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Research paper

Clarifying the distal to proximal tephrochronology of the Millennium (B–Tm) eruption, Changbaishan Volcano, northeast China

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ABSTRACT

Tephra dispersed during the Millennium eruption (ME), Changbaishan Volcano, NE China provides one of the key stratigraphic links between Asia and Greenland for the synchronization of palaeoenvironmental records. However, controversy surrounds proximal-distal tephra correlations because (a) the proposed proximal correlatives of the distal ME tephra (i.e. B–Tm) lack an unequivocal chronostratigraphic context, and (b) the ME tephra deposits have not been chemically characterized for a full spectrum of element using grain-specific techniques. Here we present grain-specific glass chemistry, including for the first time, single grain trace element data, for a composite proximal sequence and a distal tephra from Lake Kushu, northern Japan (ca. 1100 km away from Changbaishan). We demonstrate a robust proximal-distal correlation and that the Kushu tephra is chemically associated with the ME/B–Tm. We propose that three of the proximal pyroclastic fall units were erupted as part of the ME. The radiocarbon chronology of the Kushu sedimentary record has been utilised to generate a Bayesian age-depth model, providing an age for the Kushu tephra which is consistent with high resolution ages determined for the eruption and therefore supports our geochemical correlation. Two further Bayesian age-depth models were independently constructed each incorporating one of two ice-core derived ages for the B–Tm tephra, providing Bayesian modelled ages of 933–949 and 944–947 cal AD (95.4%) for the Kushu tephra. The high resolution ice-core tephra ages imported into the deposition models help test and ultimately constrain the radiocarbon chronology in this interval of the Lake Kushu sedimentary record. The observed geochemical diversity between proximal and distal ME tephra deposits clearly evidences the interaction of two compositionally distinct magma batches during this caldera forming eruption.

1. Introduction

The Millennium eruption (ME) from the Changbaishan Volcano was a very large (VEI ≈ 7) eruption with the potential for ash dispersal across the Northern Hemisphere. Whilst the eruption was estimated to have had substantial volatile and sulfate aerosol emissions (Horn and Schmincke, 2000; Guo et al., 2002), it lacked a

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global impact on climate (Xu et al., 2013; Sun et al., 2014a). Distal products of the ME (i.e. B–Tm) have been reported in many localities including the Sea of Japan, the Japanese Archipelago (Machida and Arai, 1983; Furuta et al., 1986; Machida et al., 1990; Fukusawa et al., 1998; Nanayama et al., 2003; Kamite et al., 2010; Okuno et al., 2011; Hughes et al., 2013), northeast China (Sun et al., 2015) and the Greenland ice cores (Sun et al., 2014a) (Fig. 1a). As such it provides one of the potential key stratigraphic links between Asia and Greenland for the synchronization of palaeoenvironmental records. The proposed correlations between the distal ME tephra deposits and the Changbaishan Volcano (Machida et al., 1990; Sun et al., 2014a, 2015) require detailed chronostratigraphic studies and geochemical analyses of the proximal deposits and distal records. However, the proximal correlatives reported therein lack chronostratigraphic context and the ME tephra units have not been chemically characterized for a full spectrum of element using grain-specific techniques. Here we present the results of geochemical investigations of tephra units from proximal deposits with chronostratigraphic context, and a distal archive from Japan. This is then used to re-evaluate the proximal deposits, distal correlatives and the overall chronology for this eruption.

2. Background

2.1. Proximal volcanic deposits

The Changbaishan Volcano, situated on the border between China and North Korea (42°00′ N, 128°03′ E, Fig. 1a), is a polygenetic central stratovolcano with three main eruptive stages: early shield building, middle cone construction and a late explosive stage (Wei et al., 2007, 2013). During the latest explosive stage (<20 ka: Wei et al., 2013), a major caldera-forming eruption occurring at ~ AD 1000 (i.e. the "Millennium" eruption) produced a ca. 4.5 km wide caldera containing the crater lake called Tianchi (Machida et al., 1990).

