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What caused the denudation of the Menderes Massif: Review of crustal evolution, lithosphere structure, and dynamic topography in southwest Turkey

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ABSTRACT

The deformation of Earth's lithosphere in orogenic belts is largely forced externally by the sinking slab, but can also be driven by internal delamination processes caused by mechanical instabilities. Here we present an integrated analysis of geophysical and geological data to show how these processes can act contemporaneously and in close proximity to each other, along a lithosphere scale discontinuity that defines the lateral boundary between the Hellenide and Anatolide segments of the Tethyan orogen in western Turkey. The Hellenides and Anatolides have experienced similar rates of convergence, but display remarkable differences in the structure of Earth's crust and lithospheric mantle across the Aegean coast of the Anatolian peninsula. We review the tectonics of southwest Turkey in the light of new and published data on crustal structure, cooling history, topography evolution, gravity, Moho topography, earthquake distribution and seismic tomography. Geological data constrain that one of Earth's largest metamorphic core complexes, the Menderes Massif, experienced early Miocene tectonic denudation and surface uplift in the footwall of a north-directed extensional detachment system, followed by late Miocene to recent fragmentation by E–W and NW–SE trending graben systems. Gravity data, earthquake locations and seismic velocity anomalies highlight a north–south oriented boundary in the upper mantle between a fast slab below the Aegean and a slow asthenospheric region below western Turkey. Based on the interpretation of geological and geophysical data we propose that the tectonic denudation of the Menderes Massif and the delamination of its subcontinental lithospheric mantle reflect the late Oligocene/early Miocene onset of transtension along a lithosphere scale shear zone, the West Anatolia Transfer Zone (WATZ). We argue that the WATZ localised along the boundary of the Adriatic and Anatolian lithospheric domains in the Miocene, when southward rollback of the Aegean slab started to affect the central Aegean–Menderes portion of the Tethyan orogen. Transtension across the West Anatolia Transfer Zone affected the entire Menderes Massif in the Early Miocene. The current crustal expression of this boundary is a NNE-trending, distributed brittle deformation zone that localised at the western margin of the denuded massif. Here, sinistral transtension accommodates the continuing velocity difference between relatively slow removal of lithospheric mantle below western Anatolia and trench retreat in the rapidly extending Aegean Sea region. Our review highlights the significance of lateral variations of the lower plate in subduction–collision systems for evolving structure and surface processes in orogenic belts, particularly in relation to the formation of continental plateaux and metamorphic core complexes.

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1. Introduction

Lithosphere architecture and strain distribution can vary substantially in orogenic belts, both across and along strike. Along-strike variations and structural complexity are common features of mountain belts such as the European Alps (e.g. Schmid et al., 2004), the Andes (e.g. Allmendinger et al., 1997), the Himalayas (e.g. An, 2006) and the Hellenide–Anatolide orogen in southeastern Europe (Ring et al., 1999a; Gessner et al., 2001c; Gessner et al., 2011; van Hinsbergen and Schmid, 2012). The causes for along-strike variations are likely to differ in individual orogenic belts, but will generally be a consequence of compositional and architectural variations in the accreting or colliding continental lithosphere fragments. Along-strike variations, however, depend not only on the composition and architecture of these fragments, but also on the differential dynamics generated by the sinking slab, and by mechanical instabilities that affect the accretion of continental arcs even at distances far from the actual tectonic margin, and shape the geology, topography and the lithosphere structure sensed by geophysical data. It has been recognised that throughout the Earth's history tectonic and magmatic accretion of continental arcs not only have played an important role in the growth of continents (Rudnick, 1995), but also as regions of long-lived thermally weakened mobile belts (Hyndman et al., 2005). Conceptual and numerical models of generic and regionally specific continental arcs suggest that deformation is not only mainly driven by external forcing by the sinking slab (Royden, 1993; Collins, 2002; Schellart et al., 2007; Spakman and Hall, 2010), but also internally, by gravitational instabilities within thermally weakened lithosphere (Houseman et al., 1981; England and Houseman, 1989; Molnar et al., 1993; Platt and England, 1993; Houseman and Molnar, 1997; Stern et al., 2006), with mechanical and thermal coupling across the subduction zone determining how these processes interact (Faccenda et al., 2009). The significance of considering 'internal drivers' such as gravitational instabilities in addition to 'external drivers' such as sinking slabs, is that synchronous contraction and extension can be accommodated in the Earth's crust over relatively short across-strike distances (Gögüs and Pysklywec, 2008; Faccenda et al., 2009). Such internal driving processes pose a challenge to the existence of regional or far-field force continua across orogens, an assumption that is often made a priori when deformation fabrics are linked with geodynamic processes in ancient orogenic belts. The partition of deformation along active continental collision zones such as the Tethyan orogen in the Eastern Mediterranean provide a natural laboratory where the recent and current evolution of geological structures can be studied and interpreted in the context of surface processes, gravity anomalies, seismicity, geodetic measurements, and mantle tomography. In the Eastern Mediterranean the southward rollback of the Hellenic subduction zone and the westward motion of Anatolia dominate the kinematics of continental plate fragments as they occur at much higher rates than the convergence between Africa and Eurasia (e.g. Reilinger et al., 2006; Pérouse et al., 2012) (Fig. 1). This study focuses on southwest Turkey, where the westward movement of Anatolia changes to the southward movement of the Aegean, where the Anatolian plateau gives way to the Aegean Sea, and where the Hellenide and Anatolide segments of the Tethyan orogen meet. We describe the regional structure across the Hellenide–Anatolide transition and, in the light of new and published apatite fission track data, discuss the tectonic models put forward for the Menderes Massif, particularly with regard to key structures like the Simav detachment and the Selimiye shear zone. We then use the structure of the Alpine nappe stack as a marker to track the deformation imposed on western Anatolia by the late Miocene to recent extension, as evidenced by topography and drainage channel morphology. Using geophysical data such as gravity, seismic velocity anomaly, and earthquake hypocentre locations we show how the geological along-strike-differences between the Hellenic and the Anatolide crustal domains relate to the