CAUSE AND SURFACE FAULTING OF THE TÜRKIYE EARTHQUAKES OF FEBRUARY 6, 2023

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BRIEFING NOTE 478

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TECTONICS AND PLATE BOUNDARY FAULTS IN AND AROUND TURKEY

Türkiye and the surrounding regions are seismically active due to earthquakes that occur on faults that form the boundaries between four tectonic plates.

Clockwise from the top of the left panel of Figure 1, these are the Eurasian, Arabian, African and Anatolian Plates.

The impact of the northward moving Arabian plate on the Anatolian plate is causing it to be extruded westward between the North Anatolian Fault and the East Anatolian fault like a lemon pip, as indicated by the yellow arrows in the left panel of Figure 1 and the black half arrow pairs in the right panel of Figure 1.

The half arrow pairs show the sense of horizontal strike-slip motion on vertical faults, with one side sliding past the other, causing sudden displacements of several metres that are described further below.

The East Anatolian Fault has a left-lateral motion, in which the far side of the fault moves left horizontally past the near side.

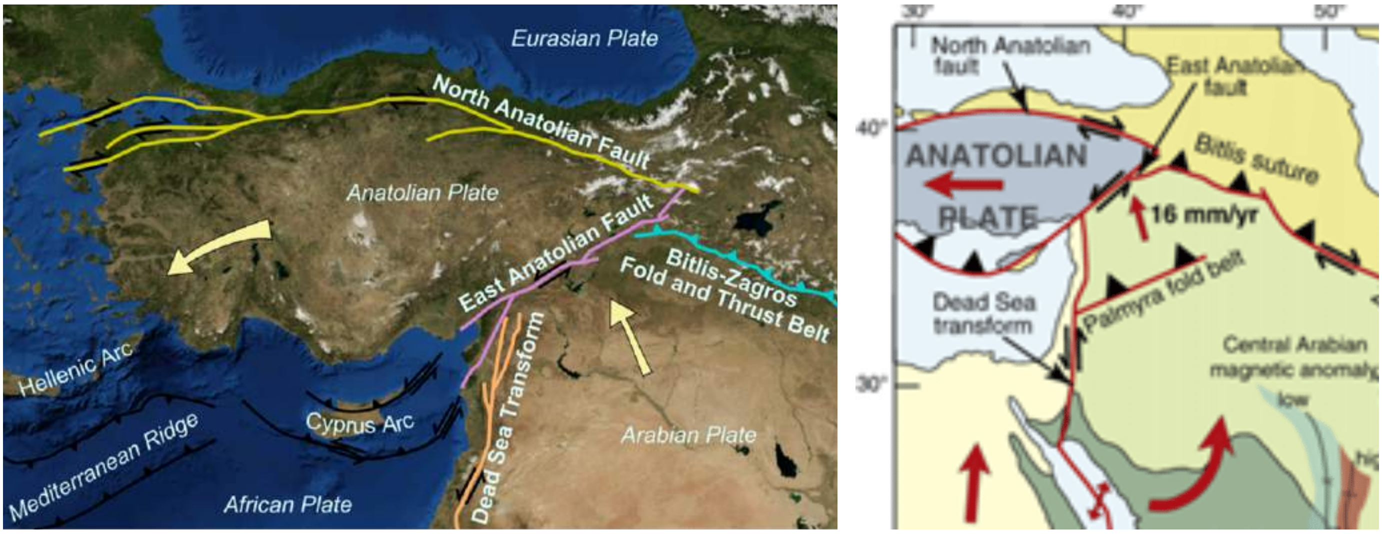

Figure 1. Left: Tectonic plates and major faults in the source region. Source: Wikipedia.
Right: Sense of motion on the North Anatolian Fault and the East Anatolian Fault shown by black half arrow pairs.

