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Seismic and magnetic susceptibility anisotropy of middle-lower continental crust: Insights for their potential relationship from a study of intrusive rocks from the Serre Massif (Calabria, southern Italy)

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A B S T R A C T

We investigated the relationships between fabric, seismic and magnetic anisotropy on lithotypes representative of a continental crust exposed in the Serre Massif (Southern Italy). In particular, from five granitoids and one metagabbro, cubes were cut according to the fabric elements and seismic properties up to 400 MPa confining pressure were measured with a triaxial multi-anvil apparatus; we also calculated the elastic properties based on the mineral content and composition. In granitoids, measured average compressional wave velocity (Vp) of the fracture-free aggregate at 400 MPa is 6.2 km/s, whereas average shear wave velocity (Vs) is 3.6 km/s, with Poisson's ratio ranging from 0.240 to 0.257, related to the modal proportions of quartz. In metagabbro, average Vp and Vs at 400 MPa are 6.9 km/s and 3.7 km/s, respectively. Results showed that intrinsic velocity distribution, after microcracks closure, depends on progressive alignment of anisotropic minerals such as biotite, amphibole and pyroxene, with maxima velocities localized within the foliation plane. Mean magnetic susceptibility, K_m, of the granitic rocks is $<300 \times 10^{-6}$ SI units, indicating that paramagnetic minerals such as biotite and amphibole control the intensity of magnetic anisotropy. Comparison of seismic and magnetic anisotropies highlighted the different role of constituting minerals over the petrophysical properties. Moreover, a positive correlation between seismic and magnetic anisotropy has been recognized, indicating that biotite and amphibole contribute to the petrophysical and textural anisotropy in the middle crust. Conversely, in metagabbro, the anisotropy of magnetic susceptibility (AMS) is controlled by magnetite and pyrrhotite although these form <10% of the rock, which dominantly comprises paramagnetic minerals such as biotite and orthopyroxene. Unlike granitoids, in metagabbro the petrophysical properties are controlled by the paramagnetic minerals, while the magnetic anisotropy is controlled by the ferromagnetic minerals. Results yielded useful constraints for the comprehension of the petrophysical behavior of the continental crust.

1. Introduction

The analysis of fabric in rocks from the middle and lower continental crust, and an understanding of the processes that lead to this fabric evolution are of global importance, particularly in studies dealing with origin of the lithosphere and related geodynamic investigations. Several geophysical and petrophysical studies have established that the crust and upper mantle are characterized by seismic anisotropy, which can be taken on account of preferred orientation of minerals, cracks and/or fractures, as well as due to occurrence of fine-scale layering (e.g. Babuska, 1981; Christensen and Mooney, 1995; Barruol and Kern, 1996; Tommasi, 1998; Weiss et al., 1999; Punturo et al., 2000; Hurich et al., 2001; Pera et al., 2003; Shapiro et al., 2004; Cella et al., 2004; Punturo et al., 2005; Cirrincione et al., 2010; Sharma et al., 2011; Tripathi et al., 2012; Punturo et al., 2014; Ferré et al., 2014; Ji et al., 2015; Pappalardo et al., 2015; Almqvist and Mainprice, 2017). These studies have highlighted that composition, including metamorphism-induced modifications in mineralogy also influence the velocity, density and reflectivity structures of the crust. Therefore, although the seismic velocity must increase with depth in the continental crust of fixed homogenous composition, the variations in the fabric on account of variations in composition and/or deformation make such one-to-one correlations quite challenging. This in turn adds to difficulties in modelling of large-scale geophysical data. Hence, a thorough understanding of the fabric in rocks (as well as fabric-intensity) from the lower/middle

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crust and upper mantle is essential to arrive at logical conclusions about anisotropies determined from petrophysical investigations in order to permit well constrained interpretation of large-scale geophysical data. This requires an investigation of rocks from an area where the continental crust is well exposed. The Serre Massif (southern Italy) provides geoscientists with a quite rare case of geological terrain, where a complete section of the Late Variscan continental crust is exposed. Kern and Schenk (1985, 1988) proposed a velocity profile for this crustal section. Later, Çifçi and Dondurur (2002) proposed a seismic model for the region and pointed out that accurate knowledge of rock physical properties by direct laboratory investigation is essential for correct interpretation of the seismic results. In addition, one of the other challenges lies in correlating the petrophysical measurements with intensity of fabric from different parts/levels of the exposed continental crust. All these data can eventually provide answers to several outstanding questions viz. (a) how is the seismic velocity related to fabric intensity and its orientation? (b) How does the fabric anisotropy change with depth and how does it influence the seismic anisotropy. Eventually, answers to these questions are expected to provide insights about the middle-lower continental crust behavior. However, to establish the above correlations between fabric intensity and petrophysical properties, it is necessary to have a reliable method that provides information about the bulk fabric of the rock. Moreover, past studies done by Romano et al. (2011), Festa et al. (2012), Festa (2014) and Fiannacca et al. (2017) on the Serre Massif reveal that a visible fabric (foliation/lineation) is not developed everywhere. Thus, in the present study we use anisotropy of magnetic susceptibility (AMS), which is known to be a useful method to determine the fabric in rocks that lack visible planar/linear fabric elements, along with the measurement of seismic anisotropy as well as petrographic and petrochemical measurements. To this aim, five granitoids cropping out along the Serre Batholith, in the central portion of the Calabrian-Peloritani Orogen together with a metagabbro from the lowermost crustal portion are investigated. The selection of samples for the study was done on the basis of visible fabric intensity, i.e. from isotropic through weakly to markedly foliated. To the best of our knowledge, a very few studies are dedicated to integrating AMS with petrophysical data (e.g. Siegesmund et al., 1991; Sharma et al., 2011); therefore the present paper enables to examine the relationship between the seismic vs. magnetic anisotropy, as controlled by rock fabric and modal composition.

