Department of Earth Sciences

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Seismic imaging of changing fault zone properties on the North Anatolian Fault near Istanbul

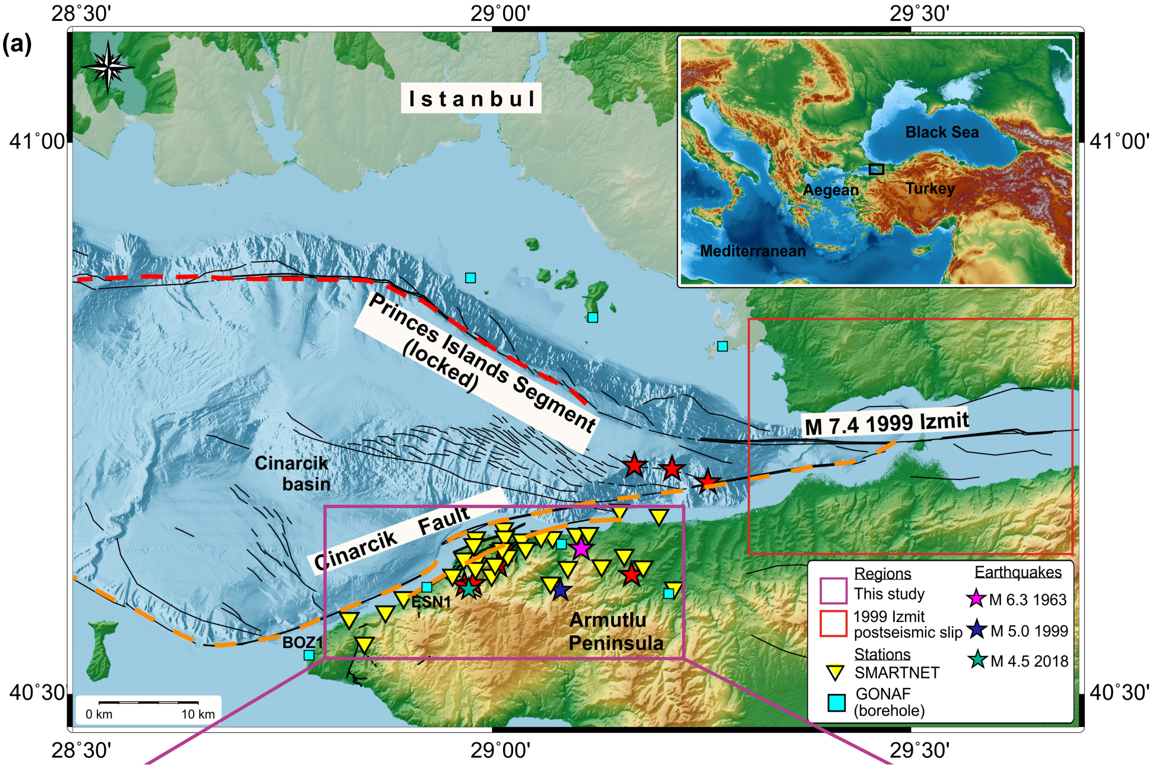

Figure 1) Map of the sea of Marmara region from Martínez-Garzón, et al. (2021), showing major strands of the North Anatolian fault, significant Earthwualke events and a subset of seismic stations to be used in this project

1. Background

The North Anatolian Fault Zone (NAFZ) is a major continental dextral strike-slip fault which extends more 1000 km across Northern Turkey with current slip rates ranging from about 20 mm/yr in the east to 25 mm/yr in the west (Reilinger et al., 2006).

Along the majority of its length the NAFZ comprises a simple single fault strand. However, as it enters the Sea of Marmara region it becomes a more complex horse-tail fault structure, dividing into at least two main strands—the southern and the northern branch (e.g. Armijo et al., 2005) (Figure **1**). The northern branch continues westward through the Sea of Marmara, while the southern branch runs to the south becoming a progressively more diffuse fault network.

