Earth and Planetary Science Letters 293 (2010) 135–139

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

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

A common volatilization trend in Transantarctic Mountain and Australasian microtektites: Implications for their formation model and parent crater location

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ARTICLE INFO

Article history:
Received 30 October 2009
Received in revised form 1 February 2010
Accepted 19 February 2010
Available online 17 March 2010

Editor: L. Stixrude

Keywords:
Transantarctic Mountain microtektites
Australasian microtektites
volatile elements
tektites
impact melting
impact glass
impact cratering

ABSTRACT

We studied the variations of the volatile major elements Na and K in Transantarctic Mountain microtektites and Australasian microtektites with distance from the putative source crater location in Indochina. The dataset includes 169 normal-type Australasian microtektites (101 from this study and 68 from the literature) from 24 deep-sea sediment cores up to 8000 km from Indochina, and 54 Transantarctic Mountain microtektites from northern Victoria Land, 11 000 km due southeast of Indochina. Normal-type ($MgO<5.5$ wt.% and $SiO_2=60$–78 wt.%) Transantarctic Mountain microtektites and Australasian microtektites share a common volatilization trend with Na and K contents decreasing with distance from Indochina. The average total alkali (Na_2O+K_2O) concentrations at distance ranges of 1000–2000 km, 2000–4000 km, 4000–8000 km and >8000 km are 4.27 ± 0.67 wt.% ($n=84$), 3.20 ± 1.21 wt.% ($n=50$), 2.10 ± 0.25 wt.% ($n=35$) and 1.25 ± 0.25 wt.% ($n=54$), respectively. The trend highlights a relationship between increasing loss of volatiles in microtektites with longer trajectories and higher temperature-time regimes which should be taken into account in microtektite formation modeling. The trend is consistent with a previous hypothesis that Transantarctic Mountain microtektites belong to the Australasian strewn field and that Indochina is the target region for the parent catastrophic impact.

1. Introduction

Tektites are siliceous impact glasses up to some tens of cm in size produced by the high-temperature melting of the Earth's crust during hypervelocity impacts of extraterrestrial bodies (e.g., Montanari and Koeberl, 2000). Together with microtektites (microscopic tektite glass spheroids), they form distal ejecta deposited over large areas of the Earth's surface known as strewn fields. Only a minority of impact craters is associated with tektites, and many aspects of their formation mechanism are still riddled with open issues (e.g., Melosh and Vickery, 1991; Montanari and Koeberl, 2000; Artemieva, 2002a, 2008).

The Australasian tektite/microtektite strewn field (Fig. 1) covers ~ 10% of the Earth's surface, extending from southeast Asia to much of Australia and Tasmania, and the surrounding Indian and Pacific ocean basins, and was generated by a catastrophic cosmic impact ~0.8 Mya (e.g., Baker, 1959; Izett and Obradovich, 1992; Kunz et al., 1995; Simonson and Glass, 2004; Glass and Koeberl, 2006). Paradoxically, however, after decades of investigation, the source crater for the largest and youngest tektite strewn field on Earth is still unknown, although most investigators concluded that it should be located somewhere in Indochina (e.g., Stauffer, 1978; Schnetzler, 1992; Glass and Pizzuto, 1994; Lee and Wei, 2000; Ma et al., 2004; Glass and Koeberl, 2006; Prasad et al., 2007).

Folco et al. (2008, 2009) have recently reported the discovery of Transantarctic Mountain microtektites, which were found (together with thousands of micrometeorites) in the local detritus accumulated in weathering pits and joints of several summits in Victoria Land (Fig. 1). Because of their geochemical affinity with Australasian microtektites found in deep-sea sediments from the Indian and Pacific Oceans in terms of major and trace elements and Sr and Nd isotopic composition, and their Quaternary ^{40}Ar–^{39}Ar age, these authors suggested that Transantarctic Mountain microtektites likely represent the southern extension of the Australasian tektite/microtektite strewn field. Based on the fact that Transantarctic Mountain microtektites found at the margin of the Australasian strewn field and at the furthest known distance from the hypothetical source crater in Indochina are also the most depleted in volatile elements (i.e., Pb, Na, K, Rb, Sr, Rb, Cs), Folco et al. (2008, 2009) further predicted a possible relationship between the processes controlling the loss of volatiles and ejection distance. As a consequence, they suggested that the source crater location could be broadly constrained by investigating geographic variations in the concentrations of volatile elements that are lost during the impact.

