Sedimentary Geology 340 (2016) 49–61

Contents lists available at ScienceDirect

Sedimentary Geology

journal homepage: www.elsevier.com/locate/sedgeo

Expanding the tephrostratigraphical framework for the South Shetland Islands, Antarctica, by combining compositional and textural tephra characterisation

E.J. Liu [a,*], M. Oliva [b], D. Antoniades [c], S. Giralt [d], I. Granados [e], S. Pla-Rabes [f], M. Toro [g], A. Geyer [d]

[a] Department of Earth Sciences, University of Bristol, Wills Memorial Building, Bristol, BS81RJ, UK
[b] Centre for Geographical Studies, Institute of Geography and Spatial Planning, University of Lisbon, Lisbon, Portugal
[c] Dept. Géographie & Centre d'études nordiques, Université Laval, Quebec, Canada
[d] Institute of Earth Sciences Jaume Almera, ICTJA-CSIC, Lluis Solé i Sabaris s/n, 08028 Barcelona, Spain
[e] Centro de Investigación, Seguimiento y Evaluación, Parque Nacional de la Sierra de Guadarrama, Rascafría (Madrid), Spain
[f] Centre for Ecological Research and Forestry Applications (CREAF-CSIC), Cerdanyola del Vallès, Catalonia, Spain
[g] Centre for Hydrographical Studies (CEDEX), Madrid, Spain

ARTICLE INFO

Article history:
Received 29 June 2015
Received in revised form 7 August 2015
Accepted 10 August 2015
Available online 18 August 2015

Keywords:
Tephrostratigraphy
Volcanology
Lake sediments
Antarctica
Livingston Island
Deception Island

ABSTRACT

Tephra layers preserved in lake sedimentary sequences provide valuable isochrons with which to synchronise palaeoclimatic records. However, in regions where tephra inputs are dominated by a single volcanic source, overlapping chemical compositions can preclude unambiguous correlation of tephra layers. In this study, we characterise multiple visible (macrotephra) layers within sedimentary sequences from three lakes in Byers Peninsula, Antarctica. By combining compositional analyses with additional constraints from textural componentry, we identify three distinct tephra isochrons—T1, T2, and T3—each with distinct textural properties. The relative proportion of glassy compared to crystal-rich grains varies from ~50% (T3) to ~3% (T1) of the total sample. Although the proportion of dense to vesicular grains differs only slightly between all sampled tephra layers, the dominant vesicle shape varies from spherical (T3) to irregular and polylobate (T1/T2). These textural differences can be related to variations in the eruptive processes occurring at the Deception Island source volcano. This study highlights the efficacy of a correlative approach based on both chemical and physical tephra properties for deconvolving the tephra stratigraphy in regions where chemical compositions are non-unique.

1. Introduction

Sedimentary sequences, such as those preserved in lacustrine and marine environments, provide archives of environmental processes and can help to reconstruct palaeoclimatic and palaeoecological conditions, particularly in high-latitude regions (e.g., Overpeck et al., 1997; Pienitz et al., 2004; Smol and Douglas, 2007; Bentley et al., 2009). Direct fallout of volcanic tephra from the atmosphere can form discrete deposits within successions of background sedimentation (Lowe, 2011; Fontijn et al., 2014). Primary tephra layers in lake sediments provide important time-markers (isochrons) with which to anchor chronological frameworks, and permit cross-correlations between sedimentary records even where the numerical age of the tephra is uncertain (Thorarinsson, 1944; Lowe, 2011; Fontijn et al., 2014). Furthermore, where there are robust age constraints on the deposition of a particular tephra layer (e.g., from geomagnetic palaeointensity; Willmott et al., 2006), tephrostratigraphic correlations enable the transfer of ages between sequences from different locations (Lowe, 2011).

