated from the more distant volcanoes of Mount Berlin (Marie Byrd Land, West Antarctica) and Mount Erebus (Ross Island, Southern Victoria Land). Moreover, based on glass-shard geochemistry and a 20-year analysis of atmospheric back trajectories suggesting ash transport from South America to the drilling site by the circumpolar westerly circulation, a few faint microtephra horizons are attributed to Andean volcanic activity. Two of these tephras are interpreted to be related to known Holocene explosive eruptions from the volcanoes of Mount Hudson and Mount Burney. Finally, by comparing compositional features in conjunction with age data, three TALDICE tephras have been successfully correlated with volcanic layers in other ice records of the Antarctic ice sheet. Altogether, our results expand the Antarctic tephrostratigraphic framework and add value to the prospects for continental-scale correlations between ice cores and Southern Hemisphere sediment archives.

1. Introduction

In recent decades, tephrochronology has become increasingly important due to its capability to solve issues from disparate disciplines (e.g. Lowe, 2011; and references therein). Tephra layers form isochronous surfaces on a geological timescale. If distinctive in one or more properties and sufficiently widespread, they represent valuable stratigraphic tools for correlation and dating of geological sequences. Among the diverse depositional archives that can potentially contain tephras, polar ice sheets provide unique detailed long records of past climate and atmospheric composition (e.g. Jouzel et al., 2007; Loulergue et al., 2008). Tephra studies of polar ice cores have already proved to be successful in synchronising palaeoclimate signals from widely spaced records (e.g. Davies et al., 2010), in refining timescales obtained by glaciological modelling (e.g. Narcisi et al., 2006), and in providing complementary information on past atmospheric circulation patterns (e.g. Fiacco et al., 1993).

Tephra investigations of the TALDICE ice core, drilled from the Ross Sea sector of the East Antarctic plateau, offer significant potential for palaeovolcanic and palaeoclimatic reconstructions. This 1620-m long core contains more than 100 volcanic horizons deposited over the past 250,000 years, with average frequency of the visible tephra layers estimated to be one order of magnitude greater than the ones found in deep ice cores from central East Antarctica over the last two glacial cycles. As such, the very rich tephra dossier preserved at TALDICE provides clues on eruption history of nearby volcanoes (Narcisi et al., 2010a). The TALDICE ice core is also a remarkable palaeoclimatic archive, as it holds an uninterrupted record of climate and environmental changes back to Marine Isotope Stage (MIS) 7.5, ~250 ka (Schilt et al., 2010; Stenni et al., 2011). In particular, owing to its relatively high accumulation rate, this core offers a climate record at decadal-scale resolution since the last climatic transition, a period characterised by dramatic and rapid changes throughout the world. TALDICE has been

* Corresponding author.
E-mail addresses: biancamaria.narcisi@enea.it (B. Narcisi), petit@lgge.obs.ujf-grenoble.fr (J.R. Petit), barbara.delmonte@unimib.it (B. Delmonte), claudio.scarchilli@enea.it (C. Scarchilli), stenni@units.it (B. Stenni).

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included in recent comparisons of Antarctic climate records covering the last deglaciation (Stenni et al., 2011) and the present interglacial (Masson-Delmotte et al., 2011) to document past natural variability and time relationship with Northern Hemisphere ice sheet deglacial history, and to identify mechanisms and processes lying behind the observed fluctuations. These studies have shown that, within a general homogeneous pattern, spatial climate variability related to local and regional factors is significant within the Antarctic continent. In this context, further work aimed at inspecting inter-site climate differences could benefit much from tephrochronological investigations. In fact tephra correlations between palaeorecords have several advantageous properties: a) they are independent of climate and can be scattered within the climate record, b) can potentially involve different types of archives geographically spread within the Southern Hemisphere, c) their application for matching is less subjective than the use of volcanic sulphate spikes, that moreover can be recorded only in ice cores, and d) provide time planes circumventing the problem related to the lack of coherent timescales for the compared records.

Despite the fact that several Antarctic tephra records encompassing the last deglaciation and/or the present interglacial (Holocene) have been already presented (e.g. Smellie, 1999; and references therein), to date the potential of continental-scale tephra correlations has not been fully exploited. The best example of a Holocene volcanic marker across Antarctica remains the 3.5-ka tephra from South Sandwich Islands (southern Atlantic Ocean), which was originally identified in Vostok and South Pole ice cores (Palais et al., 1987) and recently detected also in the EPICA-Dome C (hereafter EDC) record (Narcisi et al., 2005). No tephra correlations linking the Antarctic ice with Southern Hemisphere sediment sequences have been presented thus far.

Here, we present the results of a tephra investigation carried out throughout the last deglaciation and Holocene sections of the TALDICE ice core, with the purpose of expanding the Antarctic tephrostratigraphic framework. We provide a detailed tephra inventory for this site including visible and non-visible ash layers. We then propose source attribution and tephra correlations between sequences of the South polar region, based on the comparison of chronological information and major element geochemical data and using particle size characteristics and the results of back trajectory studies as supplementary arguments.

