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Submarine earthquake geology in the Marmara Sea: a multidisciplinary approach for seismic risk assessment in coastal areas.

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The1999 earthquakes of Izmit and Duzce (Duzce, Mw 7.1; Izmit Mw 7.4) gave impulse to multidisciplinary geotectonic studies in north-western Turkey that allowed to address some important scientific problems concerning the North Anatolian Fault (NAF). However, major uncertainties regarding nature, geometry and slip-rates of major fault branches still persist, affecting the accuracy of seismic risk assessment in this highly populated region, including Istanbul with its 15 million inhabitants. These uncertainties are mainly related to the submerged portion of the NAF in the Sea of Marmara, where high-resolution seismo-acoustic images have only recently become available.

We carried out three marine geological/geophysical cruises in coastal key areas of the Sea of Marmara (Gulf of Izmit, northern shelf, Imrali region, Ganos and Gulf of Saros), to study the nature and geometry of major fault strands, and to reconstruct their activity in time through an integrated geological/geophysical approach of submarine earthquake geology, that involves the analysis of high resolution geophysical data (multibeam, chirp, side scan sonar, multichannel seismic reflection) in conjunction with well targeted sediment cores. The main purpose of our study was to apply the methods of paleoseismology to the submarine environment, and possibly gather new insights on the behavior of active faults that could be used in seismic risk assessment. Technological advances in the field of Marine Geology, such as accuracy of positioning and sonar systems led to carry out earthquake geological studies in submerged areas at a resolution comparable to those on land. The integrated analysis of the geo-

logical/geophysical data, has allowed us to obtain very high-resolution images of the seafloor and 3D or pseudo-3D reconstruction of key stratigraphic levels in the recent sediment column with a vertical resolution of a few cm. Recognition of piercing points (submerged paleoshorelines, river channels, submarine canyons) displaced along the fault strands represented an important tool to estimate deformation rates along single fault strands. These data are important to infer the fault behavior over geological time scales (10,000 years). Long term slip rate estimates from geological reconstructions can be used to test the significance of geodetic, short-term measurements, and analyze permanent deformation (co-seismic + post-seismic) along single fault segments.

We collected over 70 sediment cores to study the geological effects of individual earthquakes produced by the fault motion along the rupture plane and secondary structures formed by the shaking, such as turbidites, landslides and other mass-wasting deposits near the fault and in the basin depocenters. Logs of physical properties (density, magnetic susceptibility and P-wave velocity) have shown the possibility of correlating slumps or turbiditic deposits in different areas, and to study lateral and vertical variability of sea-level controlled features, such as paleo-shorelines or submerged paleo-river incisions. Analysis of the physical properties of the sediments allow correlations between key horizons identified in the cores and high resolution seismic profiles using synthetic seismograms, reconstructed from density and P-wave logs of sediment cores. Multichannel seismic profiles imaged the sedimentary sequence down to 2 km depths, i.e., the acoustic basement and the earliest deposits of the basin. They constitute the main data for a broad scale analysis of the structure of the margin and its evolution since the earliest stage of opening of the Marmara basin.

Our findings implies that submarine earthquake geology is a feasible technique since we were able to: 1) map the fault pattern, discriminating between active and inactive faults; 2) address their nature and geometry; 3) estimate slip-rates over geological time along single fault strands; 4) describe and date the past earthquakes in the sedimentary sequence; 5) recognize the submarine extent of the 1999 (last) rupture. We further stress the importance of a multidisciplinary approach that involves the fine scale reconstruction of single fault strand dynamics with the study of regional tectonics, paleoceanography, stratigraphy and ultimately basin evolution.