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From slow to fast deformation in the Marmara Sea: the SMARTNET network

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The strain energy accumulated in the Earth's crust is released by a continuum of slip processes ranging from completely aseismic (i.e., slow and continuous) to fully seismic (i.e. instant rupture with km/s propagation resulting in corresponding ground motions) through several types of intermediate signals such as episodic tremor or slow earthquakes (e.g. Shelly et al., 2006, 2007; Ide et al., 2007; Rubinstein et al., 2007; 2009; Peng and Gomberg, 2010). While it is generally accepted that the occurrence of aseismic vs. seismic deformation is controlled by the fault structure (i.e. frictional properties, existence and size of asperities) (Scholz, 2002; Rubin and Ampuero, 2005; Rubin, 2008), our current process understanding on which of these deformation types dominates under which conditions is still incomplete (Harris, 2017). Furthermore, the aseismic energy release or fault creep has been usually considered in seismic hazard models as a factor reducing the amount of energy available to produce large earthquakes (Field et al., 2014). Whether aseismic slip really leads to a decreased seismic hazard also depends on many factors, such as the fraction of the fault on which creep occurs and the effect of aseismic deformation on potentially loading nearby faults. Furthermore, recent studies have shown that large earthquakes may be preceded by an acceleration of the slow slip on the interface (Bouchon et al. 2011, 2013, Kato et al. 2012, Ruiz et al. 2014), and that moderate to large earthquakes can be triggered by the propagation of a slow deformation (Durand et al. 2014). In consequent, it is important to understand how slow and fast slip interact, and what is controlling the type of slip on a fault.

The ICDP-GONAF geophysical observatory started operating in 2015 with the main goal of characterizing the deformation in the eastern Sea of Marmara region in direct vicinity of Istanbul metropolitan region and its > 15 Million inhabitants. GONAF includes seven borehole seismic arrays at different locations of the eastern Sea of Marmara as well as four boreholes equipped with strainmeters operated by UNAVCO. Recently, a large strain signal lasting for 50 days has been found in the strainmeter data recorded at the GONAF-Esenkoy station in 2016 (Martinez-Garzon et al., 2019), suggesting that the slow slip source could be located within the nearby Cinarcik segment, an intermediate branch of the North Anatolian Fault. The offset observed in the strain signal is concomitant with the occurrence of a MW4.4 earthquake located 30km away in the Cinarcik basin. This signal also corresponds to an increase of the seismic moment released in the region, including eight earthquakes of magnitude greater than 3.5. On another hand, the strain signal does not correlate with known environmental parameters such as changes of sea level, rainfall or temperature. By consequence, we infer that this signal could indicate local slow slip on the Cinarcik fault. Before the same M_W4.4 earthquake, a sequence of foreshocks has been observed (Malin et al. 2018). These foreshocks exhibit waveforms strikingly similar to the one of the mainshock. This similarity may mean that the source area of the mainshock is failing in a repetitive way before the occurrence of the main earthquake, maybe under the action of a transient forcing, like slow slip. Furthermore, identifying clusters of seismicity based on the rescaled nearest neighbor distance between events, we show that the Cinarcik region is particularly prone to the presence of foreshocks. All these observations are in favor of the existence of interplay between slow and fast deformation in the Cinarcik fault region. It is of particular interest to understand the processes controlling the deformation in this region because the Cinarcik fault could have hosted the M6.3 earthquake which occurred in 1963, and so is contributing to increase the seismic hazard to which Istanbul is exposed.

In January 2019, in order to intensify the seismic coverage of the Armutlu Peninsula in the eastern Sea of Marmara, we deployed a temporal seismic network directly on top of the Cinarcik fault, located roughly -50 km away from the Istanbul metropolitan region. We installed at total of 20 short-period stations (1Hz and 4.5Hz) and 5 broadband stations to capture a broader frequency range and reach a good azimuthal coverage for locating microseismicity and creep processes along the onshore portion of the Cinarcik fault. The main objective of this experiment is to characterize the seismic and aseismic deformation of this eventually creeping fault which is in direct vicinity to the recent 2016 M_W 4.4 earthquake (Malin et al., 2018) and the slow-slip episode recorded in the strainmeter in relation to the MW 4.4 event (Martinez-Garzon et al., 2019)

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