Table 1
Details for the identified tephra-bearing horizons.

Sample	Visible	Bottom depth (m)	Age yr BP[a]	Maximal grain size (μm)	Method for single shard chemical analysis	Suggested source
TD85	x	84.37	670 ± 7	100	WDS	Melbourne
TD87	x	86.20	694 ± 7	80–90	WDS	Melbourne & Mt Berlin
TD193		192.25	2021 ± 66	10	EDS	Mt Hudson
TD210		209.50	2267 ± 59	15	EDS	Melbourne
TD216		215.50	2355 ± 54	<10	EDS	South American – possibly Mt Hudson
TD238	x	237.31	2684 ± 47	80	WDS	Melbourne
TD239	x	238.12	2699 ± 48	100–150	WDS	Melbourne
TD281		280.27	3375 ± 82	80	EDS	Melbourne
TD282		281.50	3392 ± 82	10	EDS	South American – possibly Puyehue-Cordón Caulle
TD299		298.25	3677 ± 92	10	EDS	Mt Burney
TD341		340.25	4420 ± 88	10	EDS	Extra-Antarctic unidentified
TD388-1	x	387.76	5277 ± 49	60	WDS	Melbourne
TD388-2	x	387.77	5277 ± 49	40	WDS	Melbourne
TD504		503.25	7570 ± 144	10	EDS	Melbourne & possibly Mt Erebus
TD554		554.00	8792 ± 193	20	EDS	Melbourne
TD642		641.75	10,900 ± 151	100	EDS	Melbourne
TD655		654.50	11,199 ± 137	15–20	EDS	Extra-Antarctic unidentified
TD662	x	661.86	11,364 ± 132	50	WDS	Melbourne
TD667		666.40	11,476 ± 128	15	EDS	Extra-Antarctic unidentified
TD681	x	680.78	11,820 ± 128	60–80	WDS	Melbourne
TD720	x	719.78	13,010 ± 127	40	WDS	Melbourne
TD741	x	740.34	13,771 ± 131	100–150	WDS	Melbourne
TD779	x	778.07	15,193 ± 145	50–70	WDS	Melbourne
TD783	x	782.59	15,370 ± 150	25	WDS	Melbourne

[a] Age according to Severi et al. (2012), estimated uncertainty from Lemieux-Dudon et al. (2010). BP stands for before 1950 AD.

2. Materials and methods

The European TALDICE project (www.taldice.org) was launched to augment scientific knowledge on palaeoclimate changes in near-coastal regions of the Antarctic ice sheet. For this purpose, a 1620-m long ice core was drilled at Talos Dome (72°49′S, 159°11′E; 2315 m), an ice dome on the eastern edge of the East Antarctic Plateau, during the field seasons 2004–2008. Climatological and glaciological characteristics of the drilling site are reported in Frezzotti et al. (2007) and Masson-Delmotte et al. (2011).

In this work we focused on the core section between 73 and 800 m depth, corresponding to the time period ca 560–16,300 years BP (before present, where present is defined as 1950 AD), with an average age uncertainty of about 100 years. The adopted age scale (Severi et al., 2012) represents a refinement of the first official chronology of the Talos Dome core (Buiron et al., 2011) and was obtained by synchronising the TALDICE volcanic sulphate signals to the EDC record with transfer of the timescale presented by Lemieux-Dudon et al. (2010) to the studied core.

In the considered core interval we located a total of 24 volcanic ash horizons related to primary air fall deposition (Table 1 and Fig. 1). Among them, 12 conspicuous tephra layers were identified during core logging/processing. Salient physical and macroscopic features of TALDICE visible layers were already illustrated in Narcisi et al. (2010a). The narrow ice samples containing visible tephra layers were sub-sampled for subsequent particulate matter recovery. Moreover, in order to complement the inventory of the prominent tephras, about 30 discrete (25 cm long) ice core samples between 73 and 700 m depth were filtered and examined microscopically for the search of primary volcanic material. These samples, formerly analysed for aeolian dust studies (Albani et al., 2012), showed anomalous features, either as mass concentration or as grain size values, compared to typical continental dust in East Antarctic ice. 12 of the investigated ice intervals proved to contain significant concentrations of glass shards showing unmodified typical morphologies and coherent geochemistry (see the discussion in Section 3). Thus, they were considered to be formed directly from volcanic plumes without significant reworking prior to and during deposition on the ice sheet.

All tephra samples were the subject of quantitative grain size measurements by Coulter Counter (Fig. 2), characterisation of particle morphology and determination of maximum grain size by scanning electron microscope (Fig. 3), and chemical analysis by electron microprobe. Chemical (nine major elements) characterisation was performed only on pristine glass particles. Detrital windblown components, significant in some studied samples bearing invisible tephras, and mineral crystals were avoided using