Tectonophysics 586 (2013) 84–94

Contents lists available at SciVerse ScienceDirect

Tectonophysics

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

Electrical conductivity in a partially molten crust from measurements on metasedimentary enclaves

Fabio Ferri [a,*], Benoit Gibert [b], Marie Violay [b,1], Bernardo Cesare [a]

[a] Dipartimento di Geoscienze, Università di Padova, via G. Gradenigo 6, I-35131 Padova, Italy
[b] Laboratoire Géosciences Montpellier UMR CNRS 5243, Université Montpellier II, 34095 Montpellier, France

ARTICLE INFO

Article history:
Received 13 February 2012
Received in revised form 31 October 2012
Accepted 3 November 2012
Available online 14 November 2012

Keywords:
Electrical conductivity
Enclave
Melting
Lower crust
Migmatite
Alborán

ABSTRACT

The complex electrical impedance of a garnet–biotite–sillimanite residual enclave in the Neogene dacite of El Hoyazo (SE Spain) has been determined up to 978 °C at 200–300 MPa. This well studied material represents a direct sampling of the Alborán Domain thinned lower crust undergoing partial melting. The paragenesis is garnet + biotite + sillimanite + plagioclase + graphite ± cordierite coexisting with widespread (~10 wt.%) rhyolitic melt occurring as inclusions and interstitial glass and developed during regional anatexis at 850 ± 50 °C and 500–700 MPa.

The samples were used in cyclic measurements consisting in heating–cooling ramps at progressively higher maximum temperature to observe the effect of reactions on conductivity. In the first cycle up to 850 °C at 2–3 kbar, re-melting of the interstitial glass is achieved with no additional reactions and logarithmic conductivity (S/m) is up to −1.5. At T > 950 °C new melt with orthopyroxene + ilmenite is produced from biotite partial breakdown and the logarithmic conductivity (S/m) is up to −0.7. Application of mixing models as Hashin–Shtrikman bounds or Archie's Law, shows that once interconnected, melt controls the electrical conductivity of the enclave. The electrical conductivity of the rock can be simulated with the electrical conductivity data obtained on the starting Matrix glass of the enclave and with the new melt.

Our experimental results obtained on a graphitic metasedimentary material evidence show that graphite does not contribute to the conductivity enhancement and that the electrical anomaly observed below the Betics can be explained as effect of partial melting of a residual crust. Comparison with previous works on mafic granulites shows that similar conductivity values can be achieved both by melting of a residual felsic crust or by melting of mafic materials and suggests that pelitic rocks can be more common at deep levels than expected.

© 2012 Elsevier B.V. All rights reserved.

1. Introduction

Magnetotelluric (MT) measurements reveal that the lower continental crust contains extensive zones of anomalous high electrical conductivity (e.g., Losito et al., 2001; Monteiro Santos et al., 2002; Pous et al., 1999; Schilling et al., 1997; Solon et al., 2005). As several petrological processes lead to a modification of conduction mechanisms and may explain such anomalies (e.g., Nover, 2005), discrimination and identification of these processes is impossible from MT data alone.

Indeed, the electrical conductivity of rocks can be significantly enhanced in the presence of well interconnected and highly conductive phases that are present in a low-conductive, mineral matrix. The conductive phases can be solid (e.g., graphite, Glover and Vine, 1992 and ore minerals, Martì et al., 2009), or fluid (e.g., silicate melts, Gaillard et al., 2004 and brines, Nesbitt, 1993). The conductivity of fluids is strongly dependent on their composition i.e. on the amount and type of charge carriers (H_2O, Na^+ and Ca^{2+} for melts, Gaillard, 2004; Na^+, K^+ and salts for brines, Glover et al., 2000; Nesbitt, 1993). Recent works revealed that additional processes may concur to conductivity enhancement at subsolidus conditions, like the presence of trace amounts of H_2O in nominally anhydrous minerals (e.g., plagioclase and pyroxene, Yang et al., 2011), or the oxidation of Fe due to amphibole dehydroxylation (Wang et al., 2012). In order to discriminate the dominant conducting mechanisms, in situ laboratory measurements are needed at HP–HT conditions on rocks representative of deep crustal protoliths.

