Earth and Planetary Science Letters 480 (2017) 97–106

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Seismic anisotropy in the Hellenic subduction zone: Effects of slab segmentation and subslab mantle flow

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ARTICLE INFO

Article history:
Received 22 May 2017
Received in revised form 28 September 2017
Accepted 1 October 2017
Available online xxxx
Editor: P. Shearer

Keywords:
seismic anisotropy
subslab mantle flow
slab tear
Hellenic arc
trench parallel anisotropy
source-side shear wave splitting

ABSTRACT

The segmentation and differentiation of subducting slabs have considerable effects on mantle convection and tectonics. The Hellenic subduction zone is a complex convergent margin with strong curvature and fast slab rollback. The upper mantle seismic anisotropy in the region is studied focusing at its western and eastern edges in order to explore the effects of possible slab segmentation on mantle flow and fabrics. Complementary to new SKS shear-wave splitting measurements in regions not adequately sampled so far, the source-side splitting technique is applied to constrain the depth of anisotropy and to densify measurements. In the western Hellenic arc, a trench-normal subslab anisotropy is observed near the trench. In the forearc domain, source-side and SKS measurements reveal a trench-parallel pattern. This indicates subslab trench-parallel mantle flow, associated with return flow due to the fast slab rollback. The passage from continental to oceanic subduction in the western Hellenic zone is illustrated by a forearc transitional anisotropy pattern. This indicates subslab mantle flow parallel to a NE–SW smooth ramp that possibly connects the two subducted slabs. A young tear fault initiated at the Kefalonia Transform Fault is likely not entirely developed, as this trench-parallel anisotropy pattern is observed along the entire western Hellenic subduction system, even following this horizontal offset between the two slabs. At the eastern side of the Hellenic subduction zone, subslab source-side anisotropy measurements show a general trench-normal pattern. These are associated with mantle flow through a possible ongoing tearing of the oceanic lithosphere in the area. Although the exact geometry of this slab tear is relatively unknown, SKS trench-parallel measurements imply that the tear has not reached the surface yet. Further exploration of the Hellenic subduction system is necessary; denser seismic networks should be deployed at both its edges in order to achieve a more definite image of the structure and geodynamics of this area.

1. Introduction

1.1. Regional geotectonics and geodynamics

The Hellenic subduction zone is characterized as a complex tectonic region resulting from the interaction between Africa and Eurasia convergence, the SW motion of Anatolia, and the large extension affecting the Aegean due to the slab retreat (Fig. 1). The African plate moves northwards at a rate of 1 $cm\,yr^{-1}$ and subducts along the Hellenic trench forming an active volcanic arc. The associated seismicity delineates a Wadati–Benioff zone extending down to a depth of 180 km. Complementary, Anatolia is extruded westwards and its relative motion with Eurasia to the north is accommodated along the strike-slip system of the North Anatolian Fault (NAF). The African slab retreat of the last 30–35 Ma (Wortel and Spakman, 2000) causes southward motion of the Hellenic active margin and significant extension of the overriding lithosphere (Fig. 1). This indicates that slab rollback and the induced mantle flow are the major cause of the observed surface deformation (Pérouse et al., 2012; Jolivet et al., 2013). In western Greece, the Hellenic subduction system is separated by the Kefalonia Transform Fault (KTF), a dextral offset of 100 km, into the northern and southern segments which are characterized by different convergence rates and slab composition. Recent seismic data show that north of KTF the subducted lithosphere is continental in contrast to the region south of KTF where the on-going subduction is oceanic (Pearce et al., 2012). Subduction rates of 5–10 $mm\,yr^{-1}$ and $\sim$35 $mm\,yr^{-1}$ north and south of KTF, respectively, is the geodynamic response to the subduction of the dense Ionian oceanic lithosphere beneath the southern Hellenides from mid–Miocene to recent time (Royden and Papanikolaou, 2011). The total length of this subducted oceanic lithosphere beneath the Peloponnese is $\sim$300 km. Moreover, this Ionian slab is segmented into dipping

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https://doi.org/10.1016/j.epsl.2017.10.003

