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A precursor of the North Anatolian Fault in the Marmara Sea region

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ABSTRACT

Apatite (U-Th)/He and fission-track analyses of both basement and sedimentary cover samples collected around the Marmara Sea point to the existence of a system of major E–W-trending structural discontinuities active at least from the Late Oligocene. In the Early Pliocene, inception of the present-day North Anatolian Fault (NAF) system in the Marmara region occurred by reactivation of these older tectonic structures. This is particularly evident across the Ganos fault in southern Thrace, as exhumation south of it occurred during the latest Oligocene and north of it during the mid-Miocene. In this area, large tectonic structures long interpreted as the results of Plio-Quaternary NAF-related transpressional deformation (i.e. the Ganos monocline, the Korudağ anticline, and the Gelibolu folds) were in fact produced during the Late Oligocene – Early Miocene. The overall lack of significant (U-Th)/He age differences across the NAF indicates that the Early Pliocene inception of strike–slip motion in the Marmara region represents a relatively minor episode. At the scale of the entire Marmara region, the geographic pattern of exhumation ages shown in this study results instead from the complex superposition of older tectonic events including: (i) the amalgamation of Sakarya and Anatolide–Tauride terranes and (ii) Aegean-related extension.

The Marmara Sea consists essentially of depressions and ridges aligned along the E–W trend of the North Anatolian Fault (NAF; Fig. 1). This fault system, about 1500 km long, is characterised by a right-lateral strike–slip motion and constitutes the northern boundary of the westward moving Anatolian block (e.g., Jackson and McKenzie, 1988; Barka, 1992). According to the common interpretation, the NAF nucleated in eastern Anatolia (Bitlis–Zagros suture zone) during the Late Miocene (ca. 11 Ma) following the collision of the Arabia and Eurasian plates, and propagated westward reaching the Marmara region during the Pliocene (e.g., Barka, 1992; Hubert-Ferrari et al., 2002; Şengör et al., 2005). In this region, the NAF widens into a complex fault zone stretching some 100 km in a N–S direction, from Ganos Mt. in southern Thrace (Okay et al., 2004) to Kazdağ in the southern Biga peninsula (Cavazza et al., 2008). Such configuration translates into a high degree of structural complexity, with coexisting deep basins, push-up structures, and block rotations (e.g., Seeber et al., 2004). The inception of the NAF activity has been inferred based on the study of the associated sedimentary basins, with earlier studies relying mainly on the scarce palaeontological data from terrestrial sedimentary records (see Şengör et al. (2005), for a review). The oldest basins are Middle to Late Miocene in age, whereas the youngest are hardly older than the Pleistocene. Based on apatite fission-track analysis of limited number of samples, Zattin et al. (2005) suggested that the Ganos segment of the NAF follows a pre-existing structural discontinuity in existence at least by the latest Oligocene. Late Oligocene age displacement along the NAF is also supported by Uysal et al. (2006) who studied a ca. 500 km long segment of the NAF east of the Marmara Sea by radiometric dating of fault gouges. They found that an early event of significant strike–slip was initiated at about 57 Ma, but further intensified at ~26 Ma and later than ~8 Ma. Kaymakci et al. (2007), on the basis of palaeomagnetic data, proposed that the Ganos fault and other ENE-trending faults experienced dextral strike–slip activity before the Late Pliocene development of the NAF. An Oligocene major strike–slip shear zone in western Anatolia, with an estimated right-lateral offset of 100 ± 20 km, was described also by Okay et al. (2008) in the Uludağ area, located close to the city of Bursa, about 30 km south of the Marmara Sea. All these papers support the idea that pre-existing mechanical weakness zones such as faults and shear zones greatly influence the locus of subsequent tectonic activity (e.g., Holdsworth et al., 1997).

In this paper, we build on the results by Zattin et al. (2005) to give a more complete picture of the tectonic evolution of the western NAF by using (U-Th)/He and fission-track dating on apatite.

