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Crystallographic preferred orientations of exhumed subduction channel rocks from the Eclogite Zone of the Tauern Window (Eastern Alps, Austria), and implications on rock elastic anisotropies at great depths

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ABSTRACT

Crystallographic preferred orientations (CPO) of rocks from an exhumed subduction channel of the Alpine orogen were determined using time-of-flight neutron diffraction. This method allows the investigation of large polymineralic samples and, more importantly, the application of full pattern fit methods to constrain CPOs of mineralogically complex rocks. Samples studied include intensely deformed fresh and retrogressed eclogites, as well as metasediments, which are interleaved with the eclogites in the subduction channel. From the CPO, seismic properties of the samples were calculated. P-wave anisotropies of the eclogite samples are fairly low, with an average of about 1.5%, and mainly constrained by pronounced omphacite CPO. Growth and deformation of retrograde amphibole in the eclogites also led to a pronounced CPO, which has a large impact on seismic anisotropies by raising them to up to 3.7% and changing the orientations of velocity maxima. Elastic anisotropies of the subducted metasediments are higher (up to 7.4%) and constrained by quartz and mica CPO in clastics and by calcite CPO in marble. V_P/V_S ratios may help to distinguish fresh eclogites from retrogressed ones, and both rock types from mantle peridotites of downgoing lithospheric slabs in seismic imaging. Our data also indicate that subducted terrigenous sediments not only are strongly anisotropic, but also have low V_P/V_S ratios. This way there may be the potential to image them by seismic tomography at depth in active subduction channels.

1. Introduction

The interface of convergent plate boundaries is a highly dynamic tectonic environment, featuring deep subduction, offscraping of lower plate materials, underplating, and eventual exhumation by return flow towards the Earth's surface. The general concept is that of rocks moving in a subduction channel, first established by Shreve and Cloos (1986) and Cloos and Shreve (1988). These authors mainly describe the movement of material to and from depths of 30 km. More recent subduction channel models include the exhumation of previously subducted oceanic crust and sedimentary cover from depths of over 70 km (e.g. Agard et al., 2009; Angiboust et al., 2009). The generally invoked driving mechanisms are buoyancy of surrounding low-density rocks (e.g. Guillot et al., 2001; Kurz and Froitzheim, 2002), external forcing by continental fragments entering the subduction zone (e.g. De Franco et al., 2008), slab breakoff (e.g. Ratschbacher et al., 2004), or the changeover to an extensional regime in the overriding plate (e.g. Behrmann and Ratschbacher, 1989; Platt, 1986). There is a large number of recent regional studies of exhumed subduction channel rocks, which yield information on their petrology and tectonic history. Examples are the Franciscan Complex of California (e.g. Anczkiewicz et al., 2004), the Mesohellenic subduction zone in the Cyclades (e.g. Schmaedicke and Will, 2003), the Western (e.g. Bousquet, 2008) and the Eastern Alps (e.g. Kurz et al., 1998). Common to all these subduction zones are the thickness of only a few kilometres and their lithologies comprising metabasic lenses of variable size embedded in a matrix of lower-density metasediments or serpentinites.

Despite detailed field investigations and numerous models for subduction channels, the exact processes taking place within are far from being completely understood. High resolution seismic imaging – a promising tool for the deconvolution of small-scale structures at depth – is still hampered by inadequate knowledge regarding the velocity structure and elastic anisotropies. Elastic anisotropy data of rocks incorporated in subduction zones are an important source of information for the interpretation of (high resolution) seismic sections, and have been used to aid the understanding of mantle dynamics (e.g. Montagner and Guillot, 2003; Montagner and Tanimoto, 1990; Silver, 1996). In this context crystallographic preferred orientation (CPO) of the rock constituents can be used as a powerful tool to predict the elastic anisotropy of

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deformed subduction channel rocks. However, the acquisition of CPO data and, thus, obtaining first-hand information on elastic anisotropies of polymineralic rocks is not straightforward. Most studies on polymineralic rocks were conducted on materials from the upper and lower crust (e.g. Ivankina et al., 2005; Kitamura, 2006; Ullemeyer et al., 2006), or on rocks originating from above and below the continental Moho (e.g. Barruol and Kern, 1996; Llana-Fúnez and Brown, 2012; Pros et al., 2003; Ullemeyer et al., 2010). Elastic data for subduction channel rocks were provided by Mauler et al. (2000), Bascou et al. (2001), and Worthington et al. (2013), who investigated mineral CPOs of eclogites using EBSD (electron backscatter diffraction) and bulk rock elastic anisotropies calculated from the CPO data. However, these studies neither include metasedimentary rocks in the subduction channel nor retrogressed eclogites, which yield information on the processes and changes in state during exhumation. Furthermore, a methodical drawback of EBSD is the poor grain statistics due to limited sample size, which has consequences when calculating rock physical properties from CPO data.

To overcome these methodical limitations, and to offer a more comprehensive insight into the petrophysics of rock associations in a subduction channel, we present CPOs and bulk rock elastic anisotropies of principal rocks from an exhumed subduction channel: the Eclogite Zone (EZ in the following) of the Tauern Window in the Eastern Alps. The CPOs were acquired from time-of-flight neutron diffraction spectra applying the full pattern fit method for the texture evaluation, which permits a fully quantitative investigation of large rock samples with complex mineralogy. From the CPO data, we have modelled elastic anisotropies. In addition, two eclogite samples were the subject of direct P-wave velocity measurements on spherical samples, giving an impression of the crack influence on the elastic rock properties at shallow and intermediate crustal depths. Our results allow to make inferences regarding the seismic attributes of subduction channels, especially acoustic anisotropy, and guide future visualization of subduction channel structure and physical properties.

