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The geological signature of a slab tear below the Aegean

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ABSTRACT

In this paper we explore the geology of the Aegean region in the Miocene to identify the geological signature of a first-order slab tear observed in all tomographic models. From 15 to 8 Ma, the tear is associated, spatially and timely, with a fast clockwise rotation of the External Hellenides, alkaline volcanism, high-temperature metamorphic domes with a predominance of north-dipping detachments, and south-westward migration of granitoid intrusions. These features suggest a warmer geodynamic environment during the rotation and the impact of a hot mantle flow associated with the tear. The ~8 Ma duration between the first high-temperature metamorphic domes in the centre of the archipelago and the beginning of the fast rotation may correspond to the time needed for the slab to bend, stretch and finally tear.

1. Introduction

The tearing of subducting slabs play a major role in lithospheric-scale models of the Mediterranean region (Carminati et al., 1998; Faccenna et al., 2004, 2005; Govers and Wortel, 2005; Jolivet et al., 2009, 2013; Piromallo and Morelli, 2003; Spakman and Wortel, 2004; Wortel and Spakman, 2000). Similarly to slab break-off (i.e., detachment of the hanging oceanic slab by a sub-horizontal rupture), slab tearing (i.e., sub-vertical ruptures within the subducting slab) in the Mediterranean is deduced from seismic tomography models of the mantle and often associated with specific magmatic signature at the surface (Dilek and Altunkaynak, 2009; Faccenna et al., 2007). Govers and Wortel (2005) have proposed to name such lateral tears STEP-faults, standing for Subduction-Transform Edge Propagator and they studied them through mechanical modelling. They concluded that such STEPs can be stable plate tectonic features and thus influence the kinematics around for significant periods of time. However, the influence of tearing the subducting slab on the tectonic evolution of the subduction upper plate is still poorly known.

Numerical or analogue models show that laterally unconfined slabs and tears in subducting slabs should induce complex 3D mantle flow with significant toroidal component around the edges of torn slabs (Faccenda and Capitanio, 2012; Funiciello et al., 2003, 2006; Moresi et al., 2014; Piromallo et al., 2006; Sternai et al., 2014), which seems to be reflected in some seismic anisotropy data sets (Lin et al., 2011). In the case of the Aegean, the flow pattern suggested by the SKS anisotropy appears quite simple except for some anomalous directions that may result from a slab tear below Western Turkey (Paul et al., 2014). The presence of adakitic magmatic products is for instance a common characteristic leading to infer the presence of a slab tear or detachment (Omrani et al., 2008; Réhault et al., 2012; Yogodzinski et al., 2001). This common inference is based upon the simple idea that an anomalously hot mantle is required to produce this type of magma. The rise of the asthenospheric mantle through a tear may very well provide this thermal anomaly, but the geological effects of such tears are not clear and they are likely to be highly variable depending upon the area considered. Using the wealth of geological and geophysical data accumulated in the Mediterranean region we address in this work the possible geological signature of a slab tear below the Aegean region.

The geodynamic evolution of the Mediterranean region is largely controlled by the behaviour of the African slab in the asthenosphere (Doglioni et al., 2002; Faccenna and Becker, 2010; Faccenna et al.,

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2007; Jolivet et al., 2009). The apparent geometrical complexity of arcuate mountain belts (Alps, Carpathians, Dinarides, Hellenides) and back-arc basins (e.g. Alboran Sea, Liguro-Provençal Basin, Tyrrhenian Sea, Aegean Sea, Pannonian Basin) results from slab backward migration and their tearing or break-off (Berk Biryol et al., 2011; Faccenna et al., 2004; Gessner et al., 2013; Guillaume et al., 2013; Jolivet et al., 2013; Papanikolaou and Royden, 2007; Royden and Papanikolaou, 2011; Schildgen et al., 2014; van Hinsbergen and Schmid, 2012; Wortel and Spakman, 2000). The progressive tearing of the Tyrrhenian slab has resulted in the present steeply-dipping narrow stripe of lithosphere seen in tomographic models and in a progressive acceleration of slab retreat with time (Carminati et al., 1998; Faccenna et al., 2004, 2007; Rosenbaum and Lister, 2004). Several studies have described the geodynamic evolution of sedimentary basins and magmatism in this region during slab retreat and progressive tearing (Faccenna et al., 2007; Massari and Prosser, 2013; van der Meulen et al., 1998). Similar contexts can be found in the Alboran region or in the Aegean but, so far, very few studies were conducted to see which type of crustal structures could be diagnostic of slab tearing at depth, except for the work of Gessner et al. (2013) who have interpreted the exhumation and extension of the Menderes massif as a consequence of a slab tear below Western Anatolia and the formation of a left-lateral transtensional shear zone, which they name the West Anatolia Transfer Zone. In a numerical study, Le Pourhiet et al. (2012) have furthermore proposed that metamorphic domes elongated parallel to the direction of stretching in the Aegean (a-type domes, Jolivet et al., 2004a, 2004b) could be formed in such environments by differential stretching above a slab tear. The model concerns the formation of domes in a transtensional strike–slip regime but the tear itself is not modelled. In a more recent study, Sternai et al. (2014) model the distribution of strain in the upper plate above a slab tear but the detailed kinematics of exhumed material above the tear is not modelled either. By means of analogue modelling Guillaume et al. (2013) have explored the effect of lateral variations in the nature of the subducting plate (oceanic *vs* continental) and they suggested that the western recent tear of the Aegean slab is responsible for the dextral shearing of the upper plate and the formation of the Central Hellenic Shear Zone described by Royden and Papanikolaou (2011).