FAULTS RUPTURED IN THE TWO EARTHQUAKES

The Mw 7.8 earthquake of 2023 ruptured the southwestern part of the East Anatolian Fault (left side of Figure 1), and evidently triggered the occurrence of the Mw 7.5 earthquake on the Surgu Fault System nine hours later.

The locations of the two main events and their aftershocks are shown in relation to mapped faults in Figure 3. It is clear that both earthquakes occurred on previously identified faults. Figure 3 also shows numerous other active faults that belong to the complex system of faults that accommodates the westward extrusion of the Anatolian Plate.

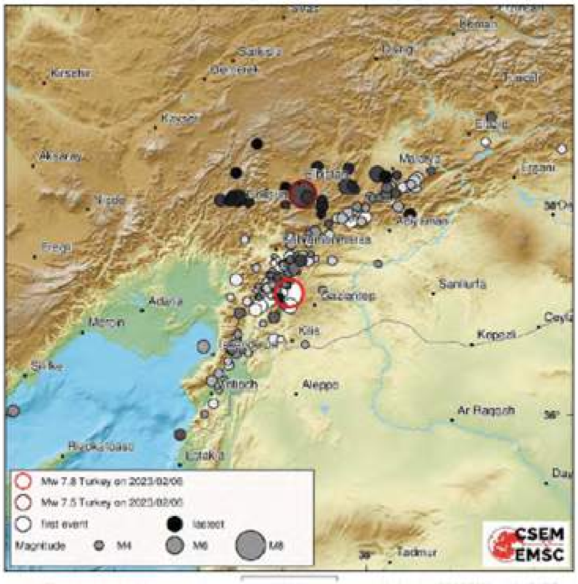

Figure 2. Locations of earthquakes from February 6 to 9, 2023, showing topography. Source: CSEM.

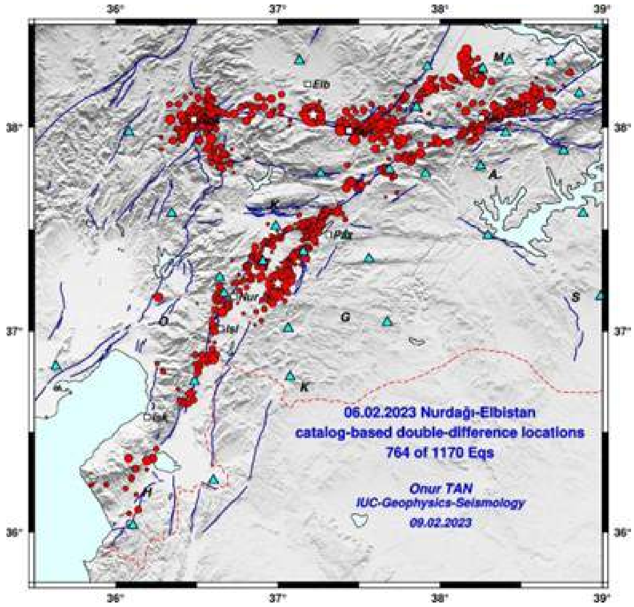

Figure 3. Locations of earthquakes from February 6 to 9, 2023 in relation to mapped faults (blue lines). Source: O. Tan, IUC.

TEMPORAL AND SPATIAL DISTRIBUTION OF AFTERSHOCKS

The temporal and spatial distribution of hundreds of aftershocks in the first 56 hours of the earthquake sequence is shown in Figure 4.

The time sequence by latitude in the left panel shows that many more aftershocks occurred after the second (Mw 7.5) event, even allowing for the latitude concentration due to the east-west strike of the second event.

In these first 56 hours, there were approximately 30 aftershocks of magnitude 5 or larger; we consider such events to have significant damage potential.

