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Review Article

Evolution of the seismicity in the eastern Marmara Sea a decade before and after the 17 August 1999 Izmit earthquake

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ABSTRACT

We review the long term evolution of seismicity in the eastern Marmara Sea over a decade, before and after the 1999 Mw 7.6 Izmit earthquake. We analyze large scale space-time variations of seismicity in the region and illustrate the impact of the recent large strike-slip earthquakes on the background activity composed of distinct pre-existing seismic clusters. Two types of aftershocks activity are observed: the first type of enhancement is on strike-slip fault segments (Izmit Fault, Princes Island section of the Main Marmara Fault, Gemlik Fault) immediately following the main shock and related to Coulomb stress transfer; the second type of enhancement is attached to extensional clusters (Yalova, Tuzla) with a few days delay in the onset of strong activation, probably related to pore pressure increase. We observe a fast decay of the activity on strike-slip segments and slower evolution of seismic clusters with extensional features. Two years after the Izmit earthquake, seismic activity returned to the pre-earthquake pattern with most of the activity occurring within extensional clusters. It appears that the influence of the last large strike-slip event on the spatial seismicity distribution in the eastern Marmara Sea is less significant than the effect of the long term regional extension.

Contents

1. Introduction

The Marmara Sea region is presently a major seismic gap along the North Anatolian Fault (NAF). The region is located at the western termination of a unique sequence of large earthquakes (M>7) initiated by the 1939 Mw 7.9 Erzincan earthquake and propagated westwards over 1000 km (Şengör et al., 2005; Stein et al., 1997; Toksöz et al., 1979). Latest in this series, the August 17, 1999 Mw 7.6 Izmit earthquake ruptured a 150 km long segment of the North Anatolian Fault (NAF) (Barka, 2002). Rupture started below the city of Izmit and propagated bilaterally along the fault (Toksoz et al., 1999). In the west, rupture terminated in the Çınarcık basin of the Marmara Sea where the NAF changes orientation with a complex transition zone (Le Pichon et al., 2001) (Fig. 1). Three months later, on

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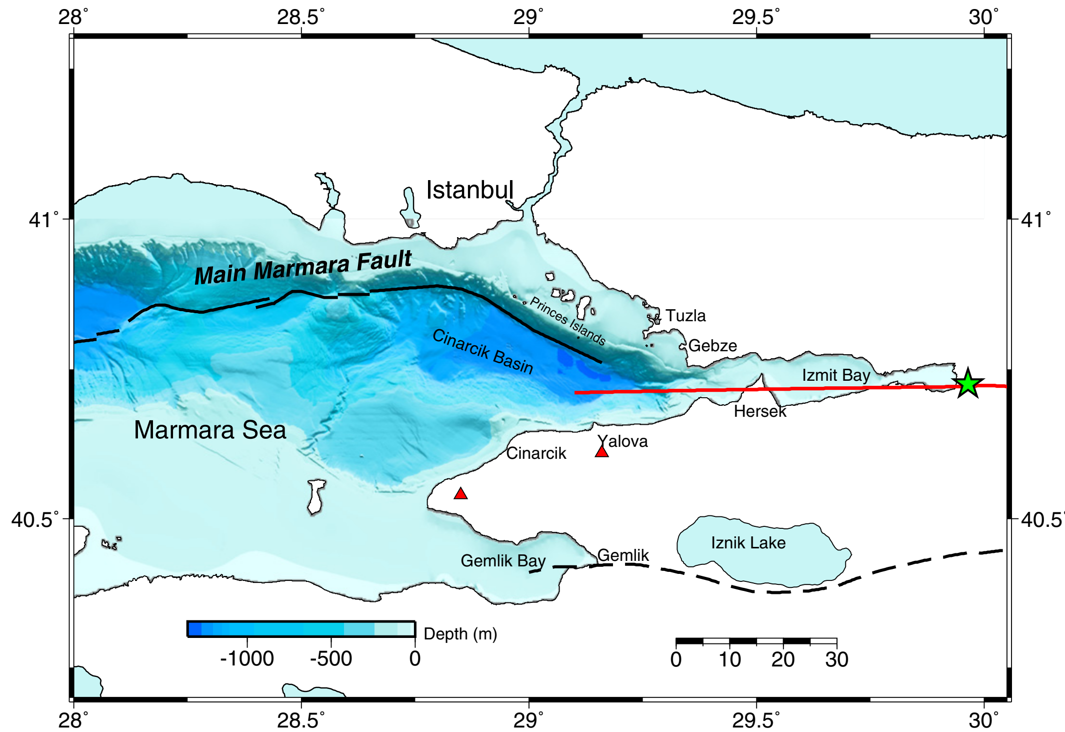

