Tectonophysics 760 (2019) 95–106

Contents lists available at ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

# Diachronous demise of the Neotethys Ocean as a driver for non-cylindrical orogenesis in Anatolia

Derya Gürer*, Douwe J.J. van Hinsbergen

*Department of Earth Sciences, Utrecht University, the Netherlands*

ARTICLE INFO

*Keywords:*
Continent-continent collision
Kinematic restoration
Neotethys
Anatolian subduction evolution
Paleomagnetism
Turkey
Sivas Basin
Pontide-Tauride collision

ABSTRACT

Continent-continent collision drives crustal deformation, topographic rise and geodynamic change. Africa-Eurasia convergence accommodated in the Eastern Mediterranean involved subduction of the Neotethyan oceanic lithosphere in Anatolia. Subduction was followed by collision of continental crust of Greater Adria with Eurasia to form the Izmir-Ankara-Erzincan suture zone. Discerning the effects of this collision from pre-collisional ophiolite obduction-related orogeny of Greater Adria is notoriously difficult. Estimates on the timing of collision in Central Anatolia are based on a forearc-to-foreland basin transition along the Eurasian margin and suggest a ~60 Ma age of initial collision. Here, we assess whether this age is also representative for collision in Eastern Anatolia and across the Cenozoic Sivas Basin that straddles the Greater Adria-Europe suture. To this end we retro-deform regional block rotations in the Pontides, the Kırşehir Block and the Taurides, building a first-order regional 'block circuit' around the Sivas Basin. We show that up to ~700 km of convergence must have been accommodated across the Sivas Basin after Central Anatolian Kırşehir-Pontide collision at ~60 Ma – an order of magnitude more than estimated crustal shortening, and that wholesale lithospheric subduction must have occurred throughout much of the Cenozoic. Paleocene collision would require that this subduction consumed continental lithosphere, which is unlikely. We consequently infer that oceanic subduction continued much longer in Eastern Anatolia, perhaps well into the Miocene. We postulate that prolonged oceanic subduction and slab pull drew the Eastern Taurides north relative to the Central Taurides, leading to shortening and oroclinal bending in Central Anatolia. The diachronous demise of the Neotethys Ocean in Anatolia, as a function of its paleogeography, is thus a likely driver for the strong non-cylindricity of the Cenozoic Anatolian collisional orogen.

## 1. Introduction

Continent-continent collision is one of the major drivers of crustal deformation, accretionary orogenesis and topographic rise. Such collisions follow the demise of ocean basins between two continents, and are often followed by a period of continental subduction and associated accretion of thin-skinned fold-and-thrust belts derived from the downgoing continental crust. Archetypes of such collisions formed after closure of the Neotethys Ocean that existed in Mesozoic time between Gondwana and Eurasia, and include the Paleocene to Early Eocene India-Asia collision associated with the rise of the Tibetan Plateau and formation of the Himalayan fold-and-thrust belt (e.g., Hodges, 2000; Hu et al., 2016a,b), or the Oligocene Arabia-Eurasia collision associated with the rise of the Iranian Plateau and formation of the Zagros fold-and-thrust belt (e.g., Agard et al., 2011; McQuarrie and van Hinsbergen, 2013). Although there are along-strike variations in shortening or metamorphic grade, the Himalaya and Zagros fold-and-thrust belts are remarkably cylindrical, whereby the main sutures and dominant thrust faults can be traced over distances up to 2000 km (McQuarrie, 2004; Yin, 2006).

In this context, the tectonic evolution of the Anatolian orogen and nascent plateau (Schildgen et al., 2012), which formed in the Eastern Mediterranean region during collision of the Gondwana-derived Adria-Turkey continent (Stampfli et al., 1991) or 'Greater Adria' (Gaina et al., 2013) and Eurasia (Fig. 1) is puzzling. Similar to the Zagros and Himalayan orogens, the Anatolian orogen and plateau evolved during and after closure of the Neotethyan ocean basin, but orogenesis was non-cylindrical with major along-strike variations in the presence or absence of major tectonic units, and in the style and timing of metamorphism, magmatism, and deformation (Fig. 2). In particular contrast to the cylindrical collisional orogens to the east, major differential vertical axis block rotations occurred within the Anatolian orogen (see compilation in Gürer et al., 2018b; Fig. 1). These rotations cannot be explained by variations in motions of the bounding African/Arabian

---

* Corresponding author.
*E-mail address:* derya.guerer@gmail.com (D. Gürer).

https://doi.org/10.1016/j.tecto.2018.06.005
Received 31 July 2017; Received in revised form 23 May 2018; Accepted 8 June 2018

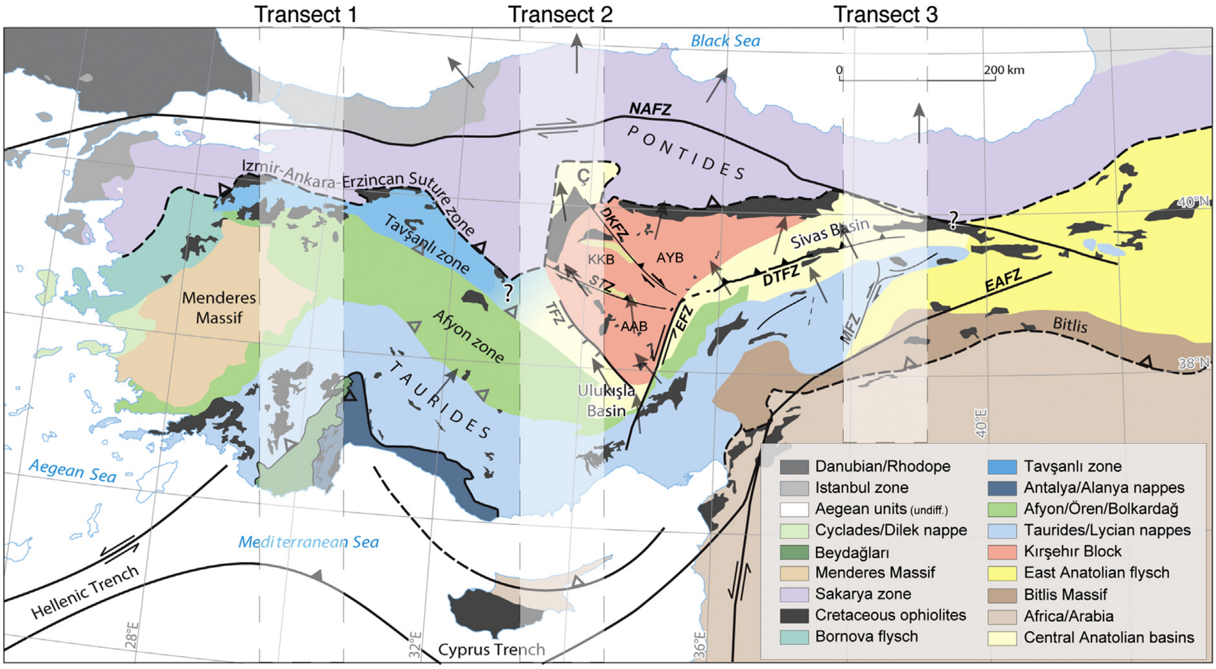

**Fig. 1.** Tectonic map of Anatolia, with rotating domains (represented by arrows) as identified in Gürer et al. (2018b). IAESZ – Izmir-Ankara-Erzincan suture zone, NAFZ – North Anatolian Fault Zone, East Anatolian Fault Zone (EAFZ), Malatya Fault Zone (MFZ), TFZ – Tuzgölü Fault Zone, DTFZ – Deliler Tecer Fault Zone, EFZ – Ecemiş Fault Zone, Ç – Çankırı Basin. The three sub-blocks of the Kırşehir Block that underwent differential rotation (Akdağ-Yozgat block (AYB), Kırşehir-Kırıkkale block (KKB), Ağaçören–Avanos block (AAB) accommodated by the Delice-Kozaklı (DKFZ) and Savcılı Thrust Zone (STZ)). The location of three N-S oriented geological transects shown in Fig. 2.

and Eurasian plates because they are contiguous along the boundaries of Anatolia.

Paleogeographic reconstructions of the Eastern Mediterranean region generally invoke along-strike contiguity of E-W trending subduction zones between Greater Adria and Eurasia and a regionally synchronous latest Cretaceous or Paleocene collision (e.g., Barrier and Vrielynck, 2008; Moix et al., 2008; Menant et al., 2016). Recent proposals, however, suggested that the Neotethys Ocean was considerably wider in Eastern Anatolia than to the west, accounting for the eastward decrease in the amount of continent-derived units within the orogen (Gürer et al., 2016; van Hinsbergen et al., 2016). If correct, such a more complex paleogeography may suggest that Neotethys Ocean closure, and the onset of collision may have varied considerably along-strike in Anatolia. Consequently, this geometry would present an ideal test case to evaluate the influence of paleogeography and along-strike collisional diachroneity on orogenesis. A quantitative kinematic restoration of the Eastern Mediterranean orogen, however, remains absent. In addition, constraining the timing of continent-continent collision that is essential to assessing the dynamics that drive orogenesis and plateau formation, is often notoriously difficult and can be controversial.

Continental collisions are frequently dated based on paleo-latitudinal overlaps between continental blocks across the suture, the first arrival of sediments of one continent on the other, the onset of shortening and metamorphism of particularly the down-going continent, or the end of marine sedimentation in the suture zone (e.g., McQuarrie and van Hinsbergen, 2013; van Hinsbergen et al., 2012; Hu et al., 2016a,b; Agard et al., 2011; Mouthereau, 2011). Applying these constraints to Neotethys Ocean closure in Anatolia, however, proves difficult. The onset of deformation and metamorphism in the down-going continent dates to a phase of pre-collisional orogeny during which the Kırşehir-Tauride continental margin was obducted by oceanic lithosphere of the Neotethyan "Anadolu Plate", which is preserved widely as Cretaceous supra-subduction ophiolites (e.g., Gürer et al., 2016). The associated metamorphism and deformation (e.g., Whitney et al., 2003) is unrelated and predates collision with the Pontides (e.g., Boztuğ et al., 2009; Lefebvre et al., 2013; van Hinsbergen et al., 2016). Collision did not terminate marine sedimentation, with widespread Eocene marine sediments found on the deformed rocks of both margins (e.g., Kaymakci et al., 2009). Paleomagnetic estimates of the timing of paleo-latitudinal overlaps between the colliding continental realms are imprecise due to small (~15°) latitudinal convergence since the Early Cretaceous and low convergence rates (e.g., Torsvik et al., 2012). Currently, the best age estimate for collision comes from a forearc to foreland basin transition at ~65–60 Ma in the Çankırı Basin (Figs. 1, 2b, Kaymakci et al., 2009) in Central Anatolia. This collision is coupled with formation of the central Pontide orocline in the overriding plate, which is interpreted to reflect indentation of the Kırşehir Block (Meijers et al., 2010). Whether this age is synchronous along-strike, however, remains poorly constrained.

In this paper, we aim to assess whether collision in the Eastern Mediterranean was synchronous or not, using a kinematic approach based on paleomagnetically quantified block rotations within deformed Eurasian and Greater Adrian units to restore Cenozoic deformation in Central Anatolia. We use a recent paleomagnetic data compilation for the Pontides, the Kırşehir Block and the Taurides, which constrains the dimensions of domains that rotated coherently since the Late Cretaceous, the timing and amount of their rotation and the location of intervening major fault zones (Gürer et al., 2018b). We use these to develop a first-order kinematic restoration of block rotations and fault motions, which allows us to calculate how much Cenozoic convergence was accommodated in Eastern Anatolia. Comparison of these estimates with known geological shortening records in the suture zone in Eastern Anatolia, which is overlain by the well-studied uppermost Cretaceous to Neogene Sivas Basin (Cater et al., 1991; Guezou et al., 1996; Kergaravat et al., 2016; Legeay, 2017; Poisson et al., 1996, 2016; Temiz, 1996) allows us to infer the style of subduction through time (accretionary vs. non-accretionary). We evaluate the likelihood of along-strike synchronicity of collision, its relation to paleogeography, its influence on non-cylindrical Eastern Mediterranean Cenozoic orogenesis and discuss the implications of our findings for subduction zone dynamics.