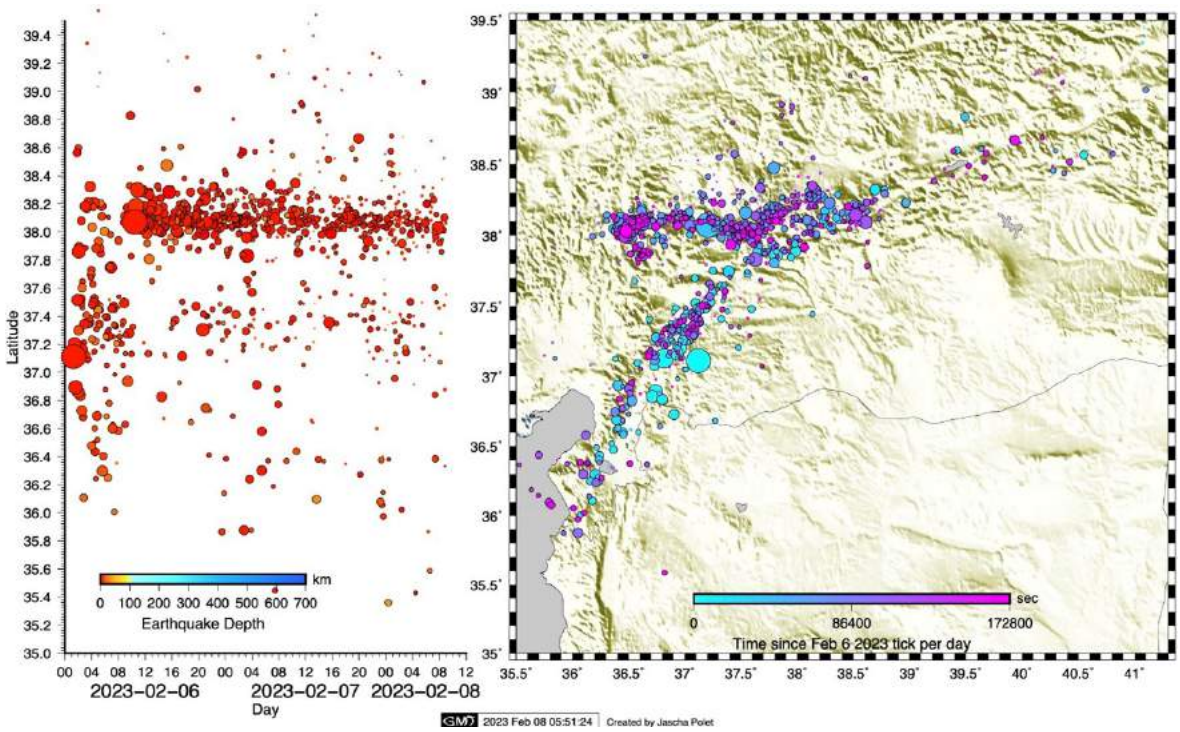

Figure 4. Time sequence of the first 56 hours of aftershocks by latitude (left) and map location (right), in which early events are turquoise and later events are purple. The two large events are shown by the two large dots. Source: Jascha Polet, using the KOERI-RETMC earthquake catalogue.

HISTORICAL EARTHQUAKES IN TÜRKIYE

The Mw 7.8 earthquake of 2023 ruptured three southwestern segments of the East Anatolian Fault that previously ruptured in separate earthquakes (Figure 5): the M 7.5 event on the Amanoa segment (grey) in 521; the M 7.4 event on the Pazarcik segment (blue) in 1513; and the M 7.1 event on the Erkenek segment (green) in 1893, collectively extending from Antioch (modern day Antakya) to Malatya. The M 7.5 event on the Yesomok segment (pink) in 1822 occurred near Aleppo in northwestern Syria, which lies south of the Amanoa segment (grey).