2. Geological setting

The Serre Massif (southern Italy, Fig. 1) occupies the central part of the Calabrian-Peloritani Orogen, a piece of Alpine chain located in the Central Mediterranean realm overthrusted on Apennine-Maghrebian chain during Cretaceous-Paleogene (Cirrincione et al., 2015). The Calabrian-Peloritani Orogen is composed of several fragments, which are either continental- and oceanic-derived units; the orogen connects the Apennine chain (Eurasian plate) to the north with the Kabylie-Maghrebian Chain in northern Africa (African plate) to the south. Such metamorphic terranes are usually related to the Variscan Orogeny (330–290 Ma, Schenk,

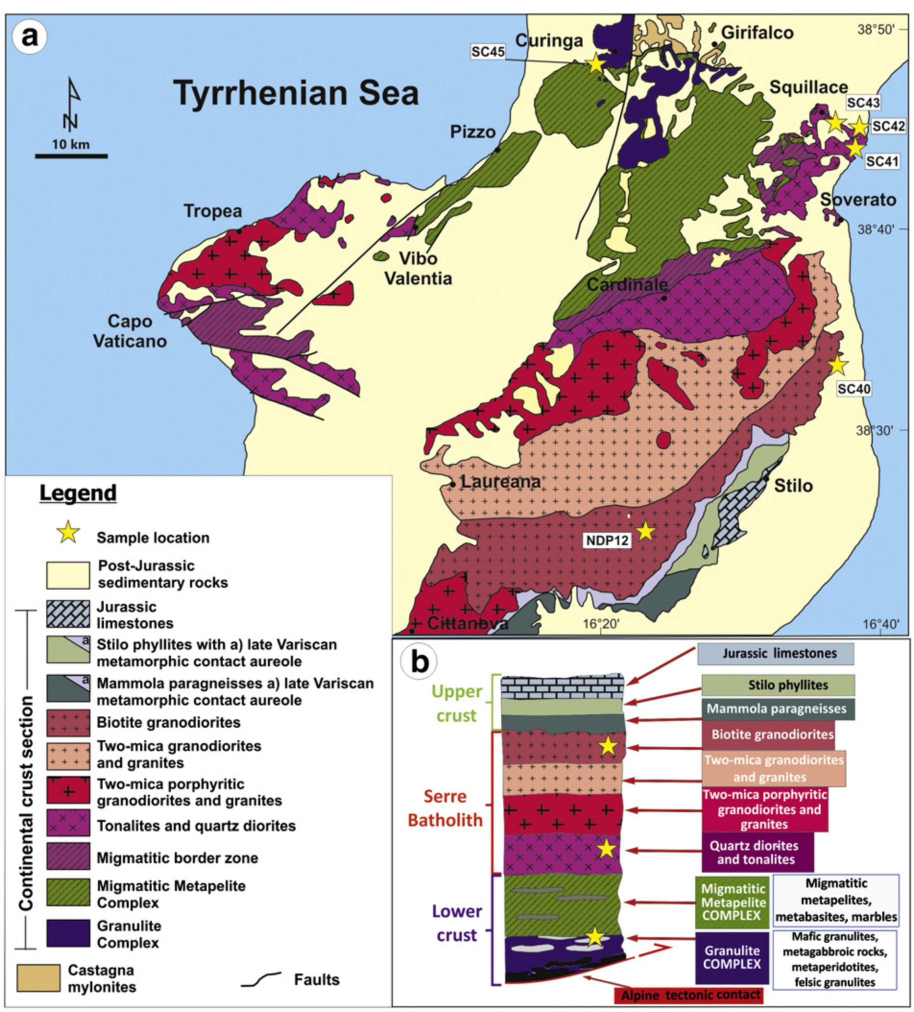

Fig. 1. a) Geological sketch map of the Serre Massif; b) schematic log of the entire crustal section, together with sample location. Modified after Fiannacca et al. (2015) and Cirrincione et al. (2015).