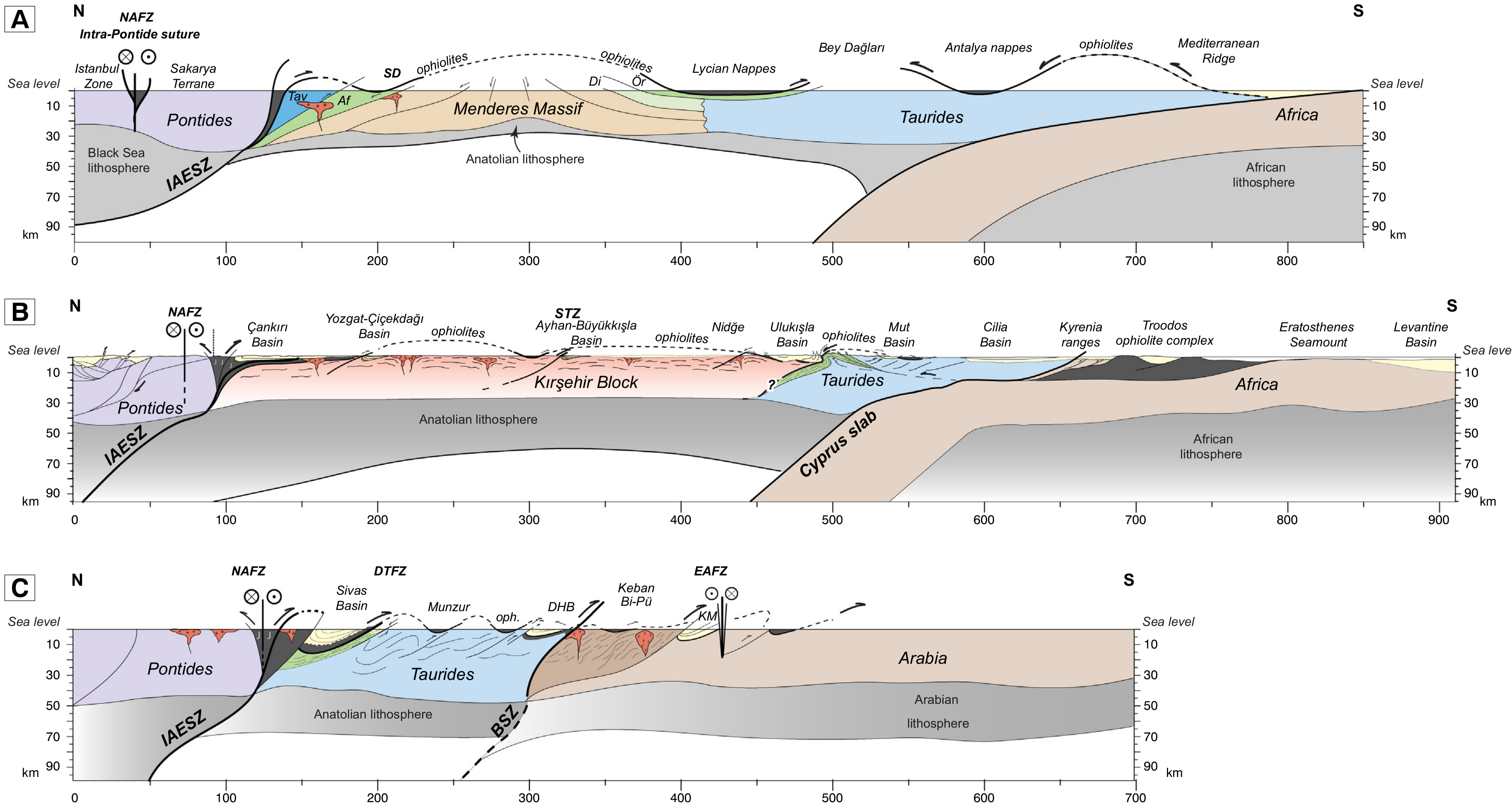

**Fig. 2.** Present-day lithospheric-scale cross-section through Anatolia. See Fig. 1 for approximate locations. Dotted thrusts illustrate the foreland propagation of accretion of the various zones through time to the overriding oceanic lithosphere of the south Anatolian subduction system. Abbreviations used: NAFZ – North Anatolian Fault Zone, IAESZ – Izmir-Ankara-Erzincan Suture Zone, Tav – Tavşanlı zone, Af – Afyon zone, SD – Simav Detachment, SFZ – Savcılı Fault Zone, BSZ – Bitlis suture zone, DTFZ – Deliler-Tecer Fault Zone, EAFZ – East Anatolian Fault Zone, DHB – Darendere-Hekimhan Basin, Bi-Pü – Bitlis-Pütürge, KM – Kahramanmaraş. For colours see legend in Fig. 1. J – marks Jurassic ophiolites, all other ophiolites are Cretaceous in age. Crustal structure and Moho shape are based on Kaya (2010), Starostenko et al. (2004), Vanacore et al. (2013) in western Anatolia, on Ben-Avraham et al. (2002), Feld et al. (2017), Jiménez-Munt et al. (2003) in Central Anatolia and on Angus et al. (2006), Gök et al. (2007), Zor et al. (2003) in Eastern Anatolia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

## 2. Geological setting

Anatolia today is situated in the overriding plate of an active subduction zone that consumes African lithosphere (Figs. 1, 2). The Aegean trench south of Crete continues eastward to the south of Cyprus. Farther to the east, Arabia collided with Eastern Anatolia along the Bitlis Suture Zone and subduction is no longer active and continent-continent collision occurs instead (e.g., McClusky et al., 2000). North of the present-day trench Anatolia consists of an intensely deformed and in part metamorphosed and exhumed collage of continent-derived crustal fragments and overlying oceanic-derived ophiolites (Figs. 1, 2), separated from southern Eurasian units by the Izmir-Ankara-Erzincan (IAESZ) Suture Zone that demarcates the former location of the (main) Neotethys Ocean basin.

North of the IAESZ is the Pontides mountain belt, which in Anatolia contains two main crustal units – the Istanbul and Sakarya zones. These are thought to have been part of Eurasia since at least early-mid Mesozoic time and are separated by the Mesozoic 'Intra-Pontide' Suture (Dokuz et al., 2017; Okay and Nikishin, 2015; Şengör and Yılmaz, 1981; Ustaömer and Robertson, 1997, 2010). The Central and Eastern Pontides form a fold-and-thrust belt of Paleozoic crystalline basement overlying an accretionary prism of Triassic to Jurassic rocks, overlain by a Mesozoic to Cenozoic sedimentary cover (Dokuz et al., 2017; Okay and Tüysüz, 1999; Sayit et al., 2010). The latter is intruded and overlain by arc plutons of Jurassic to Late Cretaceous, and in the east up to Miocene age (Eyuboglu et al., 2012; Okay et al., 2013). The Pontide collage experienced Cretaceous extension upon the opening of the Black Sea (Munteanu et al., 2011; Okay et al., 1994), which particularly in the Central Pontides inverted during Paleogene shortening (Espurt et al., 2014).

Within the IAESZ there are Jurassic ophiolites interpreted to have formed in the forearc of the Pontides during northward subduction of the Neotethys Ocean (Hässig et al., 2013; Topuz et al., 2012). The Jurassic ophiolites are structurally above a series of supra-subduction zone ophiolites with exclusively Cretaceous, 95–90 Ma ages, which are found scattered across and structurally overlying all tectonic units to the south of the IAESZ (Fig. 1). The Cretaceous ophiolites are interpreted to derive from a dominantly oceanic tectonic plate that intervened Africa and Eurasia in the Late Cretaceous to Cenozoic: the Anadolu Plate (Gürer et al., 2016). The units below these ophiolites are continent-derived metamorphosed and non-metamorphosed rock units of the 'Anatolide-Taurides' (Şengör and Yılmaz, 1981), or 'Greater Adria', a wide microcontinental domain with platforms and deep (perhaps in places oceanic) intervening basins, relics of which are now found in Greece, below the Adriatic Sea and in the circum-Adriatic orogens (Gaina et al., 2013). In Anatolia, these Greater Adria-derived units have an overall southward, foreland-propagating age of folding, thrusting and metamorphism (Fig. 2, van Hinsbergen et al., 2010, 2016). This configuration is interpreted to reflect overall top-to-the-south (W & E Turkey) to (south)west (C Turkey) nappe stacking during north(east)ward subduction below oceanic lithosphere preserved as ophiolites (van Hinsbergen et al., 2010, 2016; van Hinsbergen and Schmid, 2012; Gürer et al., 2016; Pourteau et al., 2013; Menant et al., 2016; Plunder et al., 2013; Gessner et al., 2001, Fig. 2). The highest structural unit below the Cretaceous supra-subduction ophiolites in western Anatolia is the HP-LT metamorphic Tavşanlı zone, and the HT-LP metamorphic Kırşehir Block in Central Anatolia (Figs. 1 and 2). U/Pb zircon crystallization and $^{40}$Ar/$^{39}$Ar cooling ages from these units suggest that they experienced their climax pressure metamorphism – corresponding or post-dating their accretion from the downgoing African Plate to the overriding, oceanic Anadolu Plate at 90–80 Ma (van Hinsbergen et al., 2016, and references therein). Since both units entered the subduction zone below the Anadolu Plate simultaneously, they must have been lateral equivalents, whereby their contrasting metamorphic grade may have been a result of the stark contrast in the obliquity of the subduction zone in which they were buried (Plunder et al., 2018; van Hinsbergen et al., 2016). There is no known equivalent of the Tavşanlı zone and Kırşehir Block, with contemporaneous ages of metamorphism, known in Eastern Anatolia (Figs. 1 and 2). To the south of the Tavşanlı zone and Kırşehir Block, as the highest structural unit of the Tauride fold-and-thrust belt, is the Afyon zone that experienced HP-LT metamorphism around 70–65 Ma (Özdamar et al., 2013; Pourteau et al., 2013) and thus arrived ~20–15 Ma after the northern units in the trench below the Anadolu Plate. The Taurides fold-and-thrust belt below the Afyon zone is made of overall non-metamorphic Precambrian to Cenozoic, dominantly platform carbonate units that thrusted in latest Cretaceous to Eocene, and in places Miocene, time (Özgül, 1984; Özgul and Tursucu, 1984). The Tavşanlı/Kırşehir units to the north and the Afyon zone were likely once separated by a deep, perhaps oceanic 'intra-Tauride basin' that subducted during the 20–15 Ma lull in accretion between ~85 and 70 Ma (van Hinsbergen et al., 2016; Gürer et al., 2016). After the Eocene, there was no accretion in the Taurides until Early to Middle Miocene collision with Arabia (Hüsing et al., 2009; Okay et al., 2010) and Late Miocene collision with continental blocks of the African margin on Cyprus (McCay and Robertson, 2013).

Large parts of the continental rocks that were incorporated in the fold-and-thrust belt since the Cretaceous were buried, metamorphosed and subsequently exhumed. The Kırşehir Block and Afyon zone of Central Anatolia exhumed in a major Late Cretaceous-Eocene extensional back-arc basin (Gautier et al., 2008; Lefebvre et al., 2011; Gürer et al., 2018b), whilst in Western Anatolia also metamorphosed parts of the Tauride platform are exposed in the dominantly Miocene Menderes extensional domain, as part of the Aegean back-arc basin (Bozkurt et al., 2011; Bozkurt and Oberhänsli, 2001; Gessner et al., 2001; van Hinsbergen, 2010).

Normally, continent-continent collisions are rather straightforward to date when collision follows subduction of an ocean basin along a single subduction zone below one of the continental margins. Such dating may then rely on e.g. the first arrival of upper plate-derived sediments on the continent of the downgoing plate, paleomagnetically determined paleolatitudinal overlaps after a period of convergence, or the onset of accretion of continental units of the downgoing plate below the upper continental margin (e.g., Hu et al., 2016a; Najman et al., 2010). However, the closure of the Neotethys Ocean in the Eastern Mediterranean region and the collision of the Pontides and Anatolide-Taurides is more difficult to date. This is mainly because of the (at least) double subduction configuration that characterized the Eastern Mediterranean region since the Late Cretaceous, which hampers discerning which part of the deformation history of particularly the Taurides is related to burial below the oceanic Anadolu Plate, and which is related to collision with the Pontides to the north (e.g., Gürer et al., 2016). Different age estimates of collision in Anatolia are then related to inferred, conceptual dynamic and magmatic responses to collision, such as upper plate shortening, lower plate shortening, or magmatic geochemistry.

One of the key tie points for the age of collision that is often cited is the evolution of the Çankırı Basin in the Central Pontides, north of the Kırşehir Block. There, a forearc to foreland basin transition was interpreted to have occurred around 65–60 Ma (Kaymakci et al., 2009), around the same time as bending of the Central Pontides started that may be a response to indentation of the Kırşehir Block (Meijers et al., 2010). Around the same time, arc magmatism ceased in the Western and Central Pontides (Boztuğ and Jonckheere, 2007; Campell et al., 2017), except for middle Eocene magmatism in the northern Kırşehir Block, around Yozgat, interpreted to be a response to slab breakoff (Keskin et al., 2008). In our analysis, we will adopt a 60 Ma initial collision age between the Kırşehir Block (and to the west, the Tavşanlı zone) and the Pontides, which will serve as reference for the kinematic restoration of Eastern Anatolia.