In this paper, we explore the geology of the Aegean Sea (Fig. 1) in the Miocene with the aim of searching for crustal structures and magmatic events that could be related to a first-order slab tear seen in all tomographic models below the eastern Aegean (Berk Biryol et al., 2011; de Boorder et al., 1998; Dilek and Altunkaynak, 2009; Ersoy and Palmer, 2013; Jolivet et al., 2013; Piromallo and Morelli, 2003; Salaün et al., 2012). We confirm that the tear, associated with a long-recognised fast clockwise rotation of the external Hellenides from 15 to 8 Ma (Kissel and Laj, 1988; van Hinsbergen et al., 2005b), is also spatially and timely associated with alkaline volcanism, the formation of high-temperature and metamorphic domes with axes parallel to the direction of extension and a predominance of top-to-the north shearing deformation and north-dipping detachments and with the southwestward migration of granitoid intrusions.

2. Geological context

Temporal constraints on the geological evolution of the Aegean Sea and the Cyclades are compiled in Figs. 2 and 3, respectively.

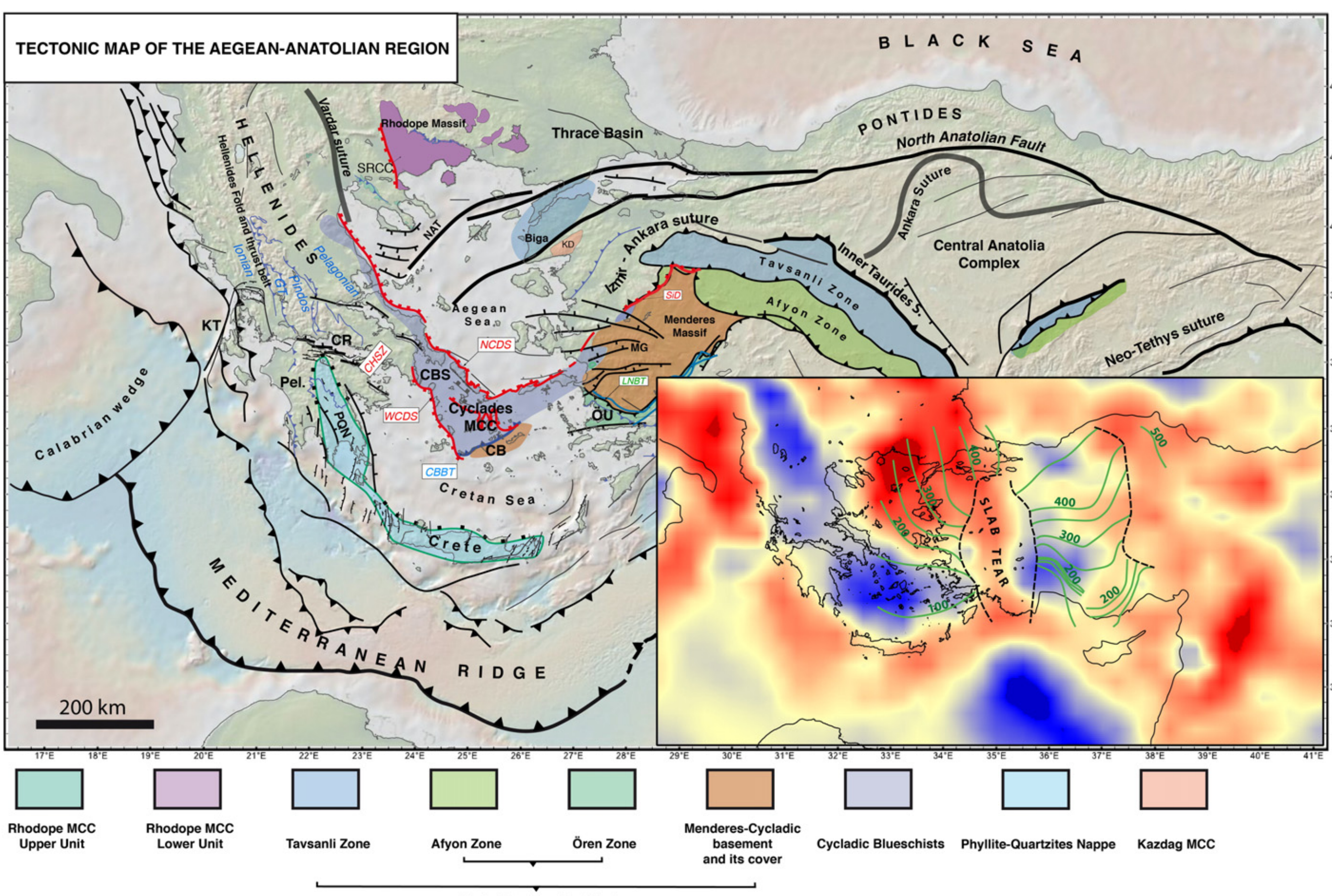

Fig. 1. Geological and geodynamic context of exhumed metamorphic complexes in the Aegean Sea and Anatolia and (insert) P-wave seismic tomography model of the upper mantle (average between 100 and 250 km) after Piromallo and Morelli (2003). The geometry of the slab tear is shown with the interpretation of the P-wave tomographic model of Berk Biryol et al. (2011) and the isobaths of the slab shown in Gessner et al. (2013).