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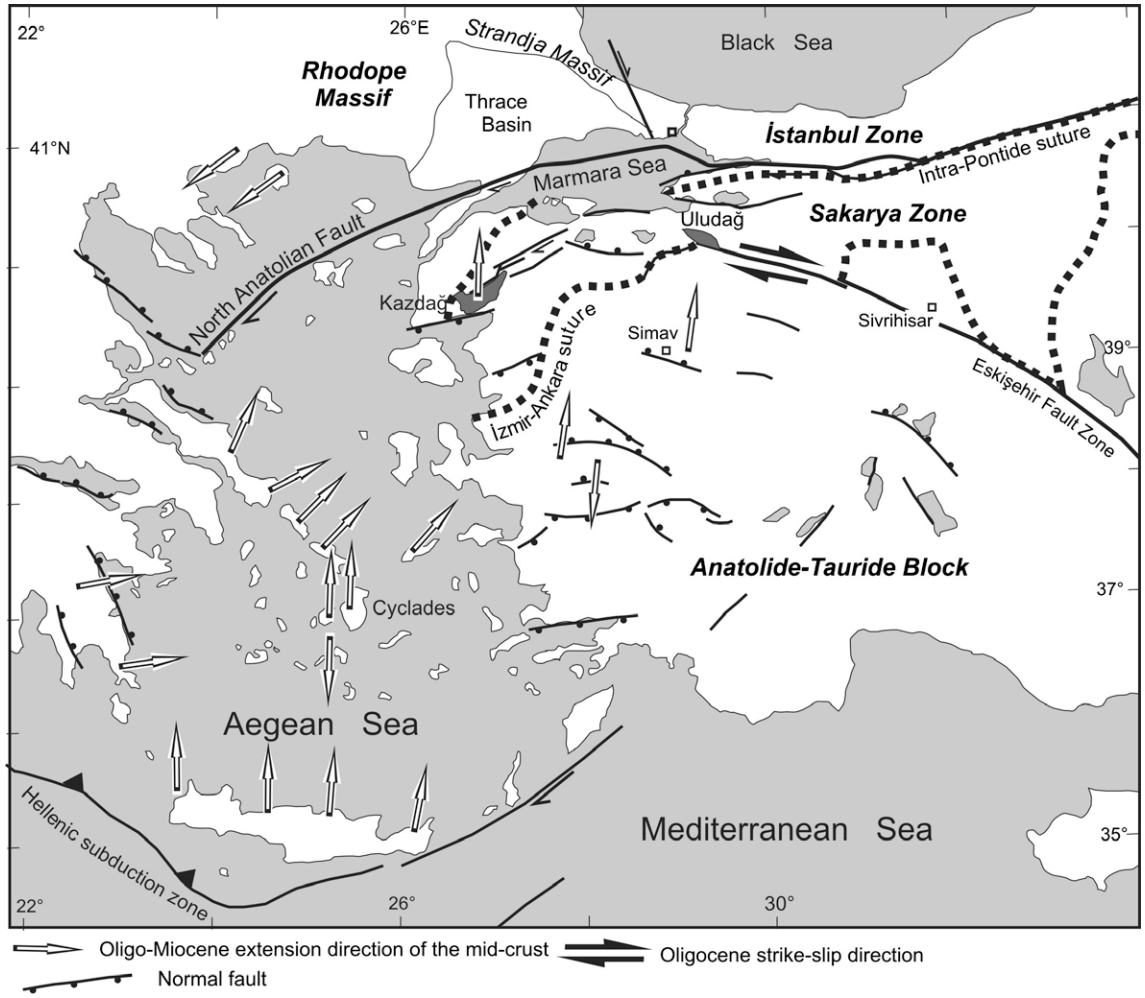

Fig. 1. Simplified tectonic map of the Marmara region showing the major terranes and sutures, as well as the North Anatolian Fault system. The large arrows refer to the direction of shear in the mid-crust during the Oligo-Miocene extension. Modified from Okay et al., 2008.

Samples were therefore collected all around the Marmara Sea and across the main strands of the fault. Our data confirm that the Marmara segments of the active NAF, regarded as post-Miocene structures, have had instead a complex evolution, as shown by the presence of pre-Late Miocene structural discontinuities along which significant vertical displacements occurred. The exact age of these earlier discontinuities is difficult to determine but should be older than the extension that affected the Aegean region since the Late Oligocene (e.g., Seyitoğlu et al., 1992; Jolivet and Faccenna, 2000). Thermochronological data by Zattin et al. (2005) demonstrate that in the Late Oligocene vertical displacements occurred along a precursor of the Ganos fault. The additional dataset presented in this paper suggests that the location and kinematics of the western NAF are controlled by position and geometry of the basement block margins inherited from Mesozoic–Cenozoic closure of oceanic basins belonging to the Tethyan realm and the ensuing collision between the bordering microcontinents.

1. Geologic setting

The Neogene tectonics of the Marmara region has been controlled by the interaction of the extensional regime driven by slab retreat along the Aegean subduction zone (e.g., Jolivet, 2001) and the westward escape of the Anatolian microplate (moving with respect to the Eurasian plate at a velocity of ~21 mm/year; e.g., Reilinger et al., 2006) guided by the NAF. In central Anatolia, over 90% of this movement is concentrated on this fault, which forms a well-defined narrow plate boundary. In the Aegean region, the rigid westward translation of the Anatolian microplate combined with back-arc spreading behind the Aegean Trench gave way to distributed north–south extension along E–W–trending normal faults. This extension resulted in the formation of E–W trending grabens, which are the most prominent neotectonic feature of western Anatolia (Bozkurt, 2001). The same structural trend is observed in the Marmara Sea region, where the NAF developed as a complex fault system. East of the Marmara Sea, the NAF splits into two branches which, divided into sub-branches, form a zone of distributed deformation more than 120 km wide (Fig. 1; Şengör et al., 1985). However, GPS studies show that over 90% of the present-day strike–slip deformation occurs along the main northern branch of NAF passing through the Marmara Sea and continuing westward into Thrace as the Ganos segment (McClusky, 2000; Meade et al., 2002). The Marmara Sea comprises a broad shelf to the south and three deep step-over sub-basins to the north (Barka, 1997; Okay et al., 2000; Le Pichon et al., 2001; Imren et al., 2001; Armijo et al., 2002). Transpressional uplift and transtensional subsidence are associated with the Ganos fault in the western Marmara region (Okay et al., 2004; Seeber et al., 2004).

The present-day tectonic framework of Anatolia is the result of a complex evolution that initiated in the Late Cretaceous with the convergence between the African and Eurasian plates. This re-