Previous estimates of collision in Eastern Anatolia vary, and most authors have previously interpreted a Paleocene collision age between the Eastern Taurides and the Eastern Pontides. The assumption of a

Paleocene collision is based on several circumstantial lines of evidence: (i) Eocene shortening in the Taurides, suggested by Şengör and Yılmaz (1981) to reflect deformation post-dating collision with the Pontides; (ii) evidence for several Paleocene thrusts in the Eastern Pontides (Okay and Sahinturk, 1997); and (iii) Eocene 'post-collisional' extension inferred based on a widespread marine transgression of that age in the Eastern Pontides and the Kırşehir Block, and the finding of similar middle Eocene sediments in the Tauride stratigraphy (e.g., Topuz et al., 2011) (even though in the Taurides they are the top of a continuous stratigraphic succession of platform carbonates, underlying thin foreland basin clastics (Özgül, 1984)). Because of these observations, Eocene to Miocene magmatism in the Eastern Pontide arc, which continues much longer than in the Western and Central Pontides, into the Miocene, is widely interpreted as 'post-collisional' (e.g., Altunkaynak, 2007; Dilek et al., 2010; Topuz et al., 2005). This interpretation of Eocene to Miocene Eastern Pontide magmatism, however, is not uniquely required by geochemical data. Geochemical data from Eocene-Miocene Eastern Pontide arc rocks have been interpreted to reflect back-arc extension related to northward subduction along the Bitlis–-Zagros Suture Zone (Robertson et al., 2006, 2007; Vincent et al., 2005), but also as ongoing oceanic subduction below the Eastern Pontides (Akaryali, 2016; Akaryali and Akbulut, 2016; Akin, 1979; Eyuboglu et al., 2011a,b,c, 2012, 2013, 2016; Tokel, 1977), post-collisional crustal thickening (Topuz et al., 2005, 2011), or delamination of the thickened crust along the IAESZ (e.g., Dilek et al., 2010; Karsli et al., 2010).

Because Tauride-Pontide collision is widely interpreted as Paleocene or Eocene, younger deformation (and magmatism) is often interpreted as the result of Arabia-Tauride collision. Such younger deformation is for instance reflected by shortening in the Miocene of the Sivas Basin (Kergaravat et al., 2016; Legeay, 2017). Thermochronological data from Cretaceous and Eocene granitoids in the Eastern Pontides revealed a discrete episode of rapid mid-Miocene exhumation (Albino et al., 2014). Similarly, the Kösedağ and Kaçkar batholiths in the Eastern Pontides have undergone Oligocene and Early Miocene exhumation, which are speculated to reflect far-field tectonic effects of the Arabia–Eurasia collision (Boztuğ and Jonckheere, 2007).

## 3. Central Anatolian block rotations

Paleomagnetic work has revealed that Cenozoic deformation of the Pontide, Kırşehir, and Tauride domains involved major differential block rotations, often accommodated along discrete fault zones. These rotations and fault zones are key to the kinematic restoration presented in this paper. To the north, the Central Pontide orocline formed since the Paleocene with opposite rotations of ~25–30° (Meijers et al., 2010, Fig. 1). In the center of this orocline, ~30 km of post-Eocene shortening is constrained by a balanced cross section (Espurt et al., 2014), where the shortening was likely associated with Eocene-Oligocene block rotations in the Çankırı Basin (e.g., Kaymakci et al., 2003). To the south, the Kırşehir Block broke into three distinct domains that underwent differential rotations facilitated by motion along the IAESZ and the Delice-Kozaklı (DKFZ) and Savcılı (STZ) transpressional to compressional fault zones (Lefebvre et al., 2013) of Late Eocene-Oligocene age (Gülyüz et al., 2013; Isik et al., 2014; Advokaat et al., 2014; Fig. 1).

In Southern Anatolia, the Taurides also form an orocline, whereby the western part recorded ~40° post-middle Eocene clockwise rotations (Çinku et al., 2016; Kissel et al., 1993). The Eastern Taurides were part of a ~30° counter-clockwise rotating domain that also included the southern Kırşehir Block (AAB), the Ulukışla Basin and the Bolkar mountains, which underwent rotation in Oligocene to Early Miocene time (Gürer et al., 2018b and references therein; Fig. 1). Within this rotating domain is the left-lateral Ecemiş Fault Zone (EFZ) that displaced the Eastern Taurides north relative to the southern Kırşehir Block by ~70 km in Late Eocene-Oligocene time (Jaffey and Robertson, 2005; Gürer et al., 2016).

The Sivas Basin (Figs. 1, 2c) is floored by ophiolites that overlie the Eastern Tauride fold-and-thrust belt. The Taurides deformed and in places were metamorphosed below the oceanic lithosphere in Cretaceous-Eocene time (Özgul and Tursucu, 1984; Pourteau et al., 2013). The southern Sivas Basin margin contains Eocene marine turbidites, deposited during Tauride thrusting, and an Oligocene terrestrial cover (Poisson et al., 1996). Within the Sivas Basin, the major Deliler-Tecer Fault Zone (DTFZ) placed ophiolitic mélange, overlain by Paleocene-Eocene volcano-sedimentary rocks, over folded Oligocene redbeds. To the North, the Paleocene-Eocene volcano-sedimentary sequence is unconformably overlain by Miocene marine and continental clastic rocks (Temiz, 1996). Paleomagnetic data reveal that the footwall of the DTFZ is part of the counter-clockwise rotating Eastern Tauride domain, whereas the hanging wall experienced no or clockwise rotations, leading to identification of this fault zone as the likely bounding structure of the Southeast Anatolian counter-clockwise rotating domain (Gürer et al., 2018b). Estimates within the Sivas Basin suggested that some tens of kilometers of shortening may have occurred during various stages in the Eocene, Oligocene, and Miocene (Legeay, 2017), whereby the eastward-narrowing geometry of the basin has been attributed to an eastward-increasing shortening (Temiz, 1996). In the easternmost Sivas Basin, the Eastern Taurides are in almost direct contact with the Eastern Pontides, and only a narrow corridor with folded marine Miocene sediments and ophiolitic mélange remains in the IAESZ.

## 4. Kinematic restoration

### 4.1. Approach

To assess the amount of Cenozoic convergence accommodated across the Sivas Basin we restored the paleomagnetically constrained Cenozoic block rotations and fault displacements in Central Anatolia that occurred after the collision of the Kırşehir Block (Greater Adria) and the Pontides (Eurasia) collision. To this end, we use GPlates software ((Boyden et al., 2011); reconstruction files are provided in the Supplementary Information) to estimate Euler rotations of each block relative to adjacent blocks, and ultimately to the Eurasian reference plate. This led to a circuit of blocks that translate and rotate relative to adjacent blocks, whereby the circuit closes across the Sivas Basin between the Eastern Pontides (Eurasia) and the Eastern Taurides (Greater Adria) in Eastern Anatolia. Thus, using known vertical axis rotations of major blocks and fault displacements between these, we constrain the amount of convergence that occurred in Eastern Anatolia since collision in Central Anatolia. In our reconstruction, we decouple the rotating blocks along major fault zones previously identified as block boundaries (Gürer et al., 2018b; Lefebvre et al., 2013).

To determine the age of collision in Eastern Anatolia, we need to restore convergence between the northern margin of the Tauride fold-and-thrust belt – here taken as the Afyon zone, or where this zone is absent, the otherwise structurally highest and most northern continental Tauride nappe exposed below the ophiolites and the Pontides. Post-60 Ma convergence accommodated south of this northern margin, i.e. within the Tauride fold-and-thrust belt, the Menderes Massif, or south of the Taurides, does not contribute to Tauride-Pontide convergence but accommodates Africa/Arabia-Tauride convergence instead. The shortening history of the Taurides is thus irrelevant for our analysis and not taken into account in detail here.

Our reconstruction is cast in context of the reconstruction of the Arabia-Eurasia collision zone in Iran of McQuarrie and van Hinsbergen (2013) in the east, and the Western Anatolia-Aegean reconstruction, including the Miocene to recent North Anatolian Fault Zone displacement restoration of van Hinsbergen and Schmid (2012) in the west, and takes into account Paleogene extension in Central Anatolia (Gürer et al., 2018a). Our reconstruction approach, after restoring late Neogene NAFZ displacement, is illustrated in Fig. 3. First, we restored the

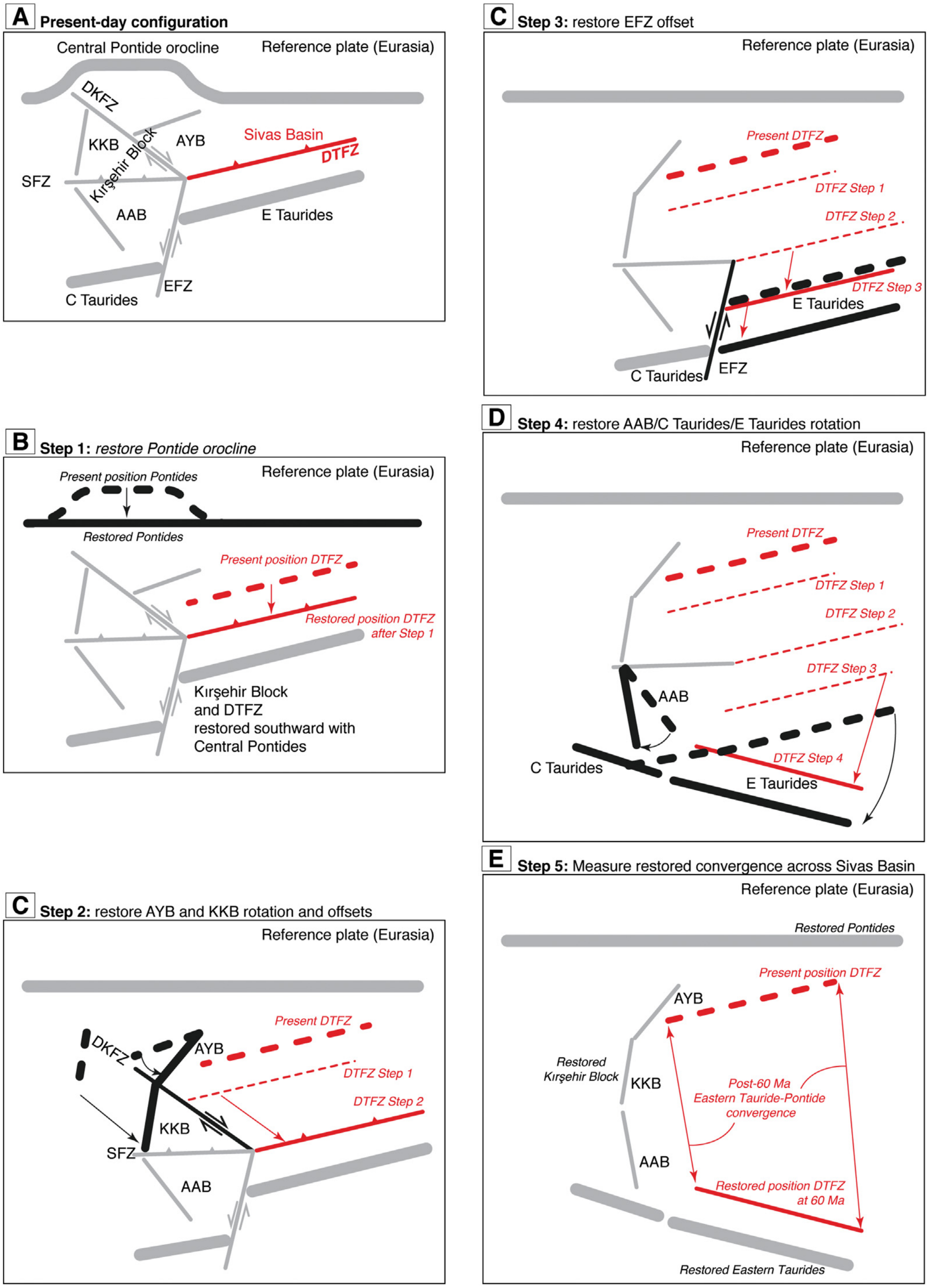

**Fig. 3.** Step-wise approach to reconstructing post-60 Ma convergence across the Sivas Basin in a Eurasia-fixed reference frame. Key to abbreviations: AAB – Ağaçören–Avanos block, AYB – Akdağ-Yozgat block, DKFZ – Delice-Kozaklı Fault Zone, DTFZ – Deliler Tecer Fault Zone, EFZ – Ecemiş Fault Zone, KKB – Kırşehir-Kırıkale block, STZ – Savcılı Thrust Zone.