The chemical 'fingerprint' of a tephra layer (e.g., glass major element composition) is often used to correlate between different sediment records, assuming that the layer represents primary deposition without reworking over long timescales (e.g., Boygle, 1999; Gudmundsdóttir et al., 2011; Oladottir et al., 2011). Nevertheless, miscorrelation may occur if (1) a single volcanic source dominates the volcanogenic input to a catchment (as chemical differences between eruptive deposits can often be subtle), (2) tephras with multiple compositions are erupted during a single eruption, or (3) there is the potential for tephra reworking (e.g., Björck et al., 1991; Hodgson et al., 1998; Lee et al., 2007; Lowe, 2011; Fontijn et al., 2014; Hopkins et al., 2015). Variations in the physical properties of volcanic tephra can be used complementary to compositional analyses to identify specific tephra deposits (e.g., Cioni et al., 2008; Liu et al., 2014). The external morphology of ash particles, and their internal crystal and bubble textures also provide insights into the style of eruption responsible for producing particular tephra horizons, as these ash characteristics are controlled by the magma properties and the conditions under which the magma ascends and erupts

* Corresponding author.
E-mail address: emma.liu@bristol.ac.uk (E.J. Liu).

http://dx.doi.org/10.1016/j.sedgeo.2015.08.002
0037-0738/

(Heiken and Wohletz, 1985; Cioni et al., 2008, 2014; Wright et al., 2012; Andronico et al., 2014; Liu et al., 2015).

In this study, we analyse multiple tephra layers within sedimentary sequences from three lakes in Byers Peninsula (Livingston Island, South Shetland Islands, Antarctica). We combine morphological observations of tephra grains with quantitative textural componentry to inform our interpretation of glass compositional analyses. Using these data, we explore the potential for uniquely characterising tephra horizons in a region where the volcanogenic input is dominated by a single volcanic source. Furthermore, we evaluate whether the sampled tephra layers represent primary fall deposits or have likely been reworked and redeposited from the lake catchments. By combining the results presented in this study with existing age constraints (Björck et al., 1991; Hodgson et al., 1998; Toro et al., 2013), we extend the tephrochronological framework of Byers Peninsula and contribute to the development of a regional tephrochronology in the South Shetland Islands.

2. Geological setting and tephrochronology of the South Shetland Islands

The South Shetland Islands (SSI) are part of a Mesozoic–Cenozoic magmatic arc, separated from the northern Antarctic Peninsula by the Bransfield Strait marginal basin (Fig 1a, b), which opened in response to continental back-arc extension <1.4 Ma (Lawver et al., 1995; Martí et al., 2013). Arc magmatism and subsequent rifting resulted in the development of several active or recently active volcanic centres in the region of the SSI: Deception Island, Penguin Island, Bridgeman Island, several submarine seamounts and numerous remnant volcanic centres on Livingston, Greenwich, and King George Islands (e.g., Fretzdorff and Smellie, 2002; Lee et al., 2007). Holocene volcanic activity in this region has been dominated by eruptions from Deception Island, a composite volcanic system comprising a mostly submerged caldera ~10 km in diameter (e.g., Smellie, 2001; Martí et al., 2013). Deception Island has erupted a wide spectrum of magma compositions from basalt to dacite (along a medium-K tholeiitic series; Lee et al., 2007), with eruptive styles including both magmatic (Strombolian to Plinian) and hydromagmatic activity (Smellie, 1990, 2001; Pedrazzi et al., 2014). The compositional fields of Deception Island eruptives are sufficiently distinct from those of the other volcanic centres in the SSI to be well-characterised on the basis of major element compositions (Björck et al., 1991; Fretzdorff and Smellie, 2002; Lee et al., 2007).

Byers Peninsula is located in the western region of Livingston Island, ~40 km from the Deception Island volcano (Fig. 1b). The peninsula is dominated by a central plateau at an elevation of 40–90 m above sea level, surrounded by Holocene marine terraces and the present-day beach (López-Martínez et al., 2012; Fig 1c). Although once fully glaciated, Byers Peninsula now forms the largest ice-free area in the SSI. Numerous lakes and ponds were formed throughout Byers Peninsula following the retreat of the Rotch Dome during the Holocene (Toro et al., 2007). Radiocarbon ages of the basal sediments of Lake Limnopolar indicate the onset of deglaciation of the central plateau by c. 8300 calibrated (cal) yr BP, with progressive eastwards retreat of the Rotch Dome glacier (Toro et al., 2013; Oliva et al., 2014).

