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Amphibole-bearing migmatites from the Variscan Belt of NE Sardinia, Italy: Partial melting of mid-Ordovician igneous sources

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ABSTRACT

Amphibole-bearing migmatites from north-eastern Sardinia, Italy, are characterized by tonalitic to granodioritic leucosomes made up of quartz, plagioclase, K-feldspar, biotite, ±amphibole, and garnet. The leucosomes show higher SiO_2, Na_2O, Sr and lower TiO_2, Fe_2O_{3tot}, MgO, MnO, P_2O_5, K_2O and Rb content as compared to the mesosomes. The granodioritic leucosomes differ from the tonalitic leucosomes for significantly higher Ba and K_2O content. The mesosomes and the leucosomes show slightly fractionated REE patterns with moderate negative and positive Eu anomalies, respectively. The leucosomes show lower $^{87}Rb/^{86}Sr$ ratios (0.279–0.581) than the mesosomes (0.634–1.121), whereas the $^{147}Sm/^{144}Nd$ ratios are similar in leucosomes (0.12–0.14) and mesosomes (0.11–0.14). Mineralogical, geochemical and isotopic data suggest that the migmatites formed by in situ partial melting of a biotite+plagioclase+quartz-bearing protolith with 2–4 wt.% added water. Variable degrees of melt loss were responsible for the observed compositional variability in the leucosomes, whereas solid-state re-equilibration of the migmatites leads to a general re-equilibration of mineral compositions after partial melting. The amphibole-bearing migmatites record maximum *P–T* conditions of 700–750 °C and 1.0–1.2 GPa, probably lower than, but near to, the *P–T* conditions of peak metamorphism. Zircon morphology suggests an igneous origin for the migmatite protolith. Pb–Pb zircon dating yielded a mean value of 452±3 Ma and an isochron age of 461±12 Ma which is interpreted as the emplacement age of the migmatite protolith.

1. Introduction

Amphibole-bearing migmatites have been reported in the anatectic massif of the southern Schwarzwald (Black Forest, Germany, Büsch et al., 1974), in the Central Gneiss Complex Coast Mountains, British Columbia (Lappin and Hollister, 1980; Kenah and Hollister, 1983), in the Archaean high-grade Gneiss Belt, Northern Gallatin Range Montana, USA (Mogk, 1992), in the Tormes Gneiss Dome, Iberian Massif (Escuder Viruete, 1999) and in the Phikwe Complex, Botswana (Chavagnac et al., 1999). According to Kenah and Hollister (1983), tonalitic leucosomes from migmatites of the Central Gneiss Complex are the result of incongruent partial melting processes of the assemblage biotite+plagioclase+quartz, sometimes with the addition of Al-rich hornblende. Tonalitic leucosomes, suggestive of local-internally derived anatexis were found and described by Pattison (1991) as veins transecting granulite facies metagabbros from the Grenville province, Ontario, Canada. Segregated and vein-type tonalitic migmatites, developed within Archaean metabasites, south of the Grenville front are also described by Sawyer (1991). Büsch et al. (1974) proposed the following reaction for the generation of amphibole (hornblende) in migmatites: Bt+An-rich Pl+Qtz=Hbl+Kfs+An-poor Pl+Ttn+H_2O (mineral abbreviations according to Kretz, 1983). According to Mogk (1992), the amphibole-bearing leucosomes from the migmatites of the Northern Gallatin Range were generated by a reaction very similar to that proposed by Kenah and Hollister (1983) with the only addition of epidote and water to the reactants biotite, plagioclase and quartz.

Laboratory experiments carried out by several authors since the beginning of the eighties (Naney, 1983; Conrad et al., 1988; Johnston and Wyllie, 1988; van der Laan and Wyllie, 1992) have shown that amphibole cannot be generated by vapor-absent reactions and the addition of excess water from an external source is essential for the production and stability of hornblende. This constraint, already pointed out by Naney (1983), has been recently confirmed by the results of the partial melting experiments carried out by Gardien et al. (2000) on gneisses consisting of 24% quartz, 42% plagioclase, 25% biotite, 9% K-feldspar and trace amounts of apatite, sphene and epidote. The experiments were performed between 800 and 900 °C and 1.0–2.0 GPa with 2–4 wt.% water content and have clarified the

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key role played by water addition in the crystallization and stability of the hornblende. Although amphibole can be generated by partial melting of gneisses and metasedimentary rocks, most of the amphibole-bearing migmatites originated by partial melting of igneous protoliths of granodioritic (Büsch et al., 1974), trondhjemitic to tonalitic (Mogk, 1992), dioritic to tonalitic (Chavagnac et al., 1999), and tonalitic (Escuder Viruete, 1999) compositions. The recent discovery of a well-exposed outcrop of amphibole-bearing migmatites in NE Sardinia gives the opportunity to investigate this kind of rock in a deep crustal sector of the Southern European Variscan chain.

The present paper tries to clarify the nature and origin of the protolith of amphibole-bearing migmatites from Sardinia through a petrographic–geochemical approach and to define the sequence of metamorphic and magmatic events in that part of the Variscan chain by means of absolute ages on zircons. Moreover, this paper supplies a comprehensive data set on mineralogy, major, trace element and isotope geochemistry of amphibole-bearing migmatites in order to constrain the process of generation of this particular type of migmatite.