Paleocene Pontide orocline (Fig. 3a) following Meijers et al. (2010). The Kırşehir Block and the Tauride units are restored southward (Fig. 3b), and a gap is restored in the Sivas Basin region – in our reconstruction chosen to be accommodated at the DTFZ, since this fault zone was interpreted to accommodate the differential Pontide-Tauride rotation (Gürer et al., 2018b). The size of this gap reflects the amount of convergence that must have been accommodated in the Sivas Basin region associated with Pontide orocline formation. Second, we restored vertical axis rotations and fault translations for the northern and central Kırşehir Block (AYB, KKB), following constraints of Lefebvre et al. (2013), which increases the size of the gap in the Sivas Basin across the DTFZ (Fig. 3c). Third, we restore the left-lateral displacement along the Ecemiş Fault Zone (Jaffey and Robertson, 2005; Gürer et al., 2016) (Fig. 3d). Finally, we restore the rotation of the SE Anatolian domain, including the southern Kırşehir Block (AAB) and the Central and Eastern Taurides, following (Gürer et al., 2018b; Fig. 3e). These four steps constrain the net amount and direction of convergence accommodated between the Pontides and the northern margin of the Eastern Taurides across the DTFZ.

Subsequently, we test the Euler rotations for each rotating domain

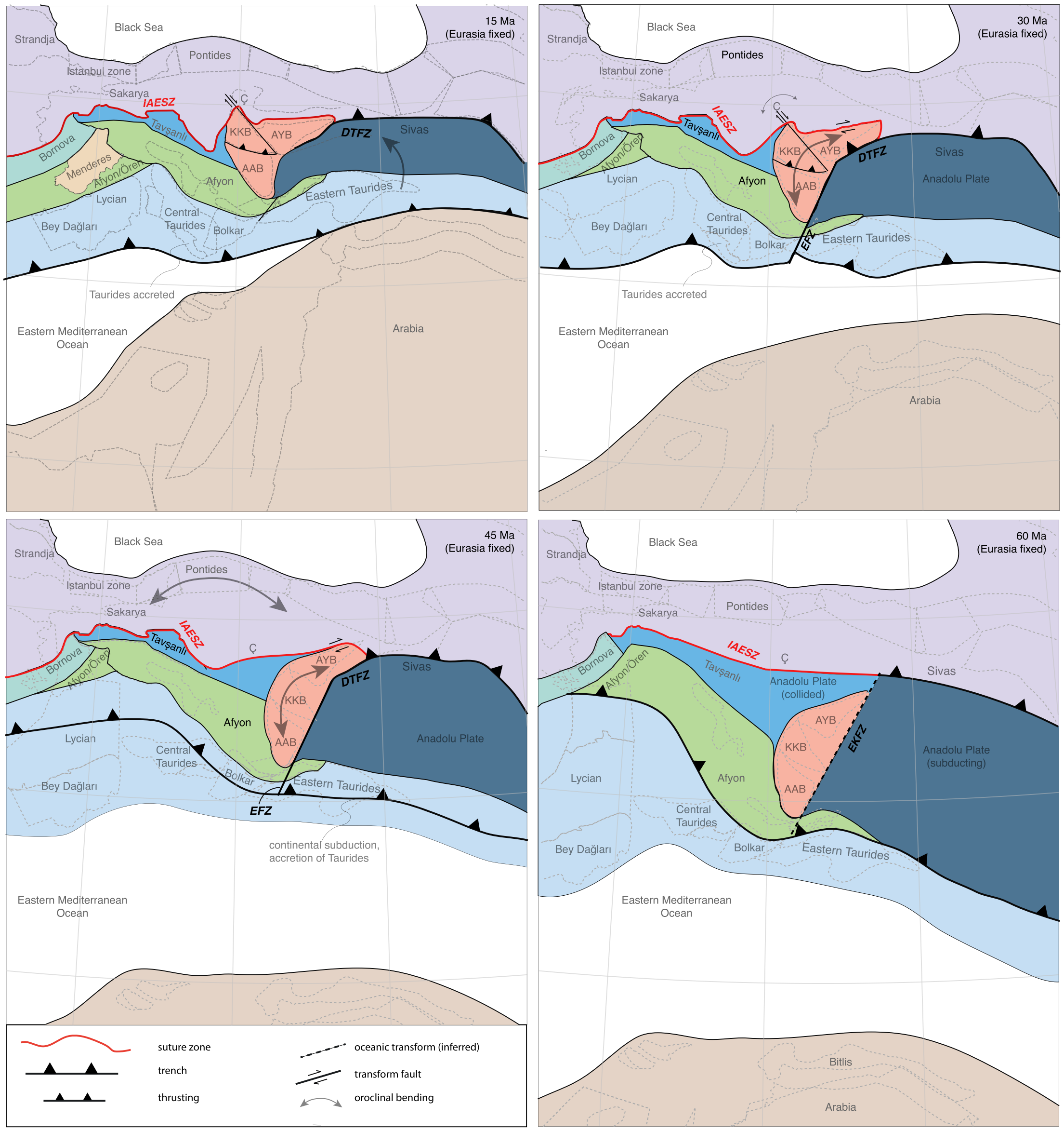

**Fig. 4.** Paleogeography and plate boundary configuration of Anatolia in a Eurasia-fixed reference frame at a) 15 Ma, b) 30 Ma, c) 45 Ma, and d) 60 Ma. Ç – Çankırı Basin. Abbreviations as in Fig. 3, EKFZ - Eastern Kırşehir Fracture Zone. Heavy red lines denote the collision zone, heavy black lines denote subduction zones. Graticules are 5°, see text for further explanation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

against paleomagnetic constraints from those domains and use this step to infer the timing of post-60 Ma rotations. The Euler rotations of each block in our reconstruction were computed relative to South Africa, using the plate circuit of Torsvik et al. (2012) with updated Eurasia-North America rotations for the Neogene of DeMets et al. (2015). These were subsequently computed with the global apparent polar wander path (APWP) of Torsvik et al. (2012) in the coordinates of the reconstructed blocks using the thereto designed tool presented in Li et al. (2017) on the online portal Paleomagnetism.org (Koymans et al., 2016). We compare the results against paleomagnetic data compiled by Gürer et al. (2018b), parametrically sampled where original directions were not published, as well as the APWP for the SE Anatolian rotating domain calculated by Gürer et al. (2018b). We iterated the kinematic reconstruction until the predicted APWP complied with the paleomagnetic data. Files used for paleomagnetic tests are provided in the Supplementary information.

### 4.2. *Result*

Our reconstruction, shown in 15 Myr time slices in Fig. 4 indicates that restoring the Central Pontide orocline to its pre-rotation geometry (Meijers et al., 2010) requires ~85 km of N-S convergence over the time period ~60–45 Ma. Restoring rotations in the Kırşehir Block (Lefebvre et al., 2013) indicates ~200 km of N-S Cenozoic convergence (~45–25 Ma). The center of the rotating Kırşehir blocks indented into the Çankırı Basin (Lefebvre et al., 2013), which led to an additional shortening of at least ~30 km as documented by Espurt et al. (2014), and the formation of a secondary, local orocline within that basin (Kaymakci et al., 2003; Lucifora et al., 2013; Cinku et al., 2011), both not restored in detail here. Finally, the amount of shortening between the Central Taurides and the Ulukışla Basin was no more than ~5 km in the Eocene-Oligocene (Gürer et al., 2016) and the Central and Eastern Taurides rotated coherently with the southern Kırşehir Block (Gürer et al., 2018b). Hence, ~320 km of convergence was accommodated by shortening and block rotations in Central Anatolia after collision at

~60 Ma. To avoid major overlaps between the clockwise and counter-clockwise rotating Tauride segments, our reconstruction additionally infers an Eocene right-lateral displacement between the Kırşehir Block and the Pontides along the IAESZ during the westward convex oroclinal bending and breaking of the Kırşehir Block in the Paleogene, consistent with the recent finding of an Eocene pull-apart basin in the North Anatolian Fault Zone region of the Central Pontides (Ottria et al., 2017) and a phase of uplift and exhumation in the northern Central Pontides constrained by low-temperature thermochronology (Ballato et al., 2018) (Fig. 4). Based on the above geological constraints, the total amount of N-S shortening between Eurasia and the northern margin of the Central Taurides since ~60 Ma is estimated at ~320 km.

We now calculate the amount of Tauride-Eurasia convergence in Eastern Anatolia, where the Kırşehir Block is absent and the Pontides and Taurides are almost touching (Fig. 1). Counter-clockwise rotation of the Central and Eastern Taurides with respect to the Eastern Pontides around a pole west of the Ulukışla Basin causes the amount of associated convergence to increase rapidly eastward, which defines the substantial non-cylindricity of Anatolian orogenesis. In addition, displacement along the EFZ (Jaffey and Robertson, 2005) adds ~70 km of Tauride-Eurasia convergence in Eastern Anatolia. Finally, we compare the apparent polar wander path (APWP) predicted this way with the APWP computed from paleomagnetic data of the Central and Eastern Taurides of Gürer et al. (2018b) (Fig. 5). The result shows that our reconstruction predicts the amount of rotation of the Eastern Taurides well, and that we restored the oldest permitted timing of the rotation, effectively maximizing the age of significant convergence across the Sivas Basin.

To illustrate the effect of uncertainties in paleomagnetic data on our estimate of total convergence accommodated across the Sivas Basin since 60 Ma, we computed reconstructions with ± 5° rotation for each block, similar to the estimates provided by paleomagnetic data (Gürer et al., 2018b; Fig. 5). Our reconstruction demonstrates an eastward increasing total convergence across the Sivas Basin of ~410 [380, 430] km in the west, and ~700 [600, 730] km in the east since ~60 Ma.

## 5. Discussion

### 5.1. Eastern Anatolian convergence and collision

As much as 700 km of Cenozoic convergence accommodated across the Sivas Basin is surprising in the light of the widely held view that continental collision between the Eastern Pontides and the Taurides must have occurred already in Paleocene time (Robertson et al., 2013; Topuz et al., 2005, 2011). Previous qualitative reconstructions agree with our quantitative restoration that the Taurides once formed a contiguous ~E-W striking belt located to the south of the Kırşehir Block, requiring that the amount of Cenozoic Tauride-Pontide convergence was hundreds of kilometers larger to the east of the Kırşehir Block than in Central Anatolia in Cenozoic time (e.g., Pourteau et al., 2010; Barrier and Vrielynck, 2008; Menant et al., 2016). A Paleocene Eastern Tauride-Pontide collision would then require that many hundreds of kilometers of convergence were accommodated by continental subduction in the Sivas Basin area, as is implied in the reconstructions of Barrier and Vrielynck (2008) and Menant et al. (2016).