Over the past centuries the NAFZ sustained several cycle-like sequences of large magnitude (M>7) earthquakes (Stein et al., 1997). Of these, the best studied is the sequence that ruptured all but the Sea of Marmara segments in a series of westward propagating events, the most recent being the Izmit (Mw 7.4) and Düzce (Mw 7.1) earthquakes of 1999 (e.g. Parsons et al., 2000). Thus the Marmara section of the North Anatolian fault constitutes a seismic gap with potential to host future large earthquakes ($M_W > 7$). This makes understanding ongoing deformation processes within this complex fault segment critical to considerations of future hazard in the region.

Partitioning between seismic and aseismic deformation between different fault segments of the Marmara region is not yet well characterized, with variable behaviour observed across the region.

On the northern fault branch the western portion of the Marmara segment between Ganos and the Central Basin, seafloor geodesy (Yamamoto et al., 2018) and the presence of long-term repeaters suggests occurrence of shallow continuous creep (Bohnhoff et al., 2017). The eastern portion of the Marmara Sea, including the Princess Island segment - the nearest portion of the fault to Istanbul, displays no such indications of fault displacement, suggesting the fault is locked (Bohnhoff et al., 2013). Right at the boundary between the creeping (west) and locked (east) segments of the NAFZ below the Marmara Sea, a M_W 5.8 earthquake occurred in 2019 (e.g. Durand et al., 2020), becoming the largest event in the region since the 1999 M_W 7.4 Izmit earthquake.

On the southern fault branch, the Cinarcik fault bounds the Çinarcik basin below the eastern Marmara Sea. The region also hosted the westernmost tip of the 1999 M_W 7.4 Izmit earthquake rupture (Armijo et al., 2005). Two slow slip transients have recently been identified in this region using the available strainmeter network in the region, each lasting 10s of days and releasing the equivalent energy of a M_W 5 earthquake (Martinez Garzon et al., 2021). The onset of each of these slow slip events coincided with a M_W 4+ earthquake in the eastern Marmara region, and it has been suggested they could have been triggered by static or dynamic stress changes from earthquakes to nearby faults.

In this project, the student will investigate temporal changes of seismic velocity across segments of the Marmara fault zone that may be related to the co-seismic static and dynamic stress transfer after the occurrence of moderate to large earthquakes. Temporal reductions in the seismic velocity have previously been observed after moderate earthquakes such as the M_W 6 earthquake in the Napa valley (Taira et al., 2015), Figure 2ab). There, spatial variability of the velocity reduction was interpreted as representing fracture damage in rocks induced by the dynamic strain.

The project will make use of seismic data from numerous seismic networks including:

- Data from permanent instruments run by the Turkish agencies KOERI and AFAD.
- Data from the geophysical borehole observatory GONAF made up of seven seismic borehole arrays.
- Data from the recent near-fault dense deployment of seismic instruments running from 2019-2020 (SMARTnet).

An initial target period for analysis will focus of the occurrence of the M_W 5.8 Marmara event on September 26th, 2019 (the largest event in the region for the last 22 years). As the earthquake occurred at the boundary between locked and creeping portions of the fault zone, it is expected that the two fault segments may have different frictional and structural properties. A seismicity catalogue covering some weeks before and after the occurrence of the M_W 5.8 (Durand et al., 2020), will be used to identify other potentially significant periods.

In the Marmara region, seasonal changes in sea level result in strong modifications of the normal stresses and pore fluid pressure acting directly on top of fault segments. In other regions such as Japan, seasonal variations in the seismic velocity field have been seen to obscure the detection smaller seismic velocity changes related to co-seismic effects (e.g. Wang et al., 2017). Thus the project will also investigate long term seasonal trends, by linking velocity variations to rainfall, barometric pressure and strainmeter data, and potentially work to remove these long term trends and better image earthquake effects.

