Geomorphological analysis of submarine fault scarps: Implications for the tectonic evolution of the Sea of Marmara pull-apart (North Anatolian Fault)

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Morphological observations of submarine fault scarps at a range of scales (height between 1-1000m) allow us to constrain the structural evolution of the Sea of Marmara during the Quaternary. To study the distribution and geometry of scarps we combine high-resolution bathymetry data at a range of scales, acquired from the sea surface with a vessel (25m-resolution, 1m vertical accuracy) and close to the sea-floor with a ROV (0.5m-resolution, 0.1m vertical accuracy). The submarine fault scarps have different ratio of strike-slip and normal faulting, consistent with the pull-apart structure. Well preserved sea-floor ruptures associated with recent large earthquakes can be identified (1912 Ms 7.4; 1999 Mw 7.4; 1894 M~7; and 1963 Ms 6.4). Offsets measured in the bathymetry across these earthquake ruptures are typically of 1 to 6m. There is also morphologic and stratigraphic evidence for older events, possibly associated with the historical earthquake sequence that severely damaged Istanbul in the 18th century. The nested morphology of normal faults at the edges of the pull-apart structure contains evidence for cumulative scarps that result from vertical slip associated with many earthquakes. A set of large (10-50m high) scarps offsets the sea floor, with morphology similar to that of individual earthquake scarps. The stratigraphy of the larger scarps is determined with 3.5kHz seismic profiles and 14C dated cores, which document precisely their evolution during the last 20kyr. Their morphology results from accumulation of slip under competing tectonic, erosion and sedimentation processes subject to climatic change and they appear to have emerged progressively after the occurrence of catastrophic sedimentary events, associated with the late Pleistocene-Holocene deglaciation. Sedimentation rates are fast (1-3mm/yr), but they do not keep up with even faster fault rates and associated subsidence that create the 1200-m-deep bathymetric sinks in Marmara. The normal faulting throw rates are particularly fast (up to 6mm/yr) at pull-apart margins. These rates are consistent with the high rates of strike slip and pull-apart extension deduced for the north Marmara fault system at larger scale. The largest cumulative scarps of the nested structure are 1km high, suggesting that the same tectonic and morphological processes prevail over the Quaternary.