Geological estimates of shortening in the ~50 km wide Sivas Basin are not higher than several tens of km and involve upper Cretaceous and Cenozoic sediments and underlying ophiolitic rocks (Legeay, 2017). Cenozoic shortening was evidently accommodated within the Tauride fold-and-thrust belt (Özgül, 1984; Özgul and Tursucu, 1984), but as pointed out before, this convergence did not account for Tauride-Pontide convergence, but Africa/Arabia-Tauride convergence instead. From this it follows that the estimated hundreds of km of Tauride-Pontide convergence kinematically restored in this paper must have been accommodated without significant accretion. This, in turn, requires (near-) wholesale lithospheric subduction. Such wholesale subduction is the default for convergent systems involving oceanic subduction (e.g. Oncken et al., 2006), whilst subduction of buoyant continental crust is commonly associated with upper crustal accretion, and hence clear shortening (e.g., Capitanio et al., 2010). From this point of view it is therefore more likely that Cenozoic convergence across the Sivas region between the northern margin of the Eastern Taurides and the Eastern Pontides, and east of the already collided Kırşehir Block, involved northward Cenozoic subduction of oceanic lithosphere of a kinematic plate that was separated from the Pontides as well as from Africa by trenches (the “Anadolu Plate” Fig. 2; Gürer et al., 2016). The existence of oceanic lithosphere east of the Kırşehir Block in the Late Cretaceous is also evident from the very short time window of no more than a few Myr between ophiolitic crust formation of the Central Anatolian ophiolites (~90 Ma, van Hinsbergen et al., 2016; and references therein) and their obduction onto the Kırşehir Block and the subsequent metamorphism of the latter (~90–85 Ma, Whitney and Hamilton, 2004). This, in combination with E-W spreading directions documented in the Central Anatolian ophiolites suggests that these

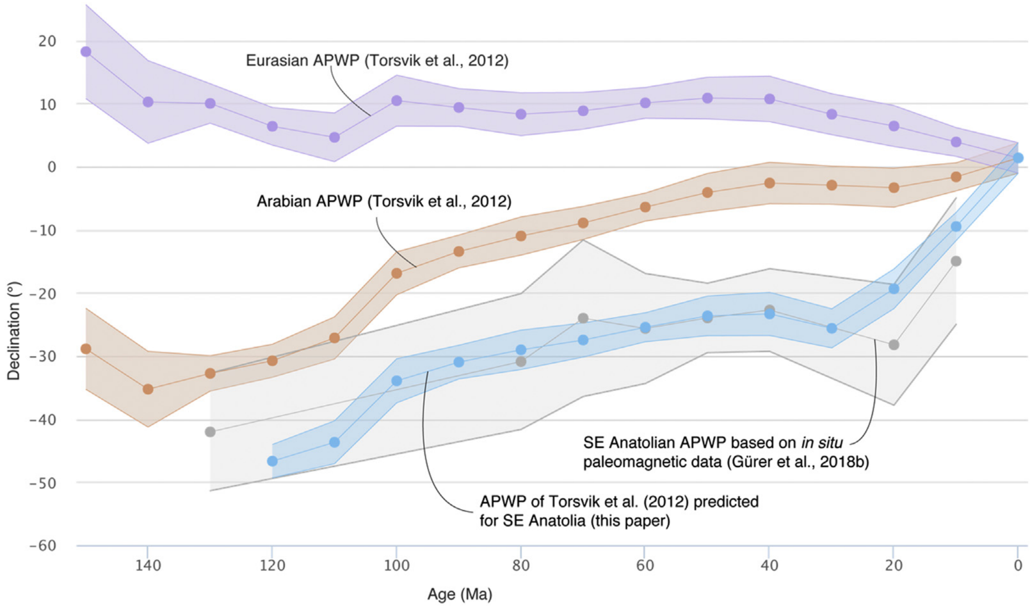

**Fig. 5.** Apparent polar wander path (APWP) of Eurasia and Arabia (Torsvik et al., 2012) compared to the APWPs that we calculated for the Eastern Tauride and the Southeast Anatolian rotating domains on the basis of the rotation poles of our best fit GPlates reconstruction (Fig. 4) for a reference location at Longitude: 40.442, Latitude: 38.991. The average declination (D; with error $\Delta D_x$) per block is given.

ophiolites formed at a ~N-S trending trenches directly east of the Kırşehir Block, and were obliquely obducted SSW-ward shortly after subduction initiation (van Hinsbergen et al., 2016; Maffione et al., 2017; Gürer et al., 2016).

At 60 Ma, the trench to the south of the Anadolu Plate must have been located structurally below the Afyon zone, which had already accreted to the upper plate in latest Cretaceous time. In Paleocene-Eocene time this southern trench clearly accommodated subduction of the continental lithosphere of the Taurides leading to accretion of the Tauride fold-and-thrust belt. After the Eocene, i.e. following the accretion of the Tauride nappe stack, and until Miocene collision with Arabia and the NE African promontory, this trench was not associated with significant accretion and consumed oceanic lithosphere that must have existed between Africa/Arabia and the accreted Tauride fold-and-thrust belt (e.g., van Hinsbergen et al., 2010; Gürer et al., 2016; Hüsing et al., 2009; Okay et al., 2010; Barrier and Vrielynck, 2008.

If oceanic subduction below the Eastern Pontides continued well into the Miocene, then previous geological arguments for Paleocene collision require an alternative explanation. First, shortening in the Taurides is not a conclusive indicator of Pontide-Tauride collision, since burial of the Taurides below the Anadolu Plate may (and did) equally create shortening and metamorphism (Gürer et al., 2016; Meijers et al., 2015; Plunder et al., 2015; Robertson et al., 2009; Sosson et al., 2016; van Hinsbergen et al., 2016). Second, the Paleocene shortening in the Eastern Pontides may well accommodate Paleocene oroclinal bending that affected the Central Pontides upon collision with the Kırşehir Block. This bending affected a width of the Pontides that well exceeded the width of the Kırşehir Block. Therefore, the moderate shortening in the Eastern Pontides may reflect collision to the west rather than the south. Third, the Eastern Tauride fold-and-thrust belt includes middle Eocene limestones and flysch (MTA, 2002), which shows that thrusting and convergence in the Taurides continued into the Middle Eocene, as was well documented farther west (Özgül, 1984), contradicting an inference of regional extension. Fourth, the geochemical signature of Eocene to Miocene magmatism in the Eastern Pontides is of calcalkaline island arc nature, which may well be the result of oceanic subduction (e.g., Eyuboglu et al., 2012). Because the geochemical signatures of Eocene and younger magmatism in the Eastern Pontides may also occur in post-collisional settings (particularly adakites, e.g., Chung et al., 2003), this magmatism alone is not conclusive evidence for much longer oceanic subduction in Eastern Anatolia than in the central and western parts. But, in combination with our kinematic restoration, such prolonged oceanic subduction in Eastern Anatolia is much more likely than the widely inferred Paleocene-Eocene collision, which implies post-collisional wholesale continental subduction. Finally, we note, that the Eastern Tauride magmatic rocks of the Eocene (Maden arc) likely formed above an oceanic subduction zone that consumed lithosphere that once intervened Arabia and the Taurides until collision in the Miocene (Hüsing et al., 2009; Moix et al., 2008; Okay et al., 2010), and are therefore associated with a different subduction zone, which has no bearing on the evolution of the Pontide arc.

Finding the northern structure that accommodated wholesale Anadolu Plate subduction (i.e., the suture), and the timing of its duration in the geology is often controversial (e.g., van Hinsbergen et al., 2012; Cowgill et al., 2016) and should be the focus of debate in Eastern Anatolian geology. We consider the DTFZ the best candidate for such a structure in the Sivas Basin. Geological analysis of the Miocene Sivas Basin (e.g., Kergaravat et al., 2016) indicates that since the Miocene, shortening has been distributed across the basin, but its pre-Miocene structure remains poorly constrained. Paleomagnetic and structural data show that block rotations must have occurred for a large part in Oligocene time to even Late Miocene time (Gürer et al., 2018b). Given the present constraints, we consider it most likely that the DTFZ is the surface expression of a former (subduction) thrust that accommodated the bulk of the ~700 km of convergence between the Eastern Taurides and the Pontides after ~65–60 Ma, until as recently as the Late Miocene.

When continental collision occurred in the reconstructed convergence history is hard to precisely estimate at this stage. On the one hand, we consider it very unlikely that collision occurred in Paleocene time, for that would require wholesale subduction of up to 700 km of continental lithosphere, whilst the geological record of rocks underlying the Sivas Basin only shows ophiolites and ophiolitic mélange. The ~30°ccw rotation of the Eastern Taurides since Late Oligocene time (Gürer et al., 2018b) shows that even in Neogene time, the amount of convergence across the Sivas Basin must have been ~200 km (Fig. 4a). The stratigraphy on either side of the Deliler-Tecer fault is different for much of the Cenozoic (e.g., Legeay, 2017) and keys to deciphering the timing of Cenozoic collision between the Eastern Pontides and Taurides are likely best found in the Sivas Basin stratigraphy, e.g. through detailed sediment provenance analysis in the northern and southern parts of the Sivas Basin.

### *5.2. Ongoing Eastern Anatolian subduction as driver for non-cylindrical orogenesis?*

Prolonged oceanic subduction in Eastern Anatolia after initial collision in Central Anatolia at ~60 Ma suggests a paleogeography in which the Neotethys Ocean was wider in Eastern Anatolia (Gürer et al., 2016; van Hinsbergen et al., 2016). Kinematic restorations of ophiolite belts overlying Greater Adria units in Central and Eastern Anatolia infer that a sharp kink, likely representing a pattern of E-W striking passive margin and N-S striking fracture zone patterns. We conceptually infer that the eastern margin of the Kırşehir Block was such a fracture zone (Eastern Kırşehir Fracture Zone (EKFZ) in Fig. 4), which existed since the Triassic opening of the Neotethys Ocean.

Paleogeographically controlled prolonged subduction in Eastern Anatolia may provide a novel and straightforward explanation for the highly non-cylindrical, Eocene to Miocene Central and Eastern Anatolian deformation history. This deformation is often regarded as the result of Eocene Arabia-Tauride collision, which would then have started as early as 50 Ma (e.g., Rolland, 2017; Rolland et al., 2012). Since 50 Ma, there has been ~1100 km of Arabia-Eurasia convergence, and since the latest Eocene (~35 Ma) there was ~800 km of convergence (McQuarrie and van Hinsbergen, 2013; van der Boon et al., 2018). Our restoration, including the major convergence restored between the Taurides and Pontides, still places the northern Arabian margin ~300–400 km south of the Taurides throughout the Eocene and Oligocene and predicts that Arabia-Tauride collision occurred in Middle Miocene time. Such a young Arabia-Tauride collision age agrees well with thermochronological constraints from the Bitlis suture zone and adjacent foreland basins (e.g., Hüsing et al., 2009; Okay et al., 2010; Pearce et al., 1990). The presence of a Cenozoic subducting slab below the Eastern Pontides that follows from our analysis may provide an alternative driving mechanism for Paleogene Central Anatolian deformation and oroclinal bending.

If Neotethys subduction ceased north of the Kırşehir Block following collision with the Pontides in Central Anatolia, ongoing subduction in the Sivas region would have led to continued northward slab pull on the eastern part of the Tauride fold-and-thrust belt (Fig. 4). Because the Taurides, as part of the Anadolu Plate, extended farther west than the Eastern Pontide slab, we propose that northward pull of that slab may have exerted a moment on the Taurides, which also drove N-S shortening and oroclinal bending in Central Anatolia (Fig. 4). Because there was no collision yet in Eastern Anatolia, northward motion of the Eastern Taurides met less resistance, inducing counterclockwise rotation of the SE Anatolian domain. Governed by the location of the EKFZ, the Ecemiş Fault Zone formed when bending alone could no longer accommodate the Cenozoic convergence difference between Central and Eastern Anatolia, and breaking occurred.

## 6. Conclusions

In this paper, we test whether paleogeography and related along-strike collision diachroneity may have played a role in the non-cylindricity in Anatolian orogenesis. We provide a kinematic restoration of Central and Eastern Anatolian block rotations and fault displacements that suggests that after collision between Greater Adria (Kırşehir-Taurides) and Eurasia (Pontides) at ~60 Ma in Central Anatolia, as much as 700 km of convergence was yet to be accommodated between the Eastern Taurides and the Eastern Pontides. This convergence is not reflected in major shortening, requiring wholesale subduction accommodating most of this convergence. If continental collision in the Eastern Pontides was Paleocene, as widely inferred, this subduction must have been continental, which in the light of geological constraints is unlikely. The age of collision in Eastern Anatolia is thus likely much younger than in Central Anatolia, consistent with ongoing arc magmatism in the Eastern Pontides until the Miocene. When collision occurred exactly remains open for further geological analysis. Systematic investigations on the spatial and temporal distribution and geochemical signatures of the Eastern Pontide and Eastern Tauride magmatic rocks, thermochronology and detrital studies may shed further light on the geodynamic evolution related to Neotethys subduction.

Our reconstruction based on shortening records and paleomagnetically determined rotations from Central and Eastern Anatolia suggests a mid-Miocene Arabia-Eurasia collision. We suggest that ongoing Cenozoic slab pull east of the Ecemiş Fault Zone may be a more likely driver of Central Anatolian regional block rotations and westward decreasing N-S shortening that defines the non-cylindricity of the orogen. Our study highlights the effects of paleogeography on geodynamics and indicates that diachronous collision may be a first-order driver of Anatolian geodynamic evolution and crustal deformation.

## Acknowledgements

This study was supported by ERC-Starting Grant 306810 and NWO-VIDI grant 864.11.004 to DJJvH. We thank the reviewers Andrew Roberts, Adam Forte and an anonymous reviewer for their constructive comments.

## Appendix A. Supplementary data

GPlates files of the kinematic reconstruction of Central Anatolia since 60 Ma that lies at the base of Fig. 4. Central_Anatolia.gpml contains the shape file of the reconstruction. Gürer&vanHinsbergen_master.rot contains the rotation parameters, alongside rotation parameters of global reconstructions, shapefiles for which are located at www.geologist.nl/reconstructions/. Pmag_test.pmag (viewable on www.paleomagnetism.org) contains paleomagnetic data used to constrain the reconstruction. Euler_poles_701.xlsx contains Euler poles of the main blocks relative to South Africa (701) which were used to rotate the global apparent polar wander path (Torsvik et al., 2012) in coordinates of the main blocks and to test compatibility with paleomagnetic data. Supplementary data to this article can be found online at https://doi.org/10.1016/j.tecto.2018.06.005.

