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Linking slab break-off, Hellenic trench retreat, and uplift of the Central and Eastern Anatolian plateaus

T.F. Schildgen [a,*], C. Yıldırım [b], D. Cosentino [c,d], M.R. Strecker [a]

[a] *Institut für Erd- und Umweltwissenschaften, and DFG Leibniz Center for Surface Processes and Climate Studies, Universität Potsdam, 14476 Potsdam-Golm, Germany*
[b] *Eurasia Institute of Earth Sciences, Istanbul Technical University, Istanbul, Turkey*
[c] *Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre, Rome, Italy*
[d] *Istituto di Geologia Ambientale e Geoingeneria (IGAG-CNR), Rome, Italy*

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ABSTRACT

The Central and Eastern Anatolian plateaus are integral parts of the world's third largest orogenic plateau. In the past decade, geophysical surveys have provided insights into the crust, lithosphere, and mantle beneath Eastern Anatolia. These observations are now accompanied by recent surveys in Central Anatolia and new data constraining the timing and magnitude of uplift along its northern and southern margins. Together with predictions from geodynamic models on the effects of various processes on surface deformation and uplift, the observations can be integrated to identify probable mechanisms of Anatolian Plateau growth.

A changeover from shortening to extension along the southern margin of Central Anatolia that is coeval with the start of uplift can be most easily associated with oceanic slab break-off and tearing. This interpretation is supported by tomography, deep seismicity (or lack thereof), and gravity data. Based on the timing of uplift, geophysical and geochemical observations, and model predictions, slab break-off likely occurred first beneath Eastern Anatolia in middle to late Miocene time, and propagated westward toward Cyprus by the latest Miocene. Alternatively, the break-off near Cyprus could have occurred in late Pliocene to early Pleistocene time, in association with collision of the Eratosthenes Seamount (continental fragment) with the subduction zone. Uplift at the northern margin of Central Anatolia appears to result from crustal shortening starting in the late Miocene or early Pliocene, which has been linked to the broad restraining bend of the North Anatolian Fault. The uplift history of the interior of Central Anatolia since the late Miocene is unclear, although shortening there appears to have ended by the late Miocene, followed by NE–SW extension. This change in the deformation style broadly coincides with faster retreat of the Hellenic trench as well as uplift of the northern and southern margins of Central Anatolia.

These different events throughout the plateau may be linked, as faster retreat of the Hellenic trench has been predicted to occur after slab break-off, which could have induced extension of Central Anatolia and helped to form the North Anatolian Fault through accelerated westward movement of Anatolia relative to Eurasia. Correlative geochronologic evidence that we summarize here supports the hypothesis that the geodynamic activity throughout the Aegean–Anatolian domain starting in latest Miocene to early Pliocene time defines a series of events that may all be linked to slab break-off.

Contents

* Corresponding author. Tel.: +49 331 977 5849.
E-mail address: tschild@uni-potsdam.de (T.F. Schildgen).

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1. Introduction

A wide range of geodynamic mechanisms has been invoked to explain the growth of high topography in orogenic belts and plateaus. In some cases, a single mechanism capable of inducing broad, regional uplift, such as lithospheric delamination, has emerged as a favored interpretation, for example in the Sierra Nevada (Jones et al., 2004; Zandt et al., 2004) and the southern Central Andes (Kay and Kay, 1993; Kay et al., 1994; Yuan et al., 2002). Often, however, delamination only occurs after significant crustal and lithospheric shortening and thickening, which itself should produce isostatic uplift. Such temporal changes in uplift mechanisms have spurred investigations into the relative contributions of crustal shortening, lithospheric thinning, lower crustal flow, magmatic addition, or other processes in producing uplift (e.g., Dewey and Burke, 1973; Froidevaux and Isacks, 1984; Allmendinger et al., 1997; Şengör et al., 2008). Further complications arise in regions near oceanic subduction zones, where the subduction of oceanic ridges, seamounts, or oceanic plateaus (Livaccari et al., 1981; Cloos, 1991; Espurt et al., 2008), changes in slab dip (Jordan et al., 1983; Gutscher et al., 2000), magmatic underplating (Brown, 1993), and slab break-off (Davies and von Blanckenburg, 1995) may all potentially deform and elevate the overriding plate. More recently, the effects of upper mantle flow in producing dynamic topography have been considered capable of producing km-scale uplift (Boschi et al., 2010; Faccenna and Becker, 2010; Karlstrom et al., 2012), while the development of large, mantle-scale convection cells may be responsible for the initial shortening seen in major orogenic plateaus like the Andes and Tibet (Faccenna et al., 2013).