In order to verify these hypotheses and ultimately help predict the source crater location, we studied the variations of the volatile major

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doi:10.1016/j.epsl.2010.02.037

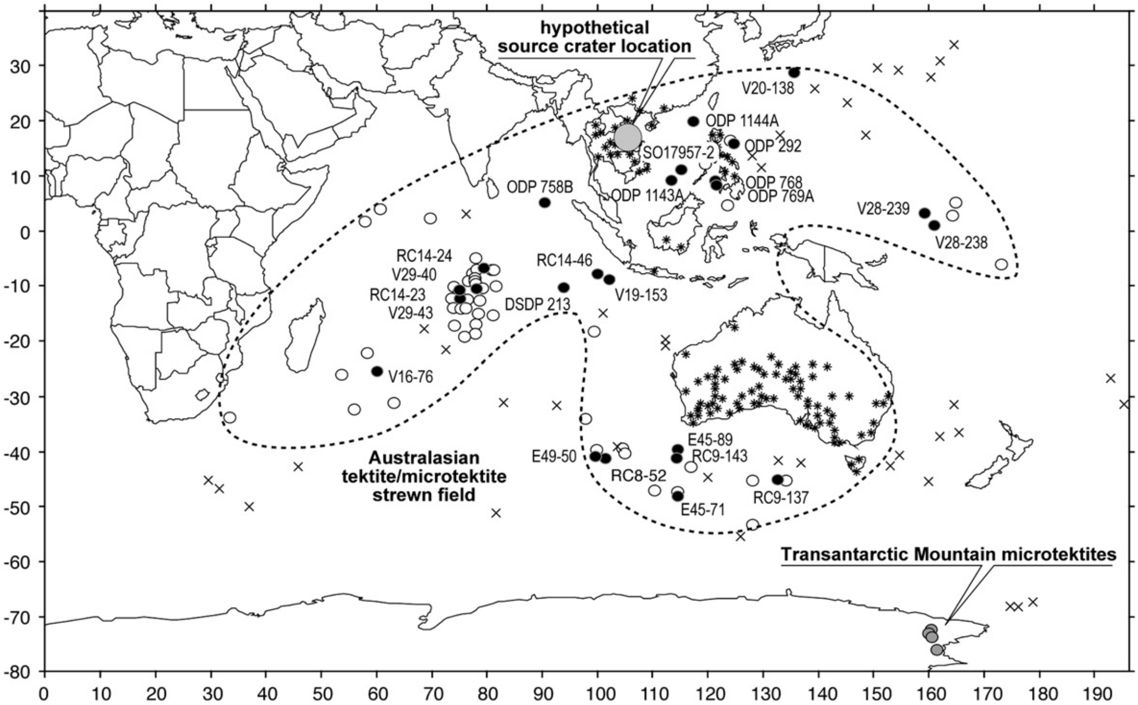

Fig. 1. Map showing the Transantarctic Mountain microtektite find locations in Victoria Land (grey circles) and the Australasian tektite/microtektite strewn field (dashed line) as defined by Glass and Koeberl (2006). Australasian microtektite-bearing sites in the ocean used in this work are indicated by filled circles. Australasian microtektite-bearing sites not used in this work are indicated by open circles. Sites in the ocean basins where Australasian microtektites were not found are indicated by "×"s. Sites where Australasian macroscopic tektites were found are marked by "*"s. The large grey circle is the hypothetical location of the Australasian tektite/microtektite source crater used in this work (ca. 18° N, 106° E). This is a compromise location between the ones proposed by Ma et al. (2004) and Glass and Koeberl (2006).

elements Na and K in Transantarctic Mountain microtektites and Australasian microtektites with distance from Indochina (Fig. 1; Table 1).