Fig. 1. Map of the eastern Marmara Sea (bathymetry data from Le Pichon et al. (2001). Continuous black lines show the Main Marmara Fault (MMF) from Le Pichon et al. (2001). Dashed line corresponds to the middle Branch (Gemlik Fault). Thick red line shows estimated surface rupture geometry of the 1999 Izmit earthquake from the aftershock locations. The green star indicates the Izmit epicenter. Red triangles show the location of thermal springs in the Armutlu peninsula.

November 12, 1999, the Düzce (Mw 7.2) earthquake was initiated near the eastern end of the Izmit rupture (Bouin et al., 2004).

Among the numerous observations accumulated on this major plate boundary, the remarkable westward migration of large earthquakes since 1939 suggests that the NAF obeys at large scale a simple deterministic evolution despite a rich history and a complex fault system at local scale. It is a strong motivation for expressing and formulating simple laws that are expected to rule the behavior of this major plate boundary from the nucleation of major events to the large scale interactions of the seismic activity. As examples of these rules, one might cite the duality of the rupture propagation (sub and super-shear) and its link with the geometry of the fault and the distribution of aftershocks (Bouchon and Karabulut, 2008; Bouchon et al., 2010) or the recent discovery of an extended nucleation phase for the Izmit earthquake that couples aseismic slip and dynamic rupture (Bouchon et al., 2011).

Large continental earthquakes do not only release stress on the ruptured segments of the fault but they also change the state of stress on unruptured segments of the same and nearby faults. Stress changes are not limited to the proximity of the hosting fault. The influence of viscoelastic relaxation in the lower crust and upper mantle is felt at distances far greater than the fault length while the transient fields from large earthquakes are known to trigger faults at large distances even with long time delays (Freed, 2005). Monitoring of seismic activity at various scales following large earthquakes provides critical information for improved understanding of the earthquake process and hazard assessment.

A central question therefore concerns the triggering mechanisms of a large earthquake: Is initiation of earthquakes on the NAF mostly influenced by lateral stress transfer as suggested by Stein et al. (1997) or by pre-existing local seismic clusters, as suggested by Dewey (1976)? It may also be a combination of the two with very long range of interactions between large earthquakes and local clusters through deep coupling (Durand et al., 2010).

The analysis of the seismicity in the Çınarcık basin appears of central importance for addressing the proposed question on the transition to the next major event in the Marmara region. Previous studies in the area have either focused on the spatial distribution of the activity in specific time periods (Barış et al., 2002; Bulut et al., 2009; Gürbüz et al., 2000; Karabulut et al., 2002; Özalaybey et al., 2002; Sato et al., 2004) or on analysis of long term observations at more regional scale with lower spatial resolution (Dewey, 1976; Durand et al., 2010). Particular studies on the NAF pointed out the importance of the seismic activity before and after large earthquakes (Dewey, 1976; Durand et al., 2010). Dewey (1976) indicated that large ruptures begin in regions with small and moderate earthquakes and then propagate into sections of the fault with lower level of seismicity. Similarly, Durand et al. (2010) showed triggering of seismic activity at large distances following the Izmit and Düzce earthquakes, and the existence of mechanical interaction between the NAF and the extension clusters.

Here we review the long term evolution of seismicity in the eastern Marmara Sea, 10 years before the Izmit earthquake to present (10 years later). We build spatio-temporal distributions of the pre-Izmit background seismicity, the post-Izmit aftershock sequence, two transitional periods (2001–2003 and 2005–2007), and the most recent period (2008–2010). We pay special attention to seismic clusters that occurred off the main strike slip faults in the aftershock zone of Izmit earthquake. We compare qualitatively the present activity with both the pre-Izmit seismicity and the aftershock sequence in relation to tectonic processes.

2. Data

We based our analysis on two types of seismicity catalogs (Table 1). The first type has been obtained from the permanent network of Kandilli Observatory and Earthquake Research Institute (KOERI) and is continuous from 1992 to 2009. Catalogs of the second type contain data from several sources with varying accuracy and resolution (Table 1). The latter type is not continuous and rather devoted to a spatial analysis of the seismicity.