The world's largest orogenic plateaus in Tibet and the Andes are typically viewed as resulting from a combination of these deep-seated processes, and appear to have grown in both elevation and areal extent through time (e.g., Isacks, 1988; Allmendinger et al., 1997; Tapponnier et al., 2001). Once attaining critical elevations, the influence of local topographic highs on the distribution and amount of rainfall and consequent erosion and deposition patterns (e.g., Bookhagen and Strecker, 2008; Roe et al., 2008) can also help to create a regional plateau morphology (Sobel et al., 2003). In some cases, these feedbacks between tectonics and surface processes appear to strongly influence the evolution of plateau margins (e.g., Hodges et al., 2004; Strecker et al., 2007, 2009).

If orogenic plateaus grow gradually through time, the relatively small Anatolian Plateau may be an early-stage analog for the world's larger orogenic plateaus. High-elevation (2 to 2.5 km average), high-relief topography in Eastern Anatolia transitions to lower elevation (1.5 to 2 km average), low-relief topography in Central Anatolia, with high-relief mountain ranges bounding the northern and southern margins of both regions (Figs. 1 and 2). While Eastern Anatolia exhibits symmetric plateau morphology in a N–S topographic swath profile (Fig. 1C), Central Anatolia has a lower interior compared to its margins, and shows a distinct asymmetry in its minimum elevations, reflecting the predominantly northward-directed drainage (Fig. 1B).

The Arabia–Eurasia collision at the eastern end of the Aegean–Anatolian domain is inferred to have started in late Eocene/Oligocene time (e.g., Jolivet and Faccenna, 2000; Agard et al., 2005; Dargahi et al., 2010; Ballato et al., 2011; McQuarrie and van Hinsbergen, 2013), or more specifically in two stages between 36 and 20 Ma and after 20 Ma (Ballato et al., 2011), and was followed by crustal shortening across Eastern Anatolia (Şengör et al., 2008). Despite a late Cretaceous to Eocene history involving shortening and the accretion of several continental fragments (e.g., Şengör and Yılmaz, 1981; Dixon and Robertson, 1984; Tekeli et al., 1984; Şengör et al., 1985; Polat, 1992; Şengör and Natal'in, 1996; Okay and Tüysüz, 1999; Tüysüz, 1999; Andrew and Robertson, 2001; Sunal and Tüysüz, 2002; Parlak and Robertson, 2004; Okay et al., 2006; Pourteau et al., 2010; Robertson et al., 2012; Pourteau et al., 2013), Central Anatolia has predominantly moved westward relative to Eurasia since the time of Arabian collision, accommodated along the North and East Anatolian strike–slip faults (Ketin, 1948; McKenzie, 1976; Şengör, 1979; Dewey and Şengör, 1979; Şengör et al., 1985). Continued Arabia–Eurasia convergence may contribute to this westward "escape" of Anatolia, but rollback of the Hellenic trench is likely the predominant force (Le Pichon, 1982; Jolivet et al., 2013), particularly considering GPS data showing westward movement of Anatolia relative to Eurasia that increases toward the trench (Reilinger et al., 1997).

The tectonic links across the Aegean–Aantolian region are fairly clear, but less obvious have been the mechanisms that have contributed to the growth of the Anatolian Plateau over time, and if those mechanisms may be related to one another. While high topography in Eastern Anatolia is largely believed to result from lithospheric slab delamination and break-off (Keskin, 2003; Şengör et al., 2003; Keskin, 2007; Şengör et al., 2008), recent work in Central Anatolia points to multiple uplift mechanisms that vary across the region. Along the northern Central Anatolian Plateau margin, Yildirim et al. (2011) suggested that the most recent phase of uplift results from strain accumulation along the broad bend of the North Anatolian Fault. Along the southern plateau margin, uplift mechanisms that have been proposed include: (1) slab break-off (Cosentino et al., 2012); (2) upwelling asthenosphere through a slab tear (Schildgen et al., 2012b); and (3) a combination of slab break-off, slab tearing, and collision of a continental fragment with the subduction zone south of Cyprus (Schildgen et al., 2012a). Uplift in the interior of Central Anatolia is difficult to constrain, but has been suggested to result from lithospheric delamination (Bartol et al., 2012), or mantle flow