## References

Advokaat, E.L., van Hinsbergen, D.J.J., Kaymakci, N., Vissers, R.L.M., Hendriks, B.W.H., 2014. Late Cretaceous extension and Palaeogene rotation-related contraction in Central Anatolia recorded in the Ayhan-Büyükkışla basin. Int. Geol. Rev. 56, 1813–1836. http://dx.doi.org/10.1080/00206814.2014.954279.

Agard, P., Omrani, J., Jolivet, L., Whitechurch, H., Vrielynck, B., Spakman, W., Monié, P., Meyer, B., Wortel, R., 2011. Zagros orogeny: a subduction-dominated process. Geol. Mag. 148, 692–725. http://dx.doi.org/10.1017/S001675681100046X.

Akaryali, E., 2016. Geochemical, fluid inclusion and isotopic (O, H and S) constraints on the origin of Pb–Zn ± Au vein-type mineralizations in the Eastern Pontides Orogenic Belt (NE Turkey). Ore Geol. Rev. 74, 1–14.

Akaryali, E., Akbulut, K., 2016. Constraints of C–O–S isotope compositions and the origin of the Ünlüpınar volcanic-hosted epithermal Pb–Zn ± Au deposit, Gümüşhane, NE Turkey. J. Asian Earth Sci. 117, 119–134.

Akin, H., 1979. Magmatismus und Lagerstättenbildung im ostpontischen Gebirge/Türkei aus der Sicht der Plattentektonik. Geol. Rundsch. 68, 1209.

Albino, I., Cavazza, W., Zattin, M., Okay, A.I., Adamia, S., Sadradze, N., 2014. Far-field tectonic effects of the Arabia—Eurasia collision and the inception of the North Anatolian Fault system. Geol. Mag. 151, 372–379.

Altunkaynak, S., 2007. Collision-driven slab breakoff magmatism in northwestern Anatolia, Turkey. J. Geol. 115, 63–82.

Angus, D.A., Wilson, D.C., Sandvol, E., Ni, J.F., 2006. Lithospheric structure of the Arabian and Eurasian collision zone in eastern Turkey from S-wave receiver functions. Geophys. J. Int. 166, 1335–1346.

Ballato, P., Parra, M., Schildgen, T.F., Dunkl, I., Yıldırım, C., Özsayın, E., Sobel, E.R., Echtler, H., Strecker, M.R., 2018. Multiple exhumation phases in the Central Pontides (N Turkey): new temporal constraints on major geodynamic changes associated with the closure of the Neo-Tethys Ocean. Tectonics. http://dx.doi.org/10.1029/2017TC004808.

Barrier, É., Vrielynck, B., 2008. Paleotectonic Maps of the Middle East: Tectono-Sedimentary-Palinspatic Maps From Late Norian to Pliocene, 14 Maps. Comm. la Cart. Geol. du monde.

Ben-Avraham, Z., Ginzburg, A., Makris, J., Eppelbaum, L., 2002. Crustal structure of the Levant Basin, eastern Mediterranean. Tectonophysics 346, 23–43.

Boyden, J.A., Müller, R.D., Gurnis, M., Torsvik, T.H., Clark, J.A., Turner, M., Ivey-Law, H., Watson, R.J., Cannon, J.S., 2011. Next-generation Plate-Tectonic Reconstructions Using GPlates.

Bozkurt, E., Oberhänsli, R., 2001. Menderes Massif (Western Turkey): structural, metamorphic and magmatic evolution - a synthesis. Int. J. Earth Sci. 89, 679–708. http://dx.doi.org/10.1007/s005310000173.

Bozkurt, E., Satır, M., Buğdaycıoğlu, Ç., 2011. Surprisingly young Rb/Sr ages from the Simav extensional detachment fault zone, northern Menderes Massif, Turkey. J. Geodyn. 52, 406–431.

Boztuğ, D., Jonckheere, R.C., 2007. Apatite fission track data from central Anatolian granitoids (Turkey): constraints on Neo-Tethyan closure. Tectonics 26.

Boztuğ, D., Jonckheere, R.C., Heizler, M., Ratschbacher, L., Harlavan, Y., Tichomirova, M., 2009. Timing of post-obduction granitoids from intrusion through cooling to exhumation in central Anatolia, Turkey. Tectonophysics 473, 223–233. http://dx.doi.org/10.1016/j.tecto.2008.05.035.

Campell, C., Taylor, M.H., Licht, A., Mueller, M., Ocakoglu, F., Moeller, A., Metais, G., Beard, K.C., 2017. Tectonic evolution of the Izmir Anakara Erzincan Suture Zone in northwestern Turkey using zircon U-Pb geochronology and Lu-Hf isotopic tracers. In: American Geophysical Union Meeting.

Capitanio, F.A., Morra, G., Goes, S., Weinberg, R.F., Moresi, L., 2010. India—Asia convergence driven by the subduction of the Greater Indian continent. Nat. Geosci. 3, 136–139.

Cater, J.M.L., Hanna, S.S., Ries, A.C., Turner, P., 1991. Tertiary evolution of the Sivas Basin, central Turkey. Tectonophysics 195, 29–46.

Chung, S.-L., Liu, D., Ji, J., Chu, M.-F., Lee, H.-Y., Wen, D.-J., Lo, C.-H., Lee, T.-Y., Qian, Q., Zhang, Q., 2003. Adakites from continental collision zones: melting of thickened lower crust beneath southern Tibet. Geology 31, 1021–1024.

Çinku, M.C., Hisarlı, Z.M., Heller, F., Orbay, N., Ustaömer, T., 2011. Middle Eocene paleomagnetic data from the eastern Sakarya Zone and the central Pontides: Implications for the tectonic evolution of north central Anatolia. Tectonics 30 (1).

Çinku, M.C., Hisarli, Z.M., Yılmaz, Y., Ülker, B., Kaya, N., Öksüm, E., Orbay, N., Özbey, Z.Ü.Ü.Ü., Cinku, M.C., Hisarli, Z.M., Yılmaz, Y., Ülker, B., Kaya, N., Öksüm, E., Orbay, N., Özbey, Z.Ü.Ü.Ü., 2016. The tectonic history of the Niğde-Kırşehir Massif and the Taurides since the Late Mesozoic: paleomagnetic evidence for two-phase orogenic curvature in Central Anatolia. Tectonics 35, 772–811.

Cowgill, E., Forte, A.M., Niemi, N., Avdeev, B., Tye, A., Trexler, C., Javakhishvili, Z., Elashvili, M., Godoladze, T., 2016. Relict basin closure and crustal shortening budgets during continental collision: an example from Caucasus sediment provenance. Tectonics 35, 2918–2947.

DeMets, C., Iaffaldano, G., Merkouriev, S., 2015. High-resolution Neogene and Quaternary estimates of Nubia-Eurasia-North America Plate motion. Geophys. J. Int. 203, 416–427.

Dilek, Y., Imamverdiyev, N., Altunkaynak, Ş., 2010. Geochemistry and tectonics of Cenozoic volcanism in the Lesser Caucasus (Azerbaijan) and the peri-Arabian region: collision-induced mantle dynamics and its magmatic fingerprint. Int. Geol. Rev. 52, 536–578. http://dx.doi.org/10.1080/00206810903360422.

Dokuz, A., Aydincakir, E., Kandemir, R., Karsli, O., Siebel, W., Derman, A.S., Turan, M., 2017. Late Jurassic magmatism and stratigraphy in the eastern Sakarya zone, Turkey: evidence for the slab breakoff of Paleotethyan oceanic lithosphere. J. Geol. 125, 1–31.

Espurt, N., Hippolyte, J.-C., Kaymakci, N., Sangu, E., 2014. Lithospheric structural control on inversion of the southern margin of the Black Sea Basin, Central Pontides, Turkey. Lithosphere 6, 26–34. http://dx.doi.org/10.1130/l316.1.

Eyuboglu, Y., Chung, S.L., Santosh, M., Dudas, F.O., Akaryali, E., 2011a. Transition from shoshonitic to adakitic magmatism in the eastern Pontides, NE Turkey: implications for slab window melting. Gondwana Res. 19, 413–429. http://dx.doi.org/10.1016/j.gr.2010.07.006.

Eyuboglu, Y., Santosh, M., Bektas, O., Ayhan, S., 2011b. Arc magmatism as a window to plate kinematics and subduction polarity: example from the eastern Pontides belt, NE Turkey. Geosci. Front. 2, 49–56. http://dx.doi.org/10.1016/j.gsf.2010.12.004.

Eyuboglu, Y., Santosh, M., Chung, S.L., 2011c. Crystal fractionation of adakitic magmas in the crust-mantle transition zone: petrology, geochemistry and U-Pb zircon chronology of the Seme adakites, eastern Pontides, NE Turkey. Lithos 121, 151–166. http://dx.doi.org/10.1016/j.lithos.2010.10.012.

Eyuboglu, Y., Santosh, M., Yi, K., Bektas, O., Kwon, S., 2012. Discovery of Miocene adakitic dacite from the Eastern Pontides Belt (NE Turkey) and a revised geodynamic model for the late Cenozoic evolution of the Eastern Mediterranean region. Lithos 146–147, 218–232. http://dx.doi.org/10.1016/j.lithos.2012.04.034.

Eyuboglu, Y., Santosh, M., Dudas, F.O., Akaryali, E., Chung, S.-L., Akdag, K., Bektas, O., 2013. The nature of transition from adakitic to non-adakitic magmatism in a slab window setting: a synthesis from the eastern Pontides, NE Turkey. Geosci. Front. 4, 353–375.

Eyuboglu, Y., Dudas, F.O., Santosh, M., Zhu, D.-C., Yi, K., Chatterjee, N., Jeong, Y.-J., Akaryali, E., Liu, Z., 2016. Cenozoic forearc gabbros from the northern zone of the Eastern Pontides Orogenic Belt, NE Turkey: implications for slab window magmatism and convergent margin tectonics. Gondwana Res. 33, 160–189.

Feld, C., Mechie, J., Hübscher, C., Hall, J., Nicolaides, S., Gurbuz, C., Bauer, K., Louden, K., Weber, M., 2017. Crustal structure of the Eratosthenes Seamount, Cyprus and S. Turkey from an amphibian wide-angle seismic profile. Tectonophysics 700, 32–59.

Gaina, C., Torsvik, T.H., van Hinsbergen, D.J.J., Medvedev, S., Werner, S.C., Labails, C., 2013. The African Plate: a history of oceanic crust accretion and subduction since the Jurassic. Tectonophysics 604, 4–25.

Gautier, P., Bozkurt, E., Bosse, V., Hallot, E., Dirik, K., 2008. Coeval extensional shearing and lateral underflow during Late Cretaceous core complex development in the Niğde Massif, Central Anatolia, Turkey. Tectonics 27. http://dx.doi.org/10.1029/2006TC002089.

Gessner, K., Ring, U., Johnson, C., Hetzel, R., Passchier, C.W., Gungor, T., 2001. An active bivergent rolling-hinge detachment system: central Menderes metamorphic core complex in western Turkey. Geology 29, 611–614. http://dx.doi.org/10.1130/0091-7613(2001)029.

Gök, R., Pasyanos, M.E., Zor, E., 2007. Lithospheric structure of the continent-continent collision zone: eastern Turkey. Geophys. J. Int. 169, 1079–1088.

Guezou, J.-C., Temiz, H., Poisson, A., Gürsoy, H., 1996. Tectonics of the Sivas basin: the Neogene record of the Anatolian accretion along the inner Tauric suture. Int. Geol. Rev. 38, 901–925.

Gülyüz, E., Kaymakci, N., Meijers, M.J.M., Van Hinsbergen, D.J.J., Lefebvre, C., Vissers, R.L.M., Hendriks, B.W.H., Peynircioglu, A.A., 2013. Tectonophysics Late Eocene evolution of the Çiçekdağı Basin (central Turkey): syn-sedimentary compression during microcontinent – continent collision in central Anatolia. Tectonophysics 602, 286–299. http://dx.doi.org/10.1016/j.tecto.2012.07.003.

Gürer, D., van Hinsbergen, D.J.J., Matenco, L., Corfu, F., Cascella, A., 2016. Kinematics of a former oceanic plate of the Neotethys revealed by deformation in the Ulukışla basin (Turkey). Tectonics 35, 2385–2416. http://dx.doi.org/10.1002/2016TC004206.

Gürer, D., Plunder, A., Kirst, F., Corfu, F., Schmid, S.M., van Hinsbergen, D.J.J., 2018a. A long-lived Late Cretaceous–early Eocene extensional province in Anatolia? Structural evidence from the Ivriz Detachment, southern central Turkey. Earth Planet. Sci. Lett. 481, 111–124. http://dx.doi.org/10.1016/j.epsl.2017.10.008.