In the SSI, tephra layers have been identified within a range of sedimentary environments, including lake sediments (Baker et al., 1975; Matthies et al., 1990; Björck et al., 1991; Hodgson et al., 1998, 2004; Tatur et al., 1999; Lee et al., 2007; Toro et al., 2013; Martínez Cortizas et al., 2014) and glacier ice (Pallàs et al., 2001; Kraus et al., 2013) from both Livingston and King George Islands, as well as in marine deposits from the Bransfield Strait (Matthies et al., 1988; Fretzdorff and Smellie, 2002) and Scotia Sea (Moreton and Smellie, 1998). The Deception Island volcano is the primary source of Quaternary tephra deposits to the SSI (Kraus et al., 2013); almost all tephra horizons have been attributed to eruptions of Deception Island, except for a horizon on King George Island tentatively linked to Penguin Island (dated 5–5.5 kyr BP; Tatur et al., 1999; Lee et al., 2007), and a marine tephra layer of unknown origin from the Bransfield Basin (Fretzdorff and Smellie, 2002). The dominance of a single source volcano, and the resulting lack of distinct compositional differentiation between glass shards from different tephra layers, has therefore hindered the establishment of a regional tephrochronology in the SSI region.

Holocene tephra layers have been analysed previously from four closely spaced lakes within Byers Peninsula: Midge, Chester Cone, Åsa (Björck et al., 1991; Hodgson et al., 1998), and Limnopolar (Toro et al., 2013) lakes. Identical tephra stratigraphies were found within cores from Midge Lake, Chester Cone, and Lake Åsa (Fig 1c), and local correlations were made for five distinct tephra layers based on direct radiocarbon dating (tephras AP2, 3, 5, 10–12, and 14, *sensu* Björck et al., 1991). Three of these tephra layers were also identified on the basis of age in distal lacustrine sequences from James Ross Island and Hope Bay, and from a moss bank on Elephant Island, along with eight additional horizons not observed in Byers Peninsula (Björck et al., 1991, 1996). Nevertheless, the same tephra layers could not be correlated to horizons

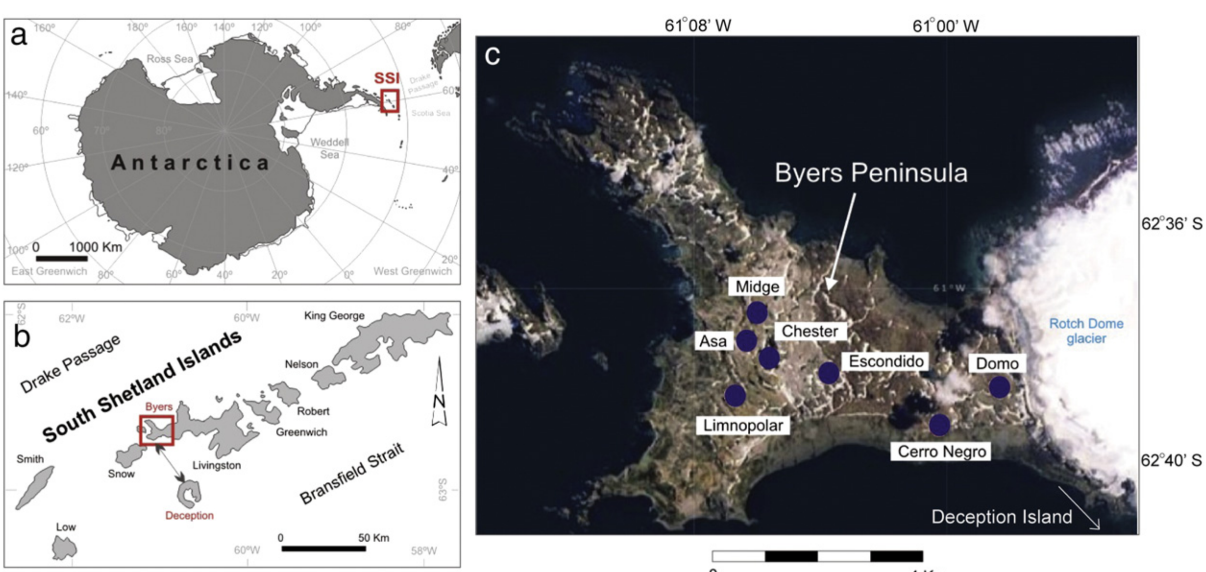

Fig. 1. Geographic location of the study area showing (a) the location of the South Shetland Islands (SSIs) relative to the Antarctic mainland; (b) the location of Byers Peninsula within Livingston Island; (c) the spatial distribution of the lakes in Byers Peninsula.