The average composition of the lower crust is inferred to be mafic from the interpretation of seismic refractions profiles with V_p values of 6.9–7.5 km/s (Rudnick, 1992; Wedepohl, 1995) combined with the analyses of granulite enclaves and exposed granulite facies terrains (Ivrea Zone, Northern Italy, Burke and Fountain, 1990). However, large uncertainties still remain and examples of felsic-intermediate lower crust are reported in the Iberian Hercynian belt (Cesare et al., 1997; Villaseca et al., 1999), in China (Gao et al., 1998) and in many

* Corresponding author. Tel.: +39 049 8279110; fax: +39 049 8279134.
E-mail addresses: fabio.ferri@unipd.it (F. Ferri), gibert@gm.univ-montp2.fr (B. Gibert), violay@ingv.it (M. Violay), bernardo.cesare@unipd.it (B. Cesare).
[1] Now at Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy.

0040-1951/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2012.11.003

other areas worldwide. Moreover, when the metamorphic grade increases to granulite facies conditions, the seismic velocities and densities of residual rocks formed by anatexis of former pelites (Ferri et al., 2007) approach those of mafic rocks (Guy et al., 2011) so that the conventional distinction between metasedimentary (felsic) and mafic composition only on the basis of seismic profiles becomes questionable.

The purpose of the present paper is to describe the first electrical conductivity measurements of natural samples of rocks originated from felsic metasedimentary material undergoing partial melting by using residual enclaves from the Alborán lower crust. These rocks represent a direct sampling of the shallowest crustal levels of the southern Betics (Acosta-Vigil et al., 2010 and references therein), an area where geophysical properties (e.g., seismic velocities, electrical resistivity and heat flow) are well known (Calvert et al., 2000; Carbonell et al., 1998; Fernández et al., 1998; Martì et al., 2009; Pous et al., 1999). The enclaves from El Hoyazo are ideal candidates for the study because: 1) they belong to the crust immediately overlying the present day Moho, as inferred from geobarometric estimates (Cesare and Gomez-Pugnaire, 2001); 2) they represent a direct unaltered sampling quenched during volcanic extrusion; 3) they contain about 10% of the primary melt preserved as fresh glass (Ferri et al., 2007); 4) they have V_p up to 6.8–7.5 km/s and densities of 2.83–2.96 g/cm^3 (Ferri et al., 2007), i.e. similar to typical values of mafic high grade rocks (Rudnick and Fountain, 1995). For such reasons, these samples also allow comparing the physical properties of mafic and felsic high grade rocks.

The enclaves from El Hoyazo are also a rare example of melt depleted crust (*residuum*, Sawyer et al., 2011). Their melt amount is similar to the so-called *melt connectivity threshold* (MCT, ~7%) (Rosenberg and Handy, 2005), which marks a first-order rheological transition with a dramatic strength reduction. In the presence of deformation and once the MCT is achieved, the melt may segregate, leaving a melt depleted crust (the *residuum*). In this case higher volumes of melt are unlikely to be achieved on a bulk scale because of efficient melt extraction and transfer (Brown, 2007).

In the present paper, we have investigated the electrical response to crustal melting of a low melt fraction residual metapelitic crust. This situation corresponds to studying the melanosome of layered structure (stromatic) migmatites, that is the residual part of the migmatitic complex containing lower melt percentages after segregation. On the contrary, melting experiments up to very high melt fractions, which are achieved in the laboratory but unrealistic in many natural cases, rather reproduce conditions of local accumulation of melt (Gaillard et al., 2004), or those occurring in diatexite migmatites.

In the experiments, the temperature was extended to >950 °C, beyond the equilibration conditions of the enclaves, to investigate the relationships between electrical conductivity and petrology also in the case of ultra-high temperature (UHT) metamorphism (Harley, 1998).

The results are compared with MT soundings collected in the Alborán domain (Martì et al., 2009; Pous et al., 1999) and with existing data on mafic compositions at similar pressure and temperature (e.g., Maumus et al., 2005; Partzsch et al., 2000; Yang et al., 2011).

