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ICELANDIC TEPHROCHRONOLOGY - MATCHING THE PROVENANCE OF PROXIMAL AND DISTAL VOLCANIC GLASSES USING LA-ICPMS TRACE ELEMENT DATA

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Abstract

Thorarinsson (1944) pioneered the use of tephrochronology and its application in NW Europe. The basis of this chronological tool is the use of time-parallel marker tephra (i.e., ash <2mm) horizons to correlate proximal volcanic deposits with distal tephras found in marine-lacustrine-ice cores and terrestrial sequences. The trace element geochemistry of volcanic glasses [determined by LA-ICPMS] offers an improved diagnostic tool for matching the juvenile components of proximal and distal tephras and has considerable potential for assigning provenance to cryptotephras (<100 microns) provided they are of sufficient size and thickness.

Introduction

In the context of the last 100ka western Europe offers a unique opportunity to use recurrent explosive volcanic activity and widespread tephra dispersal as a basis for evaluating the temporal and spatial relationships between the migration of ancient modern humans (AMH) and abrupt environmental transitions (AETs). Tephras in (a) archaeological sites hold the key to AMH migration patterns and (b) lacustrine, marine and ice core constrain AETs. Juvenile (magmatic glass) compositions are forthcoming from (a) pumice or scoria clasts in pyroclastic fall deposits (b) pumice or fiamme in proximal pyroclastic flow deposits, (c) glass adhering to entrained xenoliths, and (d) cryptotephras at distal sites (i.e., < 100 microns). EMPA & LA-ICPMS techniques (e.g., Tomlinson et al 2010a) are applied to all proximal and distal juvenile class with SIMS utilized where particles are too small/thin. The provenance of these distal tephras is paramount and is defined by matching the geochemistry of distal juvenile clasts with the RESET geochemical database for proximal European tephras. Once diagnostic chemistries are matched, $^{40}Ar/^{39}Ar$ ages (K-rich phenocrysts) from proximal sites link the continental-lacustrine-marine archives. This time lattiice is refined with the addition of temporal detail from varve counting (lacustrine), ^{14}C, U-Th dating (archaeological sites), & biostratigraphy (marine).

Katla & the Vedde ash (*ca.* 11ka) : proximal-distal correlation

The Vedde Ash has been reported from distal terrestrial, marine and ice cores across Northern Europe and forms an important stratigraphic marker for palaeoclimatic reconstructions across the North Atlantic (e.g., Mangerud et al. 1984; Lowe and Turney, 1997; Wastegård et al., 2000; Davies et al., 2005). The Vedde ash has been dated close to its type site in Western Norway, giving a ^{14}C age of 10,310 ± 50 ^{14}C years or 11,841 to 12,383 cal years BP (Birks et al., 1996). The Vedde Ash is a bimodal rhyolitic (clear shards) and basaltic (brown shards) tephra layer believed to have been erupted from the Katla volcano in Southern Iceland (Lacasse et al., 1995). However, distal tephra correlations are soley based on somewhat equivocal data including glass shard morphology and major element EMPA chemistry indicating a basalt-rhyolite magmatic lineage. Lacasse et al (1995) identified the Sólheimar ignimbrite, erupted from Katla, as the likely source of the Ash Zone 1 tephra again on the basis of total alkali-silica (TAS) classification and feldspar compositions. These may not be diagnostic in the context of Icelandic magmatism and the potential exists for confusion between distal basalt-rhyolite cryptotephra and the many basalt-rhyolite centres on Iceland that have erupted over the last 100ka. Tomlinson et al (2010b) undertook trace (LA-ICP-MS) element analysis of volcanic glasses from a proximal volcano-stratigraphic section of the Sólheimar ignimbrite and distal glasses from the type Vedde site at Ålesund in Western Norway (Mangerud et al., 1984). The rhyolitic (SiO_2>68%) Sólheimar pumice and obsidian and the distal Vedde clear glass shards have restricted and overlapping trace element compositions that demonstrate a close correlation between the Sólheimer ignimbrite and the Vedde Ash. Importantly Tomlinson et al (2010b) highlighted key differences between the Sólheimar rhyolite and other rhyolites from the Icelandic Southern Transition Zone such that provenance can assigned with greater confidence. *They conclude that the proximal rhyolitic component of the Sólheimar ignimbrite is compositionally identical to the distal rhyolitic clasts from the classic Vedde fall locality in terms of both major and trace element geochemistry*. Magmatic variability exists along 1500 km of the tephra dispersal axis between Katla and Vedde with greater magmatic representation in the distal Vedde tephra (i.e. fall deposit) than at the proximal "bimodal" site at Sólheimer which is dominantly basaltic-andesite fall and rhyolititc flows deposits. Similar along-axis variability over 3000km was reported from continental-marine correlations between Afro-Arabia and the Indian Ocean (Ukstins-Peate et al 2003, 2008). Along axis differences appear to be characterised by (a) the most evolved magmas being located at distal sites, and (b) bimodality being restricted to proximal sites.

Thorsmork & Ash Zone 2 (*ca.* 57ka) – continental-marine correlation

Ash zone 2, an alkali rhyolite tephra layer found in north Atlantic and Arctic marine cores (Lacasse & Garbe-Schoonberg 2001) and the GISP2 Greenland ice core (Ram et al 1996), has been correlated with the Thorsmork ignimbrite. This provenance match is based on a combination of major element data and tephra stratigraphy. Tindfjallajokull, the source of the Thorsmork ignimbrite, is a bimodal basalt-rhyolite volcano in the Eastern Volcanic Zone Iceland, represented by a series of pyroclastic flow deposits. The homogenous rhyolite pumice dominates the deposit, which also contains subordinate basalt scoria (Jörgensen 1980). These two compositional components are also represented in the fiamme but there is no textural evidence for mixing or mingling between the basalt and rhyolite components. The Thorsmork ignimbrite has been the focus of $^{40}Ar/^{39}Ar$ dating (Sigurdsson et al 1998, Storey and Stecher 2009) with a robust age of 57ka (W. McIntosh 2010 pers comm). Tomlinson et al (2010a) report LA-ICP-MS and AES data for the Thorsmork rhyolite and its juvenile component. They argue that the bimodal Thorsmork ignimbrite is the product of physical mixing of basaltic and rhyolitic magmas. Furthermore Tomlinson et al (2010a) compare other potential volcanic sources from the Icelandic Southern Transition Zone (Hekla, Torfajökull, Oaerfajökull, Tindfjallajökull). Rhyolite glass from the Thorsmork Ignimbrite can be distinguished from these other Icelandic rhyolites, because the major di erences between the Icelandic rhyolites are driven by high-level processes in the magma chamber, principally phenocryst fractionation. Tomlinson et al (2010a) compare the Thorsmork glass chemistry with published trace element data for ash zone 2 tephra (SU9029) from the Irminger Basin, North Atlantic (Lacasse & Garbe-Schoonberg 2001). They conclude that *ash zone 2 is indistinguishable from the proximal Thorsmork juvenile clasts and that Ash Zone 2 is likely to be a distal sample of the Thorsmork Ignimbrite*.

Summary

Volcanic glass geochemistry offers a robust basis for matching proximal juvenile clasts, from primary fall & flow deposits, with distal tephras and cryptotephras [<100microns]. Glass chemistries from two Icelandic volcanoes have been used to demonstrate : (a) proximal-distal correlations over 1500km with Katla confirmed as the source of the "Vedde Ash" in Norway (11ka), and (b) continental-marine correlations with Thorsmork (57ka Tindfjallajokull) shown to be the source of Ash Zone 2 found in the North Atlantic marine cores.

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