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Moho, crustal architecture and deep deformation under the North Marmara Trough, from the SEISMARMARA Leg 1 offshore–onshore reflection–refraction survey

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ABSTRACT

Understanding further the nature and evolution at lithospheric scale of the Sea of Marmara on the North Anatolian Fault needs constraints on the deep crustal and Moho spatial variation. This has been probed here with offshore–onshore and OBS, Ocean Bottom Seismometer refraction seismics, in addition to coincident MCS, marine multichannel reflection seismic profiles over the whole North Marmara Trough.

The diverse strikes of MCS profiles in a dense grid allow to avoid misinterpretation of late echoes in the deep basin as Moho reflections and attribute them to sidesweeps. Moho is instead positively identified from reversed observations of first-arrival head and refracted waves at the top of the mantle obtained at large offset by land stations. A significant and sharp reduction in its depth, on the order of 5 km occurs beneath both the eastern and western rims of the North Marmara Trough, with a more progressive crustal thinning from the south.

The wide-angle reflections on OBS and land stations document in addition to Moho the top of a lower crustal reflective layer, which is also sampled by MCS profiles, and appears to follow Moho topography. The dense grid of MCS profiles along the southwestern margin of the North Marmara Trough reveals a dipping reflector through the upper crust with tilted basement blocks on top. This low-angle fault is suggested as a normal sense detachment extending in depth towards the reflective lower crust.

The upwarp of the Moho and lower crustal layer towards the North Marmara Trough suggests that crustal thinning occurs mostly in the upper crustal part, with lateral transport of the material towards WSW in the footwall of the detachment, and possibly other features to the south, in the motion of Anatolia with respect to stable Eurasia oblique to the North Marmara Trough. Thinning can be accommodated in an asymmetric partitioning of the displacement on several branching faults at lithospheric scale.

1. Introduction

1.1. Study area and methods

The North Anatolian Fault (NAF) is a continental transform boundary, which cuts across Turkey over more than 1500 km. It is accommodating about 25 mm/yr (McClusky et al., 2000) of right-lateral motion between the Anatolian and the Eurasian Plates (Fig. 1a inset). The surface expression of the North Anatolian Fault is a relatively narrow and simple fault zone over its entire morphological trace except in its western part as it becomes more complex before entering the Marmara Sea, where it is partitioned into several branches.

The Sea of Marmara has been interpreted as a large-scale transtensive region above an extensional jog on a right-lateral step-over (Armijo et al., 1999) or a releasing bend (Flerit et al., 2006) between the two North Anatolian strike-slip fault segments marked by recent large strike-slip earthquakes, the Izmit segment in the east and the Ganos one in the west. At a larger scale, it connects to the west with the Aegean region of extensional deformation.

Offshore and onshore scientific investigations have been recently conducted in the Marmara Sea region, including geological and GPS studies (Reilinger et al., 1997; Straub et al., 1997; McClusky et al., 2000; Flerit et al., 2003), high-resolution bathymetry (Armijo et al., 2002,