2. Materials and methods

The dataset used in this work includes the major element bulk composition of 54 Transantarctic Mountain microtektites and 169 normal-type Australasian microtektites (Tables 1 and S1) obtained by means of electron probe microanalyses (EPMA). 54 Transantarctic Mountain microtektites and 101 Australasian microtektites were analyzed in this work (see below) to ensure an internally consistent dataset of Na_2O and K_2O concentrations, whose accurate determination can be problematic due to their possible migration under the electron beam. The bulk compositions of the remaining 68 Australasian microtektites were gathered from the literature (Cassidy et al., 1969; Glass et al., 2004; Glass and Koeberl, 2006). Transantarctic Mountain microtektites are from Miller Butte, Frontier Mountain, Pian delle Tectiti (Timber Peak area) and Mistake Peak in Victoria Land. They are spherical, transparent, pale-yellow in color, and have diameters ranging from 153 μm to 776 μm. Their silica content ranges from 60 wt.% to 78 wt.%, and MgO ranges from 1.9 wt.% to 5.5 wt.%. On the whole, their composition is very similar to that of the Australasian microtektites classified as "normal-type" by Glass et al. (2004). Note that glass spherules of different colors and transparency were not used in this work, because of the possibility that many or most of them could be of meteoritic nature (i.e., cosmic spherules; Rochette et al., 2008; Folco et al., 2009).

The Australasian microtektites used in this work are from 24 deep-sea sediment cores from the Indian and Pacific Oceans with distances from the putative source crater location in Indochina of up to about 8000 km. They are typically spherical and their diameter ranges from 150 μm to 750 μm. In the literature, Australasian microtektites are classified into three main compositional groups according to MgO contents (e.g., Glass et al., 2004): the transparent, pale-yellow to brown, normal-type with MgO ranging from 1.8 wt.% to 5.5 wt.%; the transparent, bottle-green, high-magnesium-type with MgO > 10 wt.%; and the transparent, yellow-green, intermediate-type with intermediate MgO contents. Since the high-magnesium and, to a lesser extent, the intermediate microtektites have lower silica and alkali contents with respect to normal microtektites and since the other major oxide contents generally vary inversely with the silica content, only normal-type Australasian microtektites with SiO_2 contents similar to those of the Transantarctic Mountain microtektites (i.e., 60–78 wt.% SiO_2) were used in this study.

The major element compositions of the 54 Transantarctic Mountain microtektites and 43 Australasian microtektites analyzed in this work were obtained by averaging multiple (typically five) EPMA on polished sections. Analyses were carried out using a CAMECA SX50 electron microprobe at the Istituto di Geoscienze e Georisorse del Consiglio Nazionale delle Ricerche (IGG CNR) in Padova (Italy). Running conditions were 15 kV accelerating voltage, and a10 nA beam current. Counting time was 7 s for Na, K, Si, and 10 s for Mg, Al, Ca, Ti, Cr, Mn and Fe, and 20 s for Ni. A 15 μm-diameter defocused beam was employed to reduce migration of volatile elements. The manufacturer-supplied PAP (Pouchou and Pichoir, 1991) procedure was employed for raw data reduction. Minerals (albite, diopside, and orthoclase) and synthetic (NiO, $MnTiO_3$, and Cr_2O_3) standards were used for instrumental calibration and checked against a secondary glass standard made by Corning with composition similar to that of Transantarctic Mountain microtektites and Australasian microtektites. The latter glass standard was formerly used for the internal standardization of the analyses by Glass et al. (2004) and Glass and Koeberl (2006) used in this study. Average compositions of the analyzed microtektites are listed in Table S1.

In order to study the variations of volatile elements Na and K in Transantarctic Mountain microtektites and Australasian microtektites with distance from the hypothetical source crater region in Indochina,