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ACTIVE TECTONICS OF THE AEGEAN: Earthquake Source Parameters and Numerical Simulation of Historical Tsunamis in the Eastern Mediterranean

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Anatolia is a complex blend of multiple tectonic regimes controlled by the interaction of the Arabian, African, and Anatolia plates in one of the most rapidly deforming regions on Earth. Estimates of regional deformation and major fault movements from GPS measurements divide the area into a few major geodynamic regions including the N-S extensional region in western Turkey, a region of strike-slip extension in the northwest, the stable central interior with < 2mm/yr of internal deformation that is bound by the North Anatolian and East Anatolian fault, and a region of distributed strike-slip deformation in eastern Turkey. This diversity of neotectonic environments makes Anatolia a natural laboratory to study a variety of tectonic processes including continent-continent collision, continental escape, continental thinning, and subduction termination. In addition, the Aegean region presents an excellent opportunity to study and to constrain better quantitative models for continental deformation over a wide range of temporal and spatial scales observed in the area, explicitly on the dynamic processes of subduction and the causes and consequences of trench roll-back. Such dynamic processes are not directly measurable but must be inferred from a combination of geodynamic modeling and observational constraints, such as on slab geometry and density, the surface expression of subduction through development of topography and geologic features, and the temporal evolution of the Aegean system as a whole.

The improved focal mechanisms of earthquakes, constrained by P and SH body wave modeling as well as by first motions, show that the faulting in the western part of the Aegean region is mostly extensional in nature, on normal faults with a NW to WNW strike and with slip vectors directed NNW to NNE. There is accompanying evidence from palaeomagnetism that this western region rotates clockwise relative to stable Europe. In the central and eastern Aegean, and in NW Turkey, distributed right-lateral strike–slip is more prevalent, on faults trending NE to ENE, and with slip vectors directed NE. Palaeomagnetic data in this eastern region is more ambiguous, but consistent with very small or no rotations in the northern part and possibly anticlockwise rotations, relative to Europe, in the south. The strike–slip faulting that enters the central Aegean from the east appears to end abruptly in the SW against the NW-trending normal faults of Greece. The kinematics of the deformation is controlled by three factors: the westward motion of Turkey relative to Europe; the continental collision between NW Greece–Albania and the Apulia–Adriatic platform in the west; and the presence of the Hellenic subduction zone to the south. As the right-lateral slip on the North Anatolian Fault enters the Aegean region it splays out, becoming distributed on several parallel faults. The continental shortening in NW Greece and Albania does not allow the rotation of the western margin of the region to be rapid enough to accommodate this distributed E–W right-lateral shear, and thus leads to E–W shortening in the northern Aegean, which is compensated by N–S extension as the southern Aegean margin can move easily over the Hellenic subduction zone. The dynamics of the system, once initiated, is self-sustaining, being driven by the high topography in eastern Turkey and by the roll-back of the subducted slab beneath the southern Aegean. The geometry of the deformation resembles the behavior of a system of broken slats attached to margins that rotate. In spite of its extreme simplicity, a simple model of such broken slats is able to reproduce quantitatively most of the features of the instantaneous velocity field in the Aegean region, including: the slip vectors and nature of the faulting in the eastern and western parts; the senses and approximate rates of rotation; the overall extensional velocity across the Aegean; and the distribution of strain rates, as seen in the seismicity and topography or bathymetry, and using geodetic measurements.

Teleseismic inversion results showed that earthquakes along the Hellenic subduction zone can be classified into three major categories: [1] focal mechanisms of the earthquakes exhibiting E–W extension within the overriding Aegean plate; [2] earthquakes related to the African–Aegean convergence; and [3] focal mechanisms of earthquakes lying within the subducting African plate. Normal faulting mechanisms with left-lateral strike slip components were observed at the eastern part of the Hellenic subduction zone, and we suggest that they were probably concerned with the overriding Aegean plate. However, earthquakes involved in the convergence between the Aegean and the eastern Mediterranean lithospheres indicated thrust mechanisms with strike slip components, and they had shallow focal depths ($h < 45$ km). Deeper earthquakes mainly occurred in the subducting African plate, and they presented dominantly strike slip faulting mechanisms. Slip distributions on fault planes showed both complex and simple rupture propagations with respect to the variation of source mechanism and faulting geometry. Low stress drop values ($\Delta\sigma < 30$ bars) for all earthquakes implying typically interplate seismic activity in the region.

Furthermore, in this presentation potential source regions and Tsunami generation in the Mediterranean will be summarized and new numerical simulations will be presented since historical documents provide valuable information about earthquakes and tsunamis. Tsunami is a very large sea wave triggered by underwater earthquake, volcanic activities or landslides. These waves have unusually long-wavelength in excess of 100 kms, generated in the open ocean/sea and transformed into a series of catastrophic oscillations on the sea surface close to coastal zones. There is a long record of tsunami occurrences and damaging tsunamis have been observed repeatedly in the oceans and seas. The sources of tsunamis are still active and tsunamis are expected to occur in the future. Tsunamis could be even more catastrophic than past events, due to steadily growing occupation of the coasts for the economic development of the coastal countries in the last fifty years. Protection from natural disasters and mitigation of their effects on environment and societies are becoming more important issues all over the world. Moreover, there have been many destructive earthquakes in the Mediterranean region throughout the recorded history and many of them are rather well documented and studied. The understanding the geometry and evolution of potential seismogenic regions and the source rupture process along the main tectonic zones have crucial implications on the tsunami generation. The overall results of numerical simulations verified that damaging historical tsunamis along the Hellenic subduction zone are able to threaten particularly the coastal plains of Crete and Rhodes islands, SW Turkey, Cyprus, Levantine, and Nile Delta–Egypt regions. Thus, we cautiously recommend that special care should be considered in the evaluation of the tsunami risk assessment of the eastern Mediterranean region for future studies.