# Microearthquakes preceding a M4.2 Earthquake Offshore Istanbul

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A primary hurdle in observing small foreshocks is the detection-limit of most seismic networks, which is typically about magnitude M1-1.5. We show that a start-up test of a borehole-based seismic network with a much lower detection limit overcame this problem for an $M_w$4.2 earthquake. This earthquake occurred offshore of Istanbul, Turkey, on a fault system that is likely to rupture in an M>7 event. In three days before and two after, 62 or more earthquakes, including at least 18 foreshocks, came from the $M_w$4.2 source patch. The similarity of the foreshocks a clear increased during the hours before.. The $M_w$4.2 sequence gives the impression of stochastic failures that ended up interactively unloading stress concentrations. Such sequences have also been reported for M>7 plate-boundary events.

Our data are from the TESV station, part of the 7-station Geophysical Observatory at the North Anatolian Fault (GONAF). These borehole stations surround the eastern Marmara (Fig 1). Each GONAF site includes vertical and 3-C sensors distributed at ~75 m intervals along 300-m deep boreholes, detecting down to M~0. The TESV array detected approximately 7 times the events in the $M_w$4.2 sequence as the surface-based national network.

The 62 earthquakes were in an area with diffuse background seismicity (black dots in Fig. 1). It was possible to pick their S-P times relative to the $M_w$4.2: their average is 2.00 s +/- 0.07 s, with magnitudes from 0.1 to 4.2. We estimate epicentral distances using S-P times at GONAF stations BOZB, ESNK, and TESV. Based on local scaling relations, they cover a patch ~ 1 km².

We cross-correlated TESV's 290 deep waveform recordings, placing their maxima in a time sequential matrix, autocorrelations on its diagonal. These values range between 0.08 and 0.92 (Fig 2). This matrix contains a high-correlation sub-matrix just before the $M_w$4.2, and a less extensive one during the aftershocks. Running averages of the coefficients with varying window lengths shows their time-dependent trends. The averages were calculated retrospectively using data prior to the time point shown (Fig. 6b). The averages increased 20 hr before the $M_w$4.2, with a maximum 10 min before. They illustrate how borehole methods might aid in forecasting, perhaps even short-term alerts for evacuation.

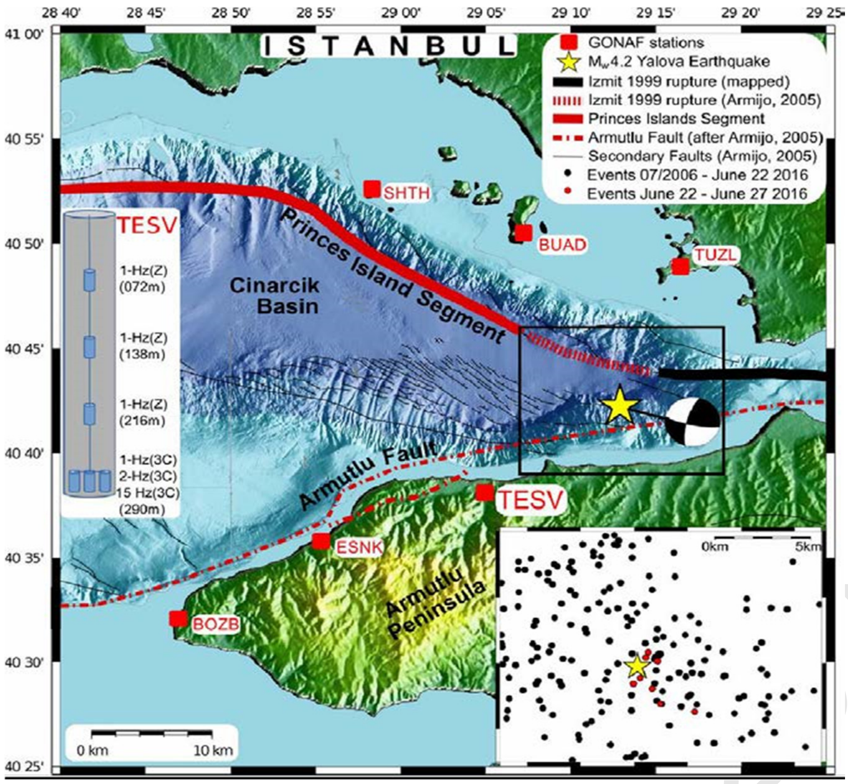


**Figure 1.** The June 25, 2016, $M_w$4.2 earthquake (yellow star) where the NAFZ branches into the Armutlu and the Princes Islands segments. Locations of GONAF borehole arrays indicated in red. The sketch on the left shows the TESV sensor distribution. The black rectangle enlarged on the lower right shows seismicity during the last decade (black) and the eight strongest events (red) of the $M_w$4.2 sequence.

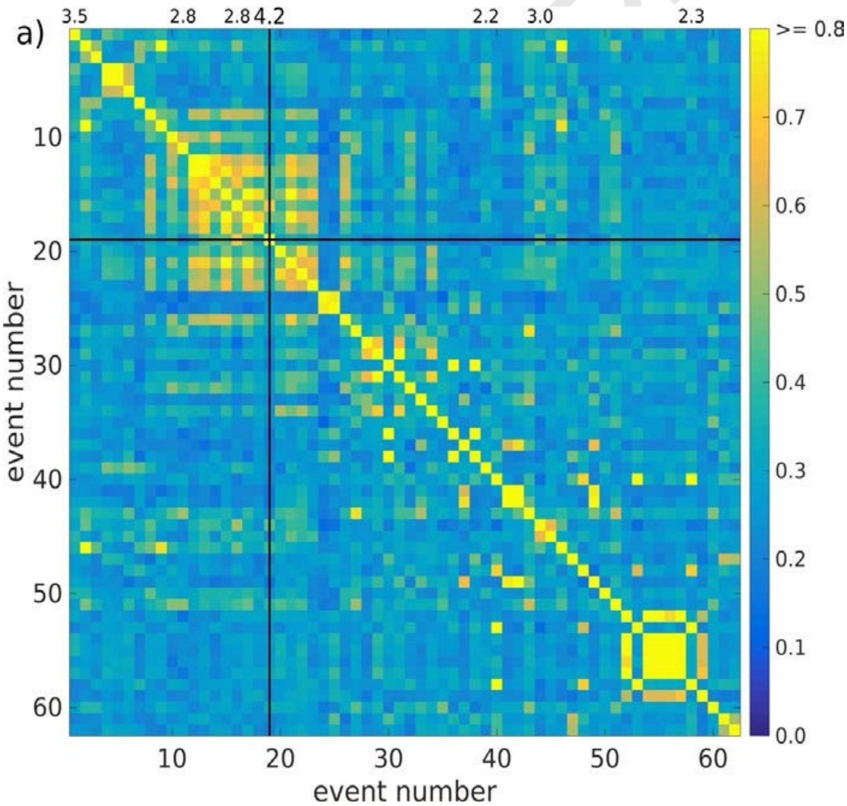


**Figure 2.** The color-coded waveform cross-correlation matrix of pairwise correlation of the 62-event sequence. The events are listed in chronological order along the left and bottom edges of the matrix. The matrix is symmetric about the diagonal, along which their autocorrelations lie. The correlation color scale is cut off at 0.8 in order to better display the variability in the coefficients. The $M_w$4.2 mainshock is shown by the black lines.