2. Methodology

To identify temporal velocity changes between stations in the network the student will analyse continuous background ambient seismic noise data that is continuously generated by ocean waves, using open source python software MsNoise (Lecocq et al., 2014).

Continuous records of seismic data will be cross-correlated between pairs of stations, allowing identification of seismic waves passing between them (Figure 2c). Changes in this continuous record over time (Figure 2d) will be analysed using waveform interferometry to compute variations in the seismic velocity of the intervening the material waves have travelled through between stations.

The project will link observations of seismic velocity changes to physical processes in the region, by comparing results to the local Earthquake catalogues and meteorological data previously described.

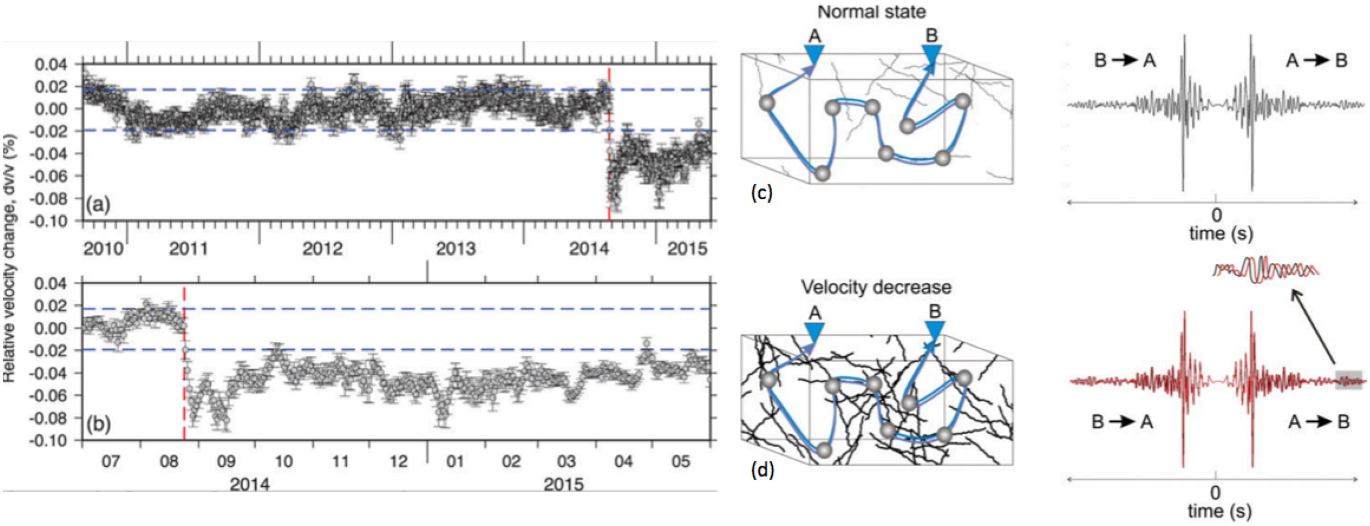

Figure 2) a) and b) Example of reduction in seismic velocity after Mw 6 Earthquake in Napa Valley from Taira et al., (2015), c) From Benguier et al., (2016) - example of the path of scattered seismic energy between two stations A and B, and the ambient noise cross-correlation signal d) change in path after earthquake damage and resulting small changes in the code of cross-correlation surface wave coda arrivals that can be used to calculate seismic velocity changes in the material

3. Training

The student will become part of a vibrant research culture in the department of Earth Sciences, in which ~80 postgraduate students work on a wide range of Earth Science research projects, where they will closely collaborate with the academic staff, postdoctoral researchers and fellows, and postgraduate students in Durham's Geodynamics and Geophsyics group. Where possible the student will also visit and collaborate with project partners in the Geomechanics research Group of GFZ Potsdam in Germany.

Training will be provided in ambient seismic noise analysis (programming, code development) as well as management of large datasets. The project is an opportunity for the student to become proficient in computer programming and large dataset analysis.

References & reading

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