2. Geological setting

The Variscan metamorphic basement of Sardinia, belongs to the southern European Variscan Belt. The Sardinian basement is divided into four tectono-metamorphic zones with decreasing metamorphic grade from NE to SW (Carmignani et al., 2001 and references therein): 1) Inner or Axial Zone subdivided into the Hercynian Migmatite Complex (MC) of northern Sardinia attaining the sillimanite+K-feldspar isograd and the Hercynian metamorphic complex with dominant amphibolite facies assemblages (Carmignani et al., 2001) adjacent to the southern side of the Posada–Asinara major tectonic line (PAL, Fig. 1); 2) Internal Nappe Zone (central-northern Sardinia) including low- to medium-grade metamorphic units; 3) External Nappe Zone (central-southern Sardinia) with low-grade metamorphic rocks; 4) External Zone (southern Sardinia, Iglesiente–Sulcis) with low- to very low-grade metamorphic rocks. In the axial zone, north of Olbia, the Migmatite Complex, includes migmatites, pelitic gneisses and Ordovician granitic–granodioritic orthogneisses (Di Simplicio et al., 1974; Ferrara et al., 1978), metabasites with eclogite to granulite facies relics (Giacomini et al., 2005; Franceschelli et al., 2007 and references therein) and calc-silicate nodules. An extensive review of the Sardinian Variscides can be found in Franceschelli et al. (2005). Near to Punta Bados (Fig. 1), the sources of the migmatites are immature greywackes and siliciclastic sediments originated from weathering and erosion of felsic Ordovician igneous rocks (Giacomini et al., 2006). Zircons from migmatites give scattered U–Pb ages between ca. 3.0 Ga and 320 Ma with a cluster of ages between ca. 480

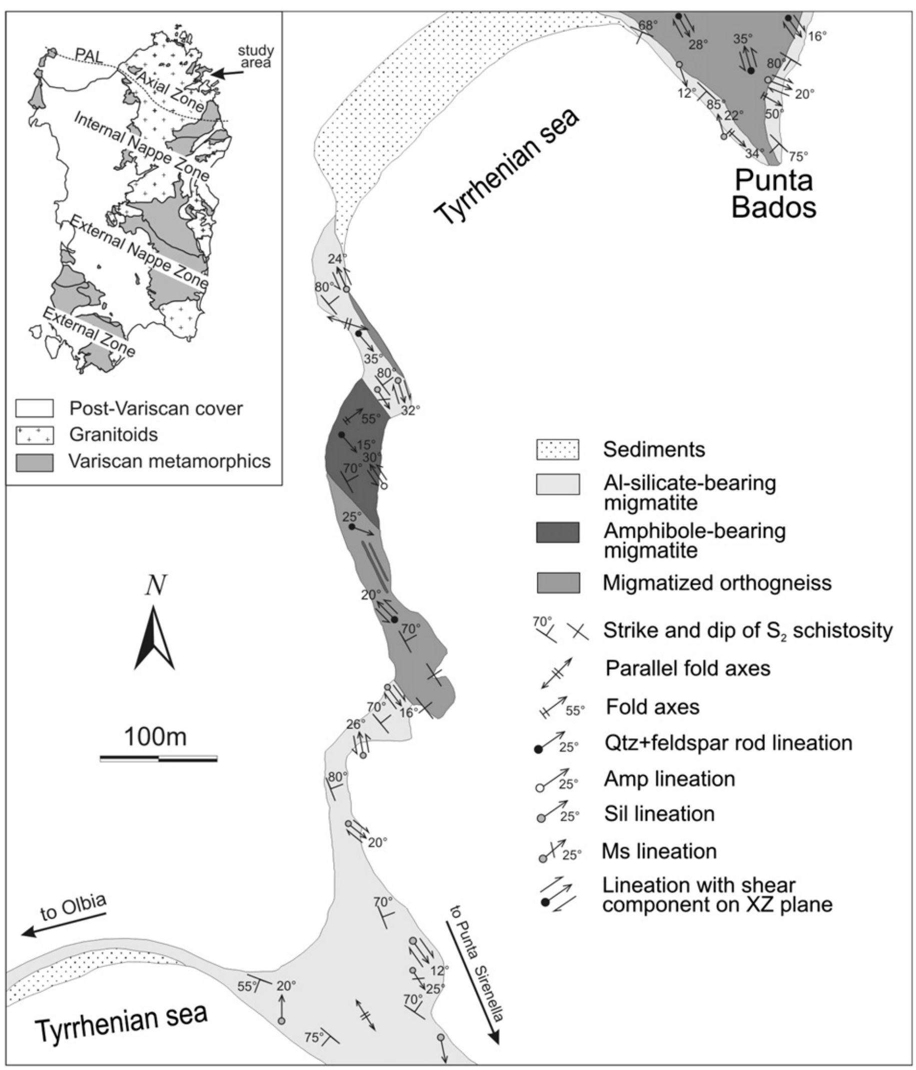

Fig. 1. Geological sketch map of Punta Sirenella–Punta Bados area, NE Sardinia, modified from Cruciani et al. (2008). At the upper left corner, the tectonic sketch map of the Variscan chain of Sardinia is shown (modified from Carmignani et al., 2001). PAL: Posada–Asinara Line.