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Reply to comment on “Preparing the ground for plateau growth: Late Neogene Central Anatolian uplift in the context of orogenic and geodynamic evolution since the Cretaceous”

Peter J. McPhee [a,b,*], Douwe J.J. van Hinsbergen [a], Ayten Koç [c]

[a] Department of Earth Sciences, Utrecht University, Utrecht, the Netherlands
[b] Institute of Geological Sciences, Freie Universität Berlin, Berlin, Germany
[c] Department of Geological Engineering, Van Yüzüncü Yıl University, Van, Turkey

We welcome Aral Okay's discussion of our recent paper (McPhee et al., 2022) on the formation of the modern Central Anatolian plateau. In our paper, we evaluated proposed mechanisms of plateau formation in the context of the long-term evolution and modern architecture of the Anatolian orogen. We concluded that no single mechanism could explain all observations and showed instead how various geodynamic and tectonic processes (small-scale delamination below the western Central Taurides; African continental margin underthrusting and slab break-off below the southern Central Taurides; and lithospheric dripping below Central Anatolia) contributed to plateau formation. We also showed how identifying these overlapping mechanisms has been challenging because they were active simultaneously. In our paper, we followed previous authors (e.g., Çiner et al., 2015; McNab et al., 2017; Meijers et al., 2018, 2020) who collected data interpreted to reflect Miocene uplift of the plateau interior. In his comment, Okay argues that these authors have misinterpreted their data and that plateau interior uplift instead occurred earlier, or gradually, since the time of deposition of the youngest marine sedimentary rocks in the plateau interior (late Eocene, c. 35 Ma; Gülyüz et al., 2013). In this reply, we briefly evaluate the extent that our analysis would have to be modified if this alternative interpretation is valid – even though we note that Okay provides no conclusive evidence to demonstrate such gradual, or early uplift.

The Central Anatolian plateau is an internally drained, relatively low-relief area, with an average elevation of around 1 km (ranging from c. 0.5 to 2 km; see Fig. 1B in McPhee et al., 2022), surrounded by higher (c. 2 to 3.5 km) mountain ranges to the north (Pontides) and south (Taurides). Widespread marine sedimentary rocks overlying the Taurides have been uplifted to as high as 2 km elevation in at least two phases of km-scale uplift since late Miocene times (e.g., Schildgen et al., 2012; Cosentino et al., 2012; Öğretmen et al., 2018). In our paper, we explored the role of proposed Neogene tectonic and geodynamic processes, including incipient continental underthrusting (e.g., McPhee and van Hinsbergen, 2019), lower crustal thickening (e.g., Fernández-Blanco et al., 2020), small-scale peeling delamination (McPhee et al., 2019), slab break-off (e.g., Portner et al., 2018), or slab segmentation (e.g., Schildgen et al., 2014) as drivers of uplift of the Taurides. Okay does not challenge the observations constraining uplift of the Taurides, nor the interpreted causes of uplift, and instead only focuses on the interpretation of plateau interior uplift. If that part of the plateau had already uplifted in the Paleogene, our conclusion that uplift there cannot be attributed to the processes that affected uplift of the Taurides (see also Koç et al., 2012, 2017) is only strengthened.

Two main phenomena have been put forward in the literature that suggest the plateau interior also uplifted from low (but non-marine) elevations since Miocene times: 1) Observation and inversion modelling of long-wavelength knick-zones in longitudinal river profiles (McNab et al., 2017), associated with active or geologically recent incision (e.g., Çiner et al., 2015); 2) Present-day $\delta^{18}O$ depletion in meteoric water, reflecting a high average elevation and the presence of topographic barriers, has been recorded in lacustrine sedimentary rocks since Miocene times, but no earlier (e.g., Meijers et al., 2018, 2020). We direct readers to these articles, which we cited and relied on in our paper, for detailed discussions of the data and modelling that underpin an interpretation of Miocene uplift. Okay argues that these authors misinterpreted the phenomena they documented and instead suggests that the modern elevation of the plateau interior has been largely inherited from Paleogene times.

If Okay's alternative interpretation is correct, then we would need to re-evaluate the likeliness of previous interpretations for uplift of the plateau interior. In our analysis, we found the lithospheric dripping hypothesis of Göğüş et al. (2017) elegant, as it explains lithospheric removal below a well-documented upper Cretaceous magmatic arc (e.g., Ilbeyli et al., 2004) in the heart of a Paleogene orocline (Lefebvre et al., 2013; Gürer et al., 2018) that underwent well-demonstrated shortening

* Corresponding author at: Department of Earth Sciences, Utrecht University, Utrecht, the Netherlands.
E-mail addresses: peter.mcphee@fu-berlin.de (P.J. McPhee), d.j.j.vanhinsbergen@uu.nl (D.J.J. van Hinsbergen).

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and crustal thickening (Gülyüz et al., 2013; Advokaat et al., 2014). Göğüş et al. (2017) argued that mantle upwelling, which accompanies lithospheric dripping, likely causes volcanism around a drip. They pointed to enigmatic late Miocene and younger volcanism in Central Anatolia (e.g., Kürkcüoglu et al., 2004; Reid et al., 2017) to support their hypothesis that lithospheric dripping may have caused Miocene uplift. On the other hand, the numerical model of Göğüş et al. (2017) also indicated that dripping may occur as soon as ten million years after lithospheric thickening. Lithospheric dripping may thus have occurred well before late Miocene times: in this scenario, however, an alternative explanation for the late Miocene Central Anatolian volcanism would be required.

Our brief evaluation shows that earlier uplift of the plateau interior strengthens our conclusion that the uplift of the Central Anatolian Plateau resulted from an interplay of multiple geodynamic processes, and that the processes that we favoured may remain viable. We note, however, that Okay's interpretation relies on perceived imperfections in interpretations that previous authors made based on their data, rather than on conclusive data demonstrating earlier uplift. Such data could, for example, include evidence for early Miocene incision of a proto-Central Anatolian Plateau that drained for instance southward, towards the well-documented marine Mut Basin. To our knowledge, however, there is no such evidence. The plateau interior was a site of fluvio-lacustrine sedimentation rather than incision (e.g., Koç et al., 2012, 2016, 2017; Gürer et al., 2016; Ozsayin et al., 2013), which may be challenging to reconcile with a proto-Central Anatolian Plateau as implied by Okay. Nevertheless, Okay's alternative views on the uplift history of the Central Anatolian plateau interior invite an objective re-evaluation of the constraints on the spatial and temporal history of plateau rise, which may allow further discrimination of the relative importance of the geodynamic drivers of plateau rise in general, and in Central Anatolia in particular. We concluded that examination of the full orogenic architecture and evolution allows the identification of the contributions of various geodynamic drivers and that no single driver explains plateau rise in Central Anatolia. That conclusion stands.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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