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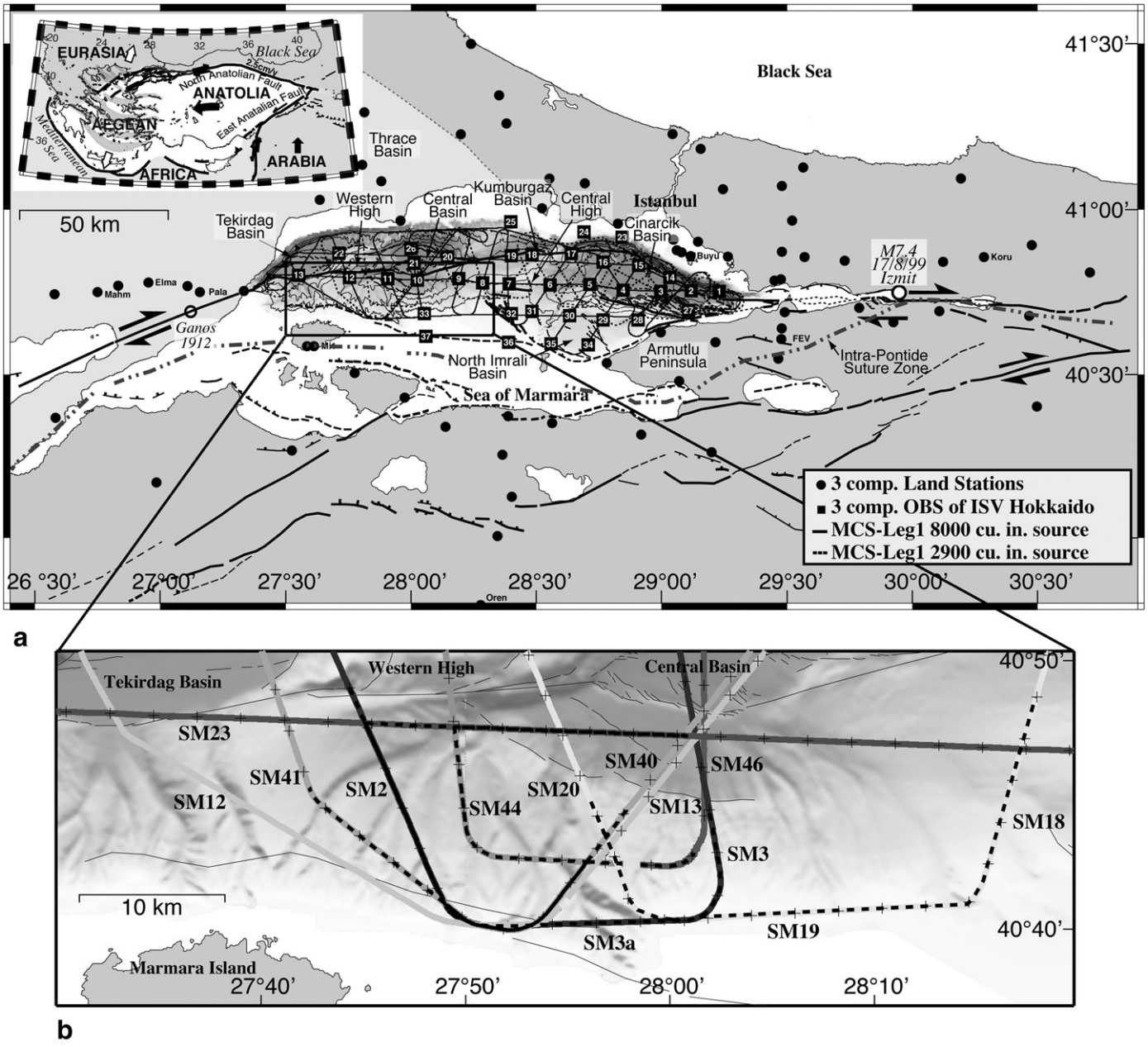

Fig. 1. a) The North Anatolian Fault (NAF) in the Marmara Sea region. Multi-beam bathymetric image of the northern Sea of Marmara collected in 2000 with R/V Le Suroît with observed and interpreted faults superimposed from Armijo et al. (2002). Elements of the SEISMARMARA-Leg1 survey: Black lines indicate the MCS profiles acquired with the 8100 cu. in. source, dashed black lines indicate the MCS profiles acquired with the 2900 cu. in source. Black circles show the land station locations and the black squares show those of the ocean bottom seismometers (OBS). Dashed grey line indicates the Intra-Pontide suture zone and the part in light-grey the limits of the Thrace Basin (after Görur and Okay, 1996). Box indicates area enlarged in b. Inset shows tectonic framework (faults from Armijo et al., 2002). b) Location map showing the interconnected profiles in the southwestern part of the North Marmara Trough with identification of profile discussed in black dash-lines.

2003; Le Pichon et al., 2001), coring and high-resolution seismic profiles (Ergun and Ozel, 1995; Smith et al., 1995; Wong et al., 1995; Aksu et al., 1999; Okay et al., 1999, 2000; Imren et al., 2001; Le Pichon et al., 2001; Parke et al., 2002; Demirbag et al., 2003).

The French–Turkish seismic survey, "SEISMARMARA-Leg1" was carried out after the 1999 earthquakes of Izmit and Düzce from July to October 2001, as a multi-method approach to investigate the seismic structure and activity of the northern Sea of Marmara, the North Marmara Trough, NMT (Hirn et al., 2002, 2003; Bécel et al., 2004) (Fig. 1). The aims of the programme were to shed light on the regional tectonics and recent evolution at crustal scale. The crustal-scale architecture of the NMT is revealed by its dense grid of Multi-Channel Marine Seismic (MCS) profiles that have an unprecedented depth of penetration. Before this survey, MCS data had been collected but only with a short recording streamer and a modest strength of the source, limiting the penetration to the sea bottom multiple.

Selected MCS profiles outlining the general architecture and lateral heterogeneity in the North Marmara Trough have been presented in Laigle et al. (2008). They revealed the supra-crustal structure of the deep Cinarcik and Central Basins as well as elements of the intra-crustal and deep structure on the southern shelf of the trough.

The present paper has a specific focus on the deep structure, with the different and additional dataset of wide-angle reflection and refraction (WARR) on both OBS and land stations. The WARR modeling reveals the deep structure under the North Marmara Trough itself,