Gürer, D., Van Hinsbergen, D.J.J., Özkaptan, M., Creton, I., Koymans, M.R., Cascella, A., Langereis, C.G., 2018b. Paleomagnetic constraints on the timing and distribution of Cenozoic rotations in Central and Eastern Anatolia. Solid Earth 9, 295–322. http://dx.doi.org/10.5194/se-9-295-2018.

Hässig, M., Rolland, Y., Sosson, M., Galoyan, G., Sahakyan, L., Topuz, G., Çelik, Ö.F., Avagyan, A., Müller, C., 2013. Linking the NE Anatolian and Lesser Caucasus ophiolites: evidence for large-scale obduction of oceanic crust and implications for the formation of the Lesser Caucasus-Pontides Arc. Geodin. Acta 26, 311–330.

Hodges, K.V., 2000. Tectonics of the Himalaya and southern Tibet from two perspectives. Geol. Soc. Am. Bull. 112, 324–350.

Hu, X., Garzanti, E., Wang, J., Huang, W., An, W., Webb, A., 2016a. The timing of India-Asia collision onset—facts, theories, controversies. Earth Sci. Rev. 160, 264–299.

Hu, X., Wang, J., BouDagher-Fadel, M., Garzanti, E., An, W., 2016b. New insights into the timing of the India—Asia collision from the Paleogene Quxia and Jialazi formations of the Xigaze forearc basin, South Tibet. Gondwana Res. 32, 76–92.

Hüsing, S.K., Zachariasse, W.-J., Van Hinsbergen, D.J.J., Krijgsman, W., Inceöz, M., Harzhauser, M., Mandic, O., Kroh, A., 2009. Oligocene-Miocene basin evolution in SE Anatolia, Turkey: constraints on the closure of the eastern Tethys gateway. Geol. Soc. Lond. Spec. Publ. 311, 107–132.

Isik, V., Uysal, I.T., Caglayan, A., Seyitoglu, G., 2014. The evolution of intraplate fault systems in central Turkey: structural evidence and Ar-Ar and Rb-Sr age constraints for the Savcili Fault Zone. Tectonics 33, 1875–1899.

Jaffey, N., Robertson, A., 2005. Non-marine sedimentation associated with Oligocene-recent exhumation and uplift of the Central Taurus Mountains, S Turkey. Sediment. Geol. 173, 53–89. http://dx.doi.org/10.1016/j.sedgeo.2003.11.025.

Jiménez-Munt, I., Sabadini, R., Gardi, A., Bianco, G., 2003. Active deformation in the Mediterranean from Gibraltar to Anatolia inferred from numerical modeling and geodetic and seismological data. J. Geophys. Res. Solid Earth 108, 2006. http://dx.doi.org/10.1029/2001JB001544.

Karsli, O., Dokuz, A., Uysal, I., Aydin, F., Kandemir, R., Wijbrans, J., 2010. Generation of the Early Cenozoic adakitic volcanism by partial melting of mafic lower crust, Eastern Turkey: implications for crustal thickening to delamination. Lithos 114, 109–120.

Kaya, C., 2010. Deep crustal structure of northwestern part of Turkey. Tectonophysics 489, 227–239. http://dx.doi.org/10.1016/j.tecto.2010.04.019.

Kaymakci, N., Duermeijer, C.E., Langereis, C., White, S.H., Van Dijk, P.M., 2003. Palaeomagnetic evolution of the Cankiri Basin (central Anatolia, Turkey): implications for oroclinal bending due to indentation. Geol. Mag. 140, 343–355. http://dx.doi.org/10.1017/S001675680300757X.

Kaymakci, N., Özçelik, Y., White, S.H., Van Dijk, P.M., 2009. Tectono-stratigraphy of the Çankırı Basin: late Cretaceous to early Miocene evolution of the Neotethyan suture zone in Turkey. Geol. Soc. Lond. Spec. Publ. 311, 67–106.

Kergaravat, C., Ribes, C., Legeay, E., Callot, J.-P., Kavak, K.S., Ringenbach, J.-C., 2016. Minibasins and salt canopy in foreland fold-and-thrust belts: the central Sivas Basin, Turkey. Tectonics 35, 1342–1366.

Keskin, M., Genç, Ş.C., Tüysüz, O., 2008. Petrology and geochemistry of post-collisional Middle Eocene volcanic units in North-Central Turkey: evidence for magma generation by slab breakoff following the closure of the Northern Neotethys Ocean. Lithos 104, 267–305.

Kissel, C., Averbuch, O., de Lamotte, D.F., Monod, O., Allerton, S., 1993. First paleomagnetic evidence for a post-Eocene clockwise rotation of the Western Taurides thrust belt east of the Isparta reentrant (Southwestern Turkey). Earth Planet. Sci. Lett. 117, 1–14. http://dx.doi.org/10.1016/0012-821X(93)90113-N.

Koymans, M.R., Langereis, C.G., Pastor-Galan, D., van Hinsbergen, D.J.J., 2016. Paleomagnetism.org: an online multi-platform open source environment for paleomagnetic data analysis. Comput. Geosci. 93, 127–137. http://dx.doi.org/10.1016/j.cageo.2016.05.007.

Lefebvre, C., Barnhoorn, A., van Hinsbergen, D.J.J., Kaymakci, N., Vissers, R.L.M., 2011. Late Cretaceous extensional denudation along a marble detachment fault zone in the Kırşehir massif near Kaman, central Turkey. J. Struct. Geol. 33, 1220–1236. http://dx.doi.org/10.1016/j.jsg.2011.06.002.

Lefebvre, C., Meijers, M.J.M., Kaymakci, N., Peynircioğlu, A., Langereis, C.G., van Hinsbergen, D.J.J., 2013. Reconstructing the geometry of central Anatolia during the late Cretaceous: large-scale Cenozoic rotations and deformation between the Pontides and Taurides. Earth Planet. Sci. Lett. 366, 83–98. http://dx.doi.org/10.1016/j.epsl.2013.01.003.

Legeay, E., 2017. Géodynamique du Bassin de Sivas (Turquie) De la fermeture d'un domaine océanique à la mise en place d'un avant-pays salifère. Université de Pau et des Pays de l'Adour.

Lucifora, S., Cifelli, F., Rojay, F.B., Mattei, M., 2013. Paleomagnetic rotations in the Late Miocene sequence from the Çankırı Basin (Central Anatolia, Turkey): the role of strike-slip tectonics. Turk. J. Earth Sci. 22 (5), 778–792 (Sep 17).

Li, S., Advokaat, E.L., van Hinsbergen, D.J., Koymans, M.R., Deng, C., Zhu, R., 2017. Paleomagnetic constraints on the Mesozoic-Cenozoic paleolatitudinal and rotational history of Indochina and South China: review and updated kinematic reconstruction. Earth Sci. Rev. 171, 58–77.

Maffione, M., Hinsbergen, D.J.J., Gelder, G.I.N.O., Goes, F.C., Morris, A., 2017. Kinematics of Late Cretaceous subduction initiation in the Neo-Tethys Ocean reconstructed from ophiolites of Turkey, Cyprus, and Syria. J. Geophys. Res. Solid Earth 122, 3953–3976.

McCay, G.A., Robertson, A.H.F., 2013. Upper Miocene—Pleistocene deformation of the Girne (Kyrenia) Range and Dar Dere (Ovgos) lineaments, northern Cyprus: role in collision and tectonic escape in the easternmost Mediterranean region. Geol. Soc. Lond. Spec. Publ. 372, 421–445.

McClusky, S., Balassanian, S., Barka, A., Demir, C., Ergintav, S., Georgiev, I., Gurkan, O., Hamburger, M., Hurst, K., Kahle, H., et al., 2000. Global Positioning System constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus. J. Geophys. Res. Solid Earth 105, 5695–5719.

McQuarrie, N., 2004. Crustal scale geometry of the Zagros fold—thrust belt, Iran. J. Struct. Geol. 26, 519–535.

McQuarrie, N., van Hinsbergen, D.J.J., 2013. Retrodeforming the Arabia-Eurasia collision zone: age of collision versus magnitude of continental subduction. Geology 41, 315–318.

Meijers, M.J.M., Kaymakci, N., Van Hinsbergen, D.J.J., Langereis, C.G., Stephenson, R.A., Hippolyte, J.-C.C., 2010. Late Cretaceous to Paleocene oroclinal bending in the central Pontides (Turkey). Tectonics 29. http://dx.doi.org/10.1029/2009TC002620.

Meijers, M.J.M., Smith, B., Kirscher, U., Mensink, M., Sosson, M., Rolland, Y., Grigoryan, A., Sahakyan, L., Avagyan, A., Langereis, C., Müller, C., 2015. A paleolatitude reconstruction of the South Armenian Block (Lesser Caucasus) for the Late Cretaceous: constraints on the Tethyan realm. Tectonophysics 644–645, 197–219. http://dx.doi.org/10.1016/j.tecto.2015.01.012.

Menant, A., Jolivet, L., Vrielynck, B., 2016. Kinematic reconstructions and magmatic evolution illuminating crustal and mantle dynamics of the eastern Mediterranean region since the late Cretaceous. Tectonophysics 675, 103–140.

Moix, P., Beccaletto, L., Kozur, H.W., Hochard, C., Rosselet, F., Stampfli, G.M., 2008. A new classification of the Turkish terranes and sutures and its implication for the paleotectonic history of the region. Tectonophysics 451, 7–39. http://dx.doi.org/10.1016/j.tecto.2007.11.044.

Mouthereau, F., 2011. Timing of uplift in the Zagros belt/Iranian plateau and accommodation of late Cenozoic Arabia–Eurasia convergence. Geol. Mag. 148 (5-6), 726–738.

MTA, 2002. Geological map of Turkey, scale 1:500,000., Mineral Research and Exploration Institute of Turkey.

Munteanu, I., Matenco, L., Dinu, C., Cloetingh, S., 2011. Kinematics of back-arc inversion of the Western Black Sea Basin. Tectonics 30.

Najman, Y., Appel, E., Boudagher-Fadel, M., Bown, P., Carter, A., Garzanti, E., Godin, L., Han, J., Liebke, U., Oliver, G., et al., 2010. Timing of India-Asia collision: geological, biostratigraphic, and palaeomagnetic constraints. J. Geophys. Res. Solid Earth 115.

Okay, A.I., Nikishin, A.M., 2015. Tectonic evolution of the southern margin of Laurasia in the Black Sea region. Int. Geol. Rev. 1–26. http://dx.doi.org/10.1080/00206814.2015.1010609.

Okay, A.I., Sahinturk, O., 1997. AAPG memoir 68: regional and petroleum geology of the Black Sea and surrounding region. In: Chapter 15: Geology of the Eastern Pontides.

Okay, A.I., Tüysüz, O., 1999. Tethyan sutures of northern Turkey. Geol. Soc. Lond. Spec. Publ. 156, 475–515. http://dx.doi.org/10.1144/GSL.SP.1999.156.01.22.

Okay, A.I., Şengör, A.M.C., Görür, N., 1994. Kinematic history of the opening of the Black Sea and its effect on the surrounding regions. Geology 22, 267–270.

Okay, A.I., Zattin, M., Cavazza, W., 2010. Apatite fission-track data for the Miocene Arabia-Eurasia collision. Geology 38, 35–38.

Okay, A.I., Sunal, G., Tüysüz, O., Sherlock, S., Keskin, M., Kylander-Clark, A.R.C., 2013.

Low-pressure - high-temperature metamorphism during extension in a Jurassic magmatic arc, Central Pontides, Turkey. J. Metamorph. Geol. http://dx.doi.org/10.1111/jmg.12058. (n/a–n/a).

Oncken, O., Hindle, D., Kley, J., Elger, K., Victor, P., Schemmann, K., 2006. Deformation of the central Andean upper plate system—facts, fiction, and constraints for plateau models. In: The Andes. Springer, pp. 3–27.

Ottria, G., Pandolfi, L., Catanzariti, R., Da Prato, S., Ellero, A., Frassi, C., Göncüoğlu, M.C., Marroni, M., Ruffini, L., Sayit, K., 2017. Evolution of an early Eocene pull-apart basin in the central Pontides (northern Turkey): new insights into the origin of the north Anatolian shear zone. Terra Nova 29, 392–400.

Özdamar, Ş., Billor, M.Z., Sunal, G., Esenli, F., Roden, M.F., 2013. First U-Pb SHRIMP zircon and 40Ar/39Ar ages of metarhyolites from the Afyon-Bolkardag Zone, SW Turkey: implications for the rifting and closure of the Neo-Tethys. Gondwana Res. 24, 377–391. http://dx.doi.org/10.1016/j.gr.2012.10.006.