The latest explosive stage recorded at Tianwen summit, on the Chinese flank of the crater contains four sequentially deposited pyroclastic fall units, C-4 [base], C-3, C-2 and C-1 [top], which are coloured yellow, light grey, dark grey and black, respectively (Fig. 1b). Stratigraphic and chronological studies of the Tianwen summit profile are summarized in Fig. 2. The lowermost C-4 yellow unit was dated by different methods and yielded ages around 4–5 ka (Liu et al., 1998; Wang et al., 2001; Yang et al., 2014). Hence, it

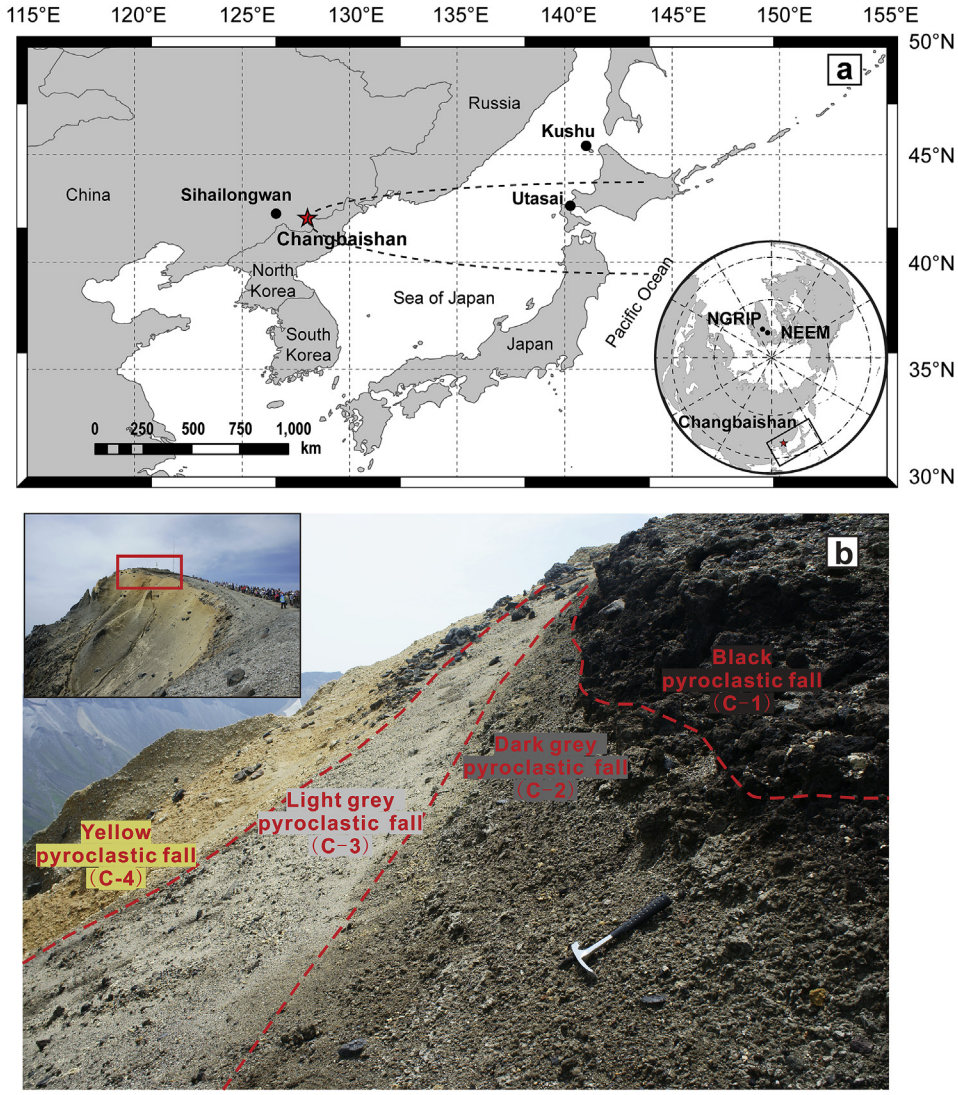

Fig. 1. (a) Location of the Changbaishan Volcano and the Lake Kushu distal archive on Rebun Island, northern Japan. The dashed line shows the previously reported distribution of B–Tm according to Machida and Arai (1983). Other occurrences of this tephra where the geochemical data used for comparison come from are marked on the map as well. (b) Sampled stratigraphy at the Tianwen summit on the Chinese flank of the Tianchi crater, Changbaishan Volcano, modified from Chen et al. (2014).