2. Sample description

2.1. Geological setting

The studied sample, named JOY2, is a metapelitic enclave collected from the dacitic lava of El Hoyazo, a volcanic centre located in the Neogene Volcanic Province (NVP) of the Betic Cordillera, SW Spain (Fig. 1; Duggen et al., 2005 and references therein). It is a representative sample of the enclaves of crustal origin that are very abundant in the lavas of El Hoyazo, making up to 15% of outcrop volume (Zeck, 1968). These enclaves are medium to coarse grained granulite-facies rocks, characterized by the typical presence of graphite, euhedral garnet, cordierite porphyroblasts, sillimanite and hercynitic spinel. Evidence of partial melting and melt extraction in these enclaves is provided by the occurrence and high abundance of fresh rhyolitic glass (quenched melt, hereafter "glass") as primary inclusions in most minerals and along grain boundaries (Cesare et al., 1997). These S-type rhyolitic melts within the enclaves (Acosta-Vigil et al., 2007) are the products of the incongruent melting of the metapelitic protoliths, not the result of melt infiltration from the enclosing dacite. Based on mass balances between melt inclusions, enclaves and potential metapelitic sources, Cesare et al. (1997) estimated a high degree (40–60 wt.%) of melt extraction from the enclaves of El Hoyazo. Based on a pseudosection calculation from a Grt–Bt–Sil enclave sample, Tajčmanová et al. (2009) proposed that enclaves equilibrated in the cordierite field at 790–825 °C and 500 MPa.

Estimated pressures correspond to a depth of ca. 20 km (assuming a crustal density of ca. 2.7 g cm^{-3}), a value that is similar to the actual Moho depth below El Hoyazo (ca. 21 km, Torne et al., 2000) and that is considered to have changed very little since the end of extension in the area. The Grt–Bt–Sil (abbreviations according to Kretz, 1983) enclave studied in this paper can confidently be considered as an analogue of the lower crust beneath the region of El Hoyazo. Such a view is supported by the persistent abundance of similar enclaves (residual partially melted graphitic metapelites) throughout the 200-km long belt of high-K volcanics in the NVP.

2.2. Bulk composition

The bulk composition of the studied sample JOY2 is reported in Table 1 and is very similar to other analyses of Grt–Bt–Sil enclaves in the literature (e.g., Cesare et al., 1997; Zeck, 1968). The rock is very low in SiO_2 (47.4 wt.%) and high in Al_2O_3 (27.9 wt.%) and FeO_{tot} (9.4 wt.%). Such extreme residual character, indicative of high degrees of melt extraction, is more pronounced than in other metapelitic enclaves of inferred restitic character, which always have $SiO_2 >$ 50 wt.% (see summary in Rudnick and Fountain, 1995). Another peculiar feature of the El Hoyazo enclaves is their high carbon content (0.85 wt.% in JOY2), which explains the abundant presence of graphite in the rocks.

2.3. Mineral and glass chemistry

The mineral composition of the Grt–Bt–Sil enclave from El Hoyazo is very homogeneous and comparable with other analyses reported by Cesare et al. (1997, 2003a, 2003b, 2005) and Cesare and Acosta-Vigil

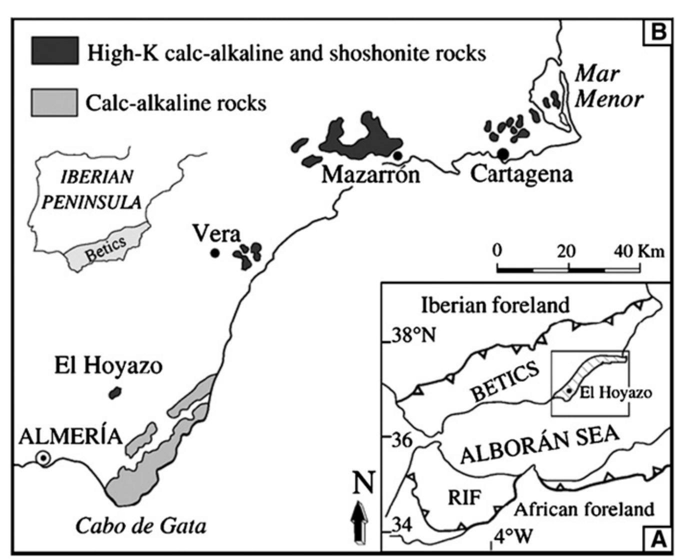

Fig. 1. Geographic location of (A) the Betic Cordilleras and Rif, and (B) volcanics of the Neogene Volcanic Province of southeastern Spain.
After López Ruiz and Rodríguez Badiola, 1980.

Download English Version:

https://daneshyari.com/en/article/4692465

Download Persian Version:

https://daneshyari.com/article/4692465

Daneshyari.com