Özgül, N., 1984. Stratigraphy and tectonic evolution of the Central Taurides. In: Geol. Taurus Belt, pp. 77–90.

Özgul, N., Tursucu, A., 1984. Stratigraphy of the Mesozoic carbonate sequence of the Munzur Mountains (Eastern Taurides). In: International Symposium on Geology of the Taurus Belt, pp. 173–180.

Pearce, J.A., Bender, J.F., De Long, S.E., Kidd, W.S.F., Low, P.J., Güner, Y., Saroglu, F., Yilmaz, Y., Moorbath, S., Mitchell, J.G., 1990. Genesis of collision volcanism in Eastern Anatolia, Turkey. J. Volcanol. Geotherm. Res. 44, 189–229.

Plunder, A., Agard, P., Chopin, C., Okay, A., 2013. Record of high-pressure overprint in metamorphic soles of the Tavşanlı zone, western Anatolia. Geophys. Res. Abstr. 15, 8465.

Plunder, A., Agard, P., Chopin, C., Pourteau, A., Okay, A.I., 2015. Accretion, underplating and exhumation along a subduction interface: from subduction initiation to continental subduction (Tavşanlı zone, W. Turkey). Lithos 226, 233–254. http://dx.doi.org/10.1016/j.lithos.2015.01.007.

Plunder, A., Thieulot, C., van Hinsbergen, D.J.J., 2018. The effect of obliquity on temperature in subduction zones: insights from 3D numerical modelling. Solid Earth Discuss. 9, 759–779.

Poisson, A., Guezou, J.C., Ozturk, A., Inan, S., Temiz, H., Gürsöy, H., Kavak, K.S., Özden, S., 1996. Tectonic setting and evolution of the Sivas Basin, central Anatolia, Turkey. Int. Geol. Rev. 38, 838–853. http://dx.doi.org/10.1080/00206819709465366.

Poisson, A., Vrielynck, B., Wernli, R., Negri, A., Bassetti, M.-A., Büyükmeriç, Y., Özer, S., Guillou, H., Kavak, K.S., Temiz, H., Orszag-Sperber, F., 2016. Miocene transgression in the central and eastern parts of the Sivas Basin (Central Anatolia, Turkey) and the Cenozoic palaeogeographical evolution. Int. J. Earth Sci. 105, 339–368. http://dx.doi.org/10.1007/s00531-015-1248-1.

Pourteau, A., Candan, O., Oberhänsli, R., 2010. High-pressure metasediments in central Turkey: constraints on the Neotethyan closure history. Tectonics 29, TC5004. http://dx.doi.org/10.1029/2009TC002650.

Pourteau, A., Sudo, M., Candan, O., Lanari, P., Vidal, O., Oberhänsli, R., 2013. Neotethys closure history of Anatolia: insights from 40 Ar–39 Ar geochronology and P-T estimation in high-pressure metasedimentary rocks. J. Metamorph. Geol. 31, 585–606. http://dx.doi.org/10.1111/jmg.12034.

Robertson, A.H.F., Ustaömer, T., Parlak, O., Ünlügenç, U.C., Taşlı, K., Inan, N., 2006. The Berit transect of the Tauride thrust belt, S Turkey: Late Cretaceous—Early Cenozoic accretionary/collisional processes related to closure of the Southern Neotethys. J. Asian Earth Sci. 27, 108–145.

Robertson, A.H.F., Parlak, O., Rizaoglu, T., Unlugenc, U., Inan, N., Tasli, K., Ustaomer, T., 2007. Tectonic evolution of the South Tethyan ocean: evidence from the Eastern Taurus Mountains (Elazig region, SE Turkey). Geol. Soc. Lond. Spec. Publ. 272, 231–270. http://dx.doi.org/10.1144/GSL.SP.2007.272.01.14.

Robertson, A.H.F., Parlak, O., Ustaomer, T., 2009. Melange genesis and ophiolite emplacement related to subduction of the northern margin of the Tauride-Anatolide continent, central and western Turkey. Geol. Soc. Lond. Spec. Publ. 311, 1. http://dx.doi.org/10.1144/SP311.Erratum.

Robertson, A.H.F., Parlak, O., Ustaomer, T., 2013. Late Palaeozoic-Early Cenozoic tectonic development of Southern Turkey and the easternmost Mediterranean region: evidence from the inter-relations of continental and oceanic units. Geol. Soc. Lond. Spec. Publ. 372, 9–48. http://dx.doi.org/10.1144/SP372.22.

Rolland, Y., Perincek, D., Kaymakci, N., Sosson, M., Barrier, E., Avagyan, A., 2012. Evidence for ~80–75 Ma subduction jump during Anatolide–Tauride–Armenian block accretion and ~48 Ma Arabia–Eurasia collision in Lesser Caucasus–East Anatolia. J. Geodyn. 56, 76–85.

Rolland, Y., 2017. Caucasus collisional history: review of data from East Anatolia to West Iran. Gondwana Res. 49, 130–146.

Sayit, K., Göncüoglu, M.C., Furman, T., 2010. Petrological reconstruction of Triassic seamounts/oceanic islands within the Palaeotethys: geochemical implications from the Karakaya subduction/accretion Complex, Northern Turkey. Lithos 119, 501–511. http://dx.doi.org/10.1016/j.lithos.2010.08.004.

Schildgen, T.F., Cosentino, D., Bookhagen, B., Niedermann, S., Yıldırım, C., Echtler, H., Wittmann, H., Strecker, M.R., 2012. Multi-phased uplift of the southern margin of the Central Anatolian plateau, Turkey: a record of tectonic and upper mantle processes. Earth Planet. Sci. Lett. 317, 85–95.

Şengör, A.M.C., Yılmaz, Y., 1981. Tethyan evolution of Turkey: a plate tectonic approach. Tectonophysics 75, 181–241.

Sosson, M., Stephenson, R., Sheremet, Y., Rolland, Y., Adamia, S., Melkonian, R., Kangarli, T., Yegorova, T., Avagyan, A., Galoyan, G., et al., 2016. The eastern Black Sea-Caucasus region during the Cretaceous: new evidence to constrain its tectonic evolution. Compt. Rendus Geosci. 348, 23–32.

Stampfli, G., Marcoux, J., Baud, A., 1991. Tethyan margins in space and time. Palaeogeogr. Palaeoclimatol. Palaeoecol. 87, 373–409. http://dx.doi.org/10.1016/0031-0182(91)90142-E.

Starostenko, V., Buryanov, V., Makarenko, I., Rusakov, O., Stephenson, R., Nikishin, A., Georgiev, G., Gerasimov, M., Dimitriu, R., Legostaeva, O., Pchelarov, V., Sava, O., 2004. Topography of the crust-mantle boundary beneath the Black Sea Basin. Tectonophysics 381, 211–233.

Temiz, H., 1996. Tectonostratigraphy and thrust tectonics of the central and eastern parts of the Sivas Tertiary basin, Turkey. Int. Geol. Rev. 38, 957–971.

Tokel, S., 1977. Doğu Karadeniz Bölgesinde Eosen yaşlı kalk-alkalen andezitler ve jeotektonizma. Turk. Jeol. Kur. Bul. 20, 49–54.

Topuz, G., Altherr, R., Schwarz, W.H., Siebel, W., Satir, M., Dokuz, A., 2005. Post-collisional plutonism with adakite-like signatures: the Eocene Saraycık granodiorite (Eastern Pontides, Turkey). Contrib. Mineral. Petrol. 150, 441–455.

Topuz, G., Okay, A.I., Altherr, R., Schwarz, W.H., Siebel, W., Zack, T., Satir, M., Sen, C., 2011. Post-collisional adakite-like magmatism in the Agvanis Massif and implications for the evolution of the Eocene magmatism in the Eastern Pontides (NE Turkey). Lithos 125, 131–150. http://dx.doi.org/10.1016/j.lithos.2011.02.003.

Topuz, G., Gocmengil, G., Rolland, Y., Çelik, O.F., Zack, T., Schmitt, A.K., 2012. Jurassic accretionary complex and ophiolite from northeast Turkey: no evidence for the Cimmerian continental ribbon. Geology 41, 255–258. http://dx.doi.org/10.1130/G33577.1.

Torsvik, T.H., der Voo, R., Preeden, U., Mac Niocaill, C., Steinberger, B., Doubrovine, P.V., van Hinsbergen, D.J.J., Domeier, M., Gaina, C., Tohver, E., et al., 2012. Phanerozoic polar wander, palaeogeography and dynamics. Earth Sci. Rev. 114, 325–368.

Ustaömer, T., Robertson, A.H.F., 1997. Tectonic-sedimentary evolution of the North Tethyan margin in the Central Pontides of northern Turkey. AAPG Mem. 68, 255–290.

Ustaömer, T., Robertson, A.H.F., 2010. Late Palaeozoic-Early Cenozoic tectonic development of the Eastern Pontides (Artvin area), Turkey: stages of closure of Tethys along the southern margin of Eurasia. Geol. Soc. Lond. Spec. Publ. 340, 281–327.

van der Boon, A., van Hinsbergen, D.J.J., Rezaeian, M., Gürer, D., Honarmand, M., Pastor-Galán, D., Krijgsman, W., Langereis, C.G., 2018. Quantifying Arabia–Eurasia convergence accommodated in the Greater Caucasus by paleomagnetic reconstruction. Earth Planet. Sci. Lett. 482. http://dx.doi.org/10.1016/j.epsl.2017.11.025.

van Hinsbergen, D.J.J., 2010. A key extensional metamorphic complex reviewed and restored: the Menderes Massif of western Turkey. Earth Sci. Rev. 102, 60–76. http://dx.doi.org/10.1016/j.earscirev.2010.05.005.

van Hinsbergen, D.J.J., Schmid, S.M., 2012. Map view restoration of Aegean–West Anatolian accretion and extension since the Eocene. Tectonics 31, TC5005. http://dx.doi.org/10.1029/2012TC003132.

van Hinsbergen, D.J.J., Kaymakci, N., Spakman, W., Torsvik, T.H., 2010. Reconciling the geological history of western Turkey with plate circuits and mantle tomography. Earth Planet. Sci. Lett. 297, 674–686. http://dx.doi.org/10.1016/j.epsl.2010.07.024.

van Hinsbergen, D.J.J., Lippert, P.C., Dupont-Nivet, G., McQuarrie, N., Doubrovine, P.V., Spakman, W., Torsvik, T.H., 2012. Greater India Basin hypothesis and a two-stage Cenozoic collision between India and Asia. Proc. Natl. Acad. Sci. 109, 7659–7664.

van Hinsbergen, D.J.J., Maffione, M., Plunder, A., Kaymakci, N., Ganerød, M., Hendriks, B.W.H.B.W.H., Corfu, F., Gürer, D., de Gelder, G.I.N.O., Peters, K., et al., 2016. Tectonic evolution and paleogeography of the Kırşehir Block and the Central Anatolian Ophiolites, Turkey. Tectonics 35, 983–1014. http://dx.doi.org/10.1002/2015tc004018.

Vanacore, E.A., Taymaz, T., Saygin, E., 2013. Moho structure of the Anatolian Plate from receiver function analysis. Geophys. J. Int. 193, 329–337.

Vincent, S.J., Allen, M.B., Ismail-Zadeh, A.D., Flecker, R., Foland, K.A., Simmons, M.D., 2005. Insights from the Talysh of Azerbaijan into the Paleogene evolution of the South Caspian region. Geol. Soc. Am. Bull. 117, 1513–1533.

Whitney, D.L., Hamilton, M.A., 2004. Timing of high-grade metamorphism in central Turkey and the assembly of Anatolia. J. Geol. Soc. Lond. 161, 823–828.

Whitney, D.L., Teyssier, C., Fayon, A.K., Hamilton, M.A., Heizler, M., 2003. Tectonic controls on metamorphism, partial melting, and intrusion: timing and duration of regional metamorphism and magmatism in the Niğde Massif, Turkey. Tectonophysics 376, 37–60. http://dx.doi.org/10.1016/j.tecto.2003.08.009.

Yin, A., 2006. Cenozoic tectonic evolution of the Himalayan orogen as constrained by along-strike variation of structural geometry, exhumation history, and foreland sedimentation. Earth Sci. Rev. 76, 1–131.

Zor, E., Sandvol, E., Gürbüz, C., Türkelli, N., Seber, D., Barazangi, M., 2003. The crustal structure of the East Anatolian plateau (Turkey) from receiver functions. Geophys. Res. Lett. 30. http://dx.doi.org/10.1029/2003GL018192.