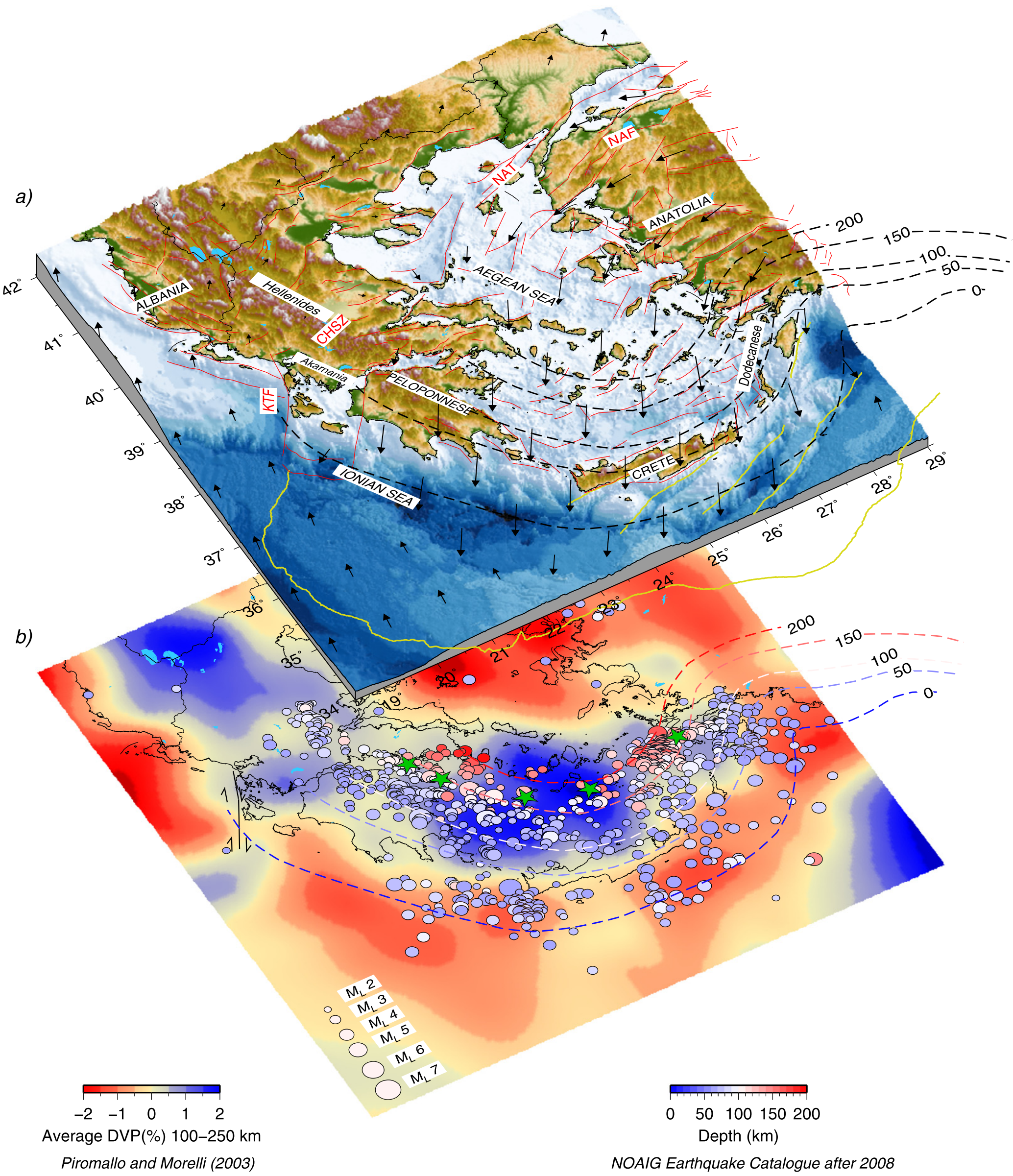

Fig. 1. (a) Topographic map of the study area with surface traces of seismogenic sources from Caputo et al. (2012) in red. The velocity vectors are modeled in the absolute plate motion reference frame GSRM-APM-1 by Pérouse et al. (2012). Yellow line delineates trench location and its secondary branches. KTF: Kefalonia Transform Fault, CHSZ: Central Hellenic Shear Zone, NAT: Northern Aegean Trough, NAF: North Anatolian Fault. (b) National Observatory of Athens – Institute of Geodynamics (NOAIG) earthquake catalog locations for events between 2008–2015 ($Depth \geq 60$ km, $M_L \geq 2$) superimposed on the average Vp perturbation of the tomography model by Piromallo and Morelli (2002) for the topmost mantle between 100 and 250 km depth. The surface trace of KTF is marked and the green stars indicate the active volcanic arc. Dashed contours of the subducting slab after Gudmundsson and Sambridge (1998) and earthquake hypocenters are colored relatively to their corresponding depth. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

panels by along-dip faults (Sachpazi et al., 2016). The intermediate depth seismicity is clustered along these faults suggesting high mechanical coupling between the two plates.

KTF may be linked to NAF through a broad transtensional Central Hellenic Shear Zone (CHSZ) separating the southern from the northern segment (Royden and Papanikolaou, 2011). As only normal faulting is identified between these two large strike slip systems, a dextral shear component is not required in the shear strain field (Pérouse et al., 2012). Moreover, Chousianitis et al. (2015) detected two pairs of shear belts, one in Akarnania and northwestern Peloponnese and one in north Aegean but found no geodetic evidence for NAF extension towards central Greece. Thus, a surface expression of a transitional regime between the northern and southern segment is not observable (Fig. 1).

Apart from hypocenters of the intermediate depth earthquakes that map the subducted slab, seismic tomography shows a high velocity body that can be followed down to at least the upper-lower mantle transition zone (Wortel and Spakman, 2000; Piromallo and Morelli, 2002). Between Crete and Cyprus a slab tear has been inferred and its rupture may be prolonged until the eastern Hellenic trench (e.g. Biryol et al., 2011). Brun and Sokoutis (2010) suggested that the slab is torn apart somewhere below southwestern Turkey, perpendicular to the direction of convergence.

1.2. Seismic anisotropy and possible origins

The observation of seismic anisotropy can provide a direct way of imaging mantle deformation. The prevailing mechanism that generates seismic anisotropy in the mantle is lattice preferred ori-