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Seismic properties of lower crustal xenoliths from El Hoyazo (SE Spain): Experimental evidence up to partial melting

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Abstract

Seismic techniques provide unique tools to investigate the structure and, in combination with petrological, geochemical and petrophysical study, the composition of the lower crust. Controversies can be solved with comparative study of metamorphic terrains or xenoliths that occur adjacent to areas where seismic refraction/reflection data are available. Xenoliths represent a direct sampling of the inaccessible lower crust at the time of the volcanism, whilst exposed crustal sections can only be used as analogue of present day lower crust.

The present study is focused on the measurements of compressional wave velocities up to conditions exceeding the beginning of melting (950 °C at 500 MPa confining pressure) on three garnet–biotite–sillimanite metapelitic xenoliths recovered from the Neogene dacites of El Hoyazo (SE Spain). They preserve widespread interstitial rhyolitic glass as evidence of primary melt extraction and represent the best example of partially molten lower crust in the Alborán Domain. The influence of glass on Vp is primarily reflected by anomalous positive dVp/dT while heating with velocity increasing at 500 MPa from 4.98 to 5.50 km s^{-1} at room temperature to 5.85–6.79 km s^{-1} at 650–700 °C. This corresponds to the glass transition where all the grain boundaries and most of the pores within the glass are closed. After this point, the velocity decreases to 6.2–6.5 km s^{-1} at 950 °C where re-melting of the glass is achieved and additional partial melt produced. On cooling, the behavior is normal with negative dVp/dT. After the thermal treatment velocities are 30% higher (6.07–7.21 km s^{-1}) and reveal that in the presence of intergranular melt velocity measurements at room temperature cannot be extrapolated to high temperatures.

P-waves measured at melting conditions are in agreement with deep seismic refraction data and tomography in the area and corroborate the hypothesis that partial melts are actually present in Alborán lower crust.

Keywords: seismic properties; xenolith; melting; lower crust; Petrophysics; Alborán Domain

1. Introduction

Seismic observations have provided unique tools to decipher the structure of the deep continental crust. In order to interpret the velocity profiles in terms of composition and petrology, a wide variety of experiments were performed since the pioneering works of Birch [1,2]

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(see [3–7]). The lower crust is directly accessible in exhumed outcrops as in Ivrea Zone and Calabria (Italy) or in xenoliths, which represent lower crustal fragments carried to surface by volcanic eruptions. Unfortunately xenolith dimensions are mostly too small for experimental investigations and large xenoliths are precious. Extremely significant are those samples which preserve traces of partial melting processes responsible for crustal differentiation. However the tentative of modelling the lower continental crust on the base of xenoliths requires some caution; in fact:

– sampling of lower crust may not be complete; most crustal xenoliths are in fact mafic and subsolidus (see [8]) while metapelitic xenoliths, and especially those with partial melt, are rare and more subject to dissolution during transport [9–11];
– because of the transport mechanisms through magmas, grain boundary modifications may occur due to rapid decompression; these involve microfracturing disaggregation of grain boundaries and melt infiltration documented by quenched glass [12,13], mineral reactions on grain boundaries and retrogressive alteration [14–16].

The presence of interstitial glass has major effects on the seismic properties of xenoliths; in mantle and crustal xenoliths measured by Parsons et al. [12], Kern et al. [13] and Gao et al. [16], for instance, samples containing glass exhibit increase of Vp with increasing temperature and anomalous low velocity with respect to similar rock types without interstitial melt and/or calculated velocities (see [14,4,6] and references therein).

This paper aims at investigating the dependence of Vp on pressure and temperature on three restitic metapelitic xenoliths recovered from El Hoyazo (south eastern Spain) up to temperatures exceeding the partial melting; the rocks are peculiar for the presence of fresh interstitial glass residue of primary melt extraction and useful to observe how anisotropy varies in concomitance with re-melting. These samples have the advantage that retrogressive reactions and other kinds of alterations related to post-melting evolution are absent except for a partial devitrification of the glass in few xenoliths.

2. Geological setting

The studied samples are xenoliths in the dacite of El Hoyazo, belonging to the Neogene Volcanic Province (hereafter NVP) of SE Spain. The NVP is a 200 km long, NE–SW trending volcanic belt at the southeastern margin of Spain [17], and consists predominantly of calc-alkaline rocks, mostly andesites [18] and minor high-K calc-alkaline to shoshonitic rocks, ranging in age from 17 to 5 Ma (references in [19–21]). The high-K calc-alkaline rocks occur as scattered, small volcanic edifices (such as El Hoyazo, see Fig. 1) and are mainly composed of Grt–Crd-bearing dacites.

Xenoliths of crustal origin are very abundant in the lavas of El Hoyazo, making up to 15% of outcrop volume [22]. The xenoliths are medium to coarse-grained granulite-facies rocks, easily recognisable by the typical presence of graphite, euhedral garnet, cordierite porphyroblasts, sillimanite and hercynitic spinel. The xenoliths have restitic bulk composition, depleted in silica and enriched in aluminium and iron (e.g. [23,24] and this paper). Xenoliths range in size from a few tens of centimetres down to single xenocrysts, which are the result of restite fragmentation and dispersion in the host lava.

Evidence of partial melting and melt extraction in the xenoliths is provided by the occurrence and high abundance of fresh rhyolitic glass (quenched melt, hereafter "glass") as primary inclusions in most minerals [23]. These S-type rhyolitic melts within the xenoliths ([25] and Acosta Vigil et al., in press) are the products of the incongruent melting of the metapelitic protoliths, not the result of melt infiltration from the enclosing dacite. In fact, the xenolith–dacite boundary is commonly sharp, without evidence of interaction. In addition, melts in inclusions and intergranular films of xenoliths are chemically different from the glass of the dacite host, which have lower Al/Si and higher K/Na [23]. Microstructures show that anatexis was accompanied by foliation development [26], indicating that the xenoliths

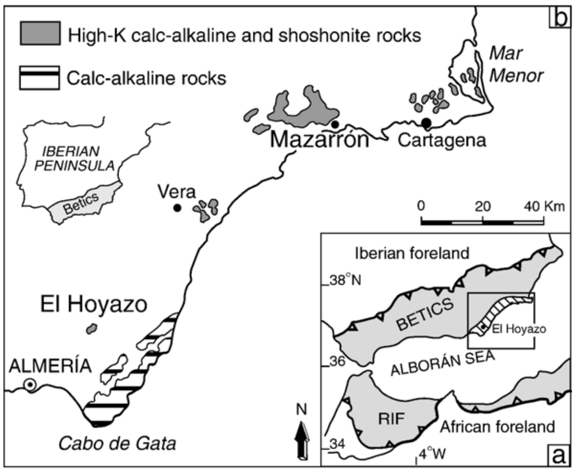

Fig. 1. Geographical location and schematic tectonic elements of the main edifices of the Miocene volcanics of the Neogene Volcanic Province within the Alborán Domain (after [55]).