2. Geological overview of study area

The EZ is located at the southern margin of the Tauern Window in the Eastern Alpine Orogen (Fig. 1A and B). The Tauern Window is a tectonic window exposing basement and cover of the lower European plate, as well as Penninic oceanic units that were initially subducted beneath the Adriatic plate and subsequently incorporated in the Alpine stack of tectonic nappes during continental collision in the Tertiary. The EZ is considered to represent the ocean-continent boundary at the distal European margin. Its general character is a volcano-sedimentary sequence formed during Jurassic rifting of the Penninic ocean (Kurz et al., 1998). Driven by the negative buoyancy of the downgoing Penninic oceanic slab, the EZ entered the subduction channel in the course of Adria–Eurasia convergent movements. The rocks were subjected to PT conditions of 2.0–2.5 GPa and 600 ± 30 °C (Dachs, 1990; Hoschek, 2001, 2004; Stöckhert et al., 1997). Rb–Sr dating by Glodny et al. (2005) and Lu–Hf dating by Nagel et al. (2013) indicate an Oligocene age for the peak PT conditions, and a fast exhumation thereafter within 1–2 Ma. Because of the fast exhumation from great depths, only part of the rocks suite was severely affected by retrograde metamorphism. With large coherent sheets of eclogite and interleaved metasediments preserved, the area offers the

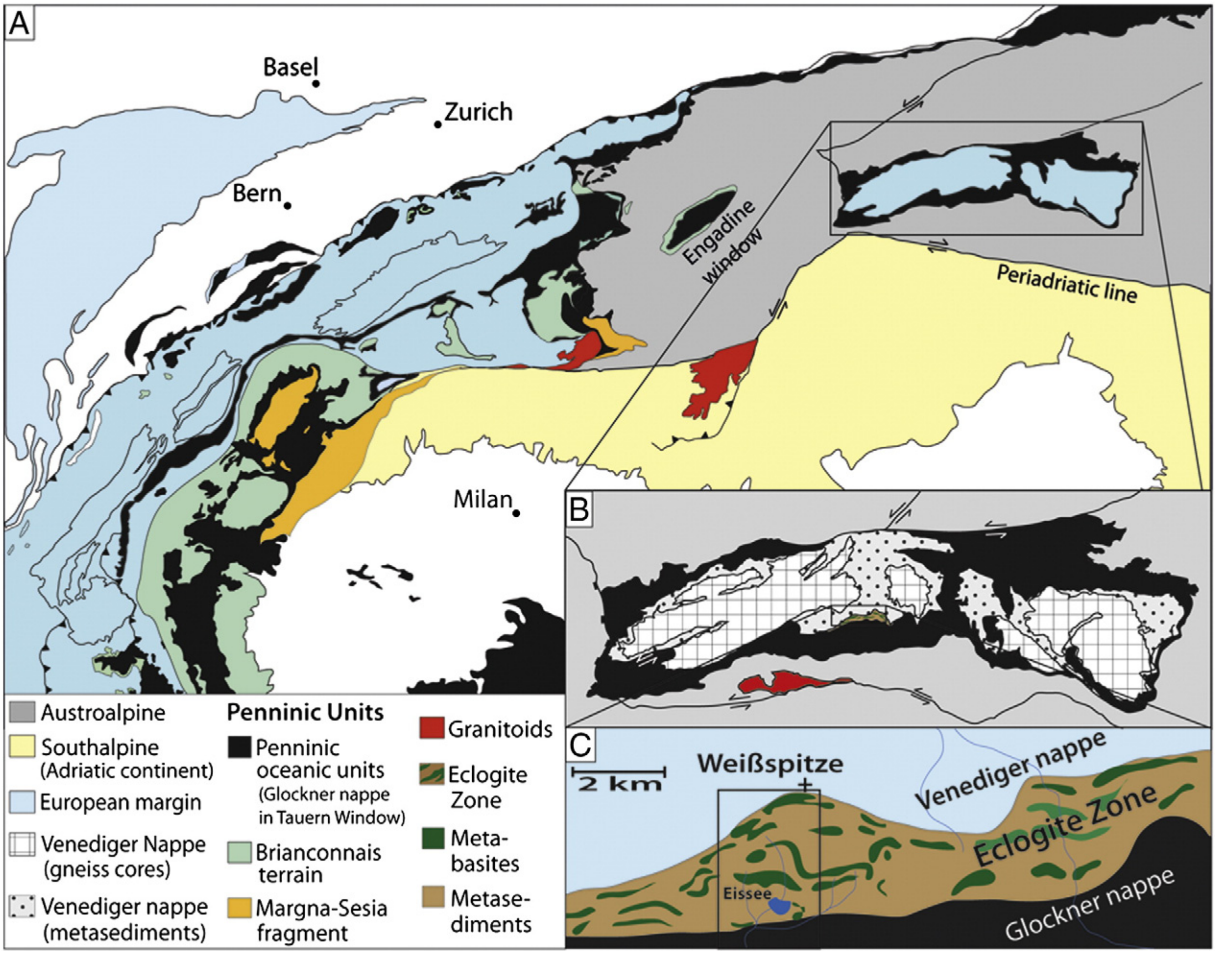

Fig. 1. Tectonic maps of A) the Alps, B) the Tauern Windom (after Schmid et al., 2013) and C) the Eclogite Zone (after Neufeld et al., 2008). The location of the field area is indicated by a frame.