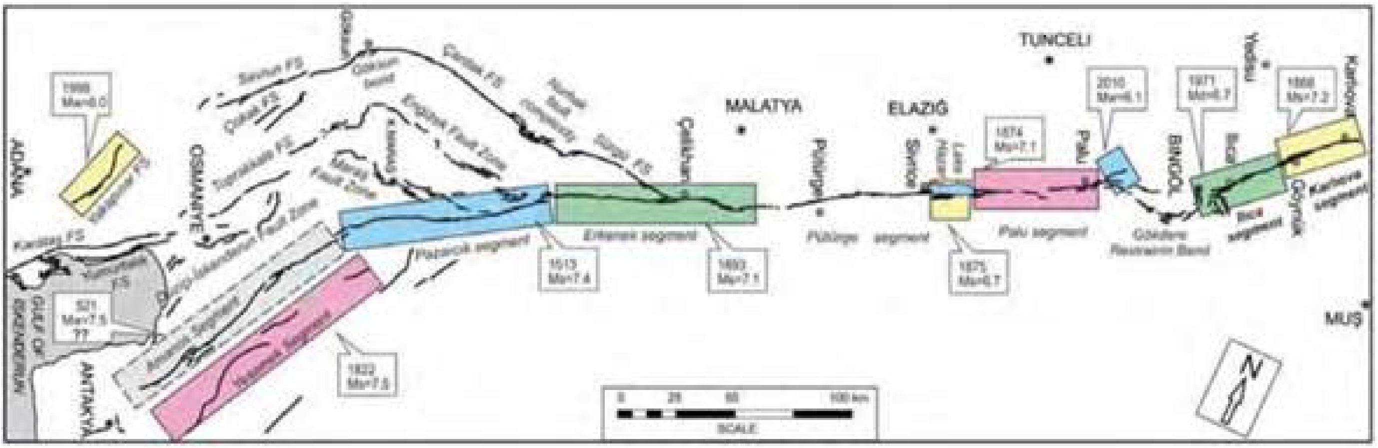

Figure 5. Faults and historical earthquakes of the East Anatolian Fault since 1513. Source: Duman and Emre (2013). This map is oriented about 30 degrees clockwise east of north.

COMPARISON OF TÜRKIYE EARTHQUAKE DEATH TOLLS

Jointly, the Mw 7.8 and 7.5 earthquakes of 2023 have already caused the fifth largest earthquake death toll in two thousand years of Turkish history, based on Wikipedia (2023).

The four larger tolls occurred in the year 115 in Antioch (modern Antakya), 260,000 deaths; the year 525 in Antioch (grey event in Figure 5, attributed to the year 521 there), 250,000 deaths; the 1268 Cilicia, Anatolia earthquake, 60,000 deaths; and the 1883 Izmir earthquake, 53,000 – 120,000 deaths.

The joint death toll in Türkiye and Syria from the 2023 events is already 35,000 deaths and still rising as of 13 February 2023, exceeding the death tolls of the Mw 7.8 Erzincan earthquake of 1939 (32,700 deaths) and the Mw 7.6 Izmit earthquake of 1999 (17,127 deaths) on the North Anatolia fault.

REMOTE SENSING OF GROUND DISPLACEMENT DUE TO FAULTING

Pixel tracking of optical satellite images from the Sentinel-1 satellite show three-component ground displacements of both the Mw 7.8 and Mw 7.5 surface ruptures (top panel of Figure 6).

In the E-W panel, there are large eastward movements (red) on the south sides of both faults and large westward movements (blue) on the north sides, indicating left-lateral motion on both faults. The blowup of the vertical panel on the bottom right of Figure 6 highlights uplifts on the north side of the fault near Iskenderun that are evidently caused by bends in the fault, due to compression of the north side of the fault as it moves southwest past the south side.

The bottom panel of Figure 6, from the Sentinel-2 satellite, shows that the fault offset along the approximately 90 km length of the Mw 7.5 earthquake rupture is almost 7 m, which is larger than the 5 m over the 250 km rupture length of the Mw 7.8 earthquake rupture.

The larger average displacement in the smaller event may be correlated with its more energetic aftershock sequence, shown in Figure 4. The images of ground displacement shown in Figure 6 are of unprecedented quality, and they will be tested for compatibility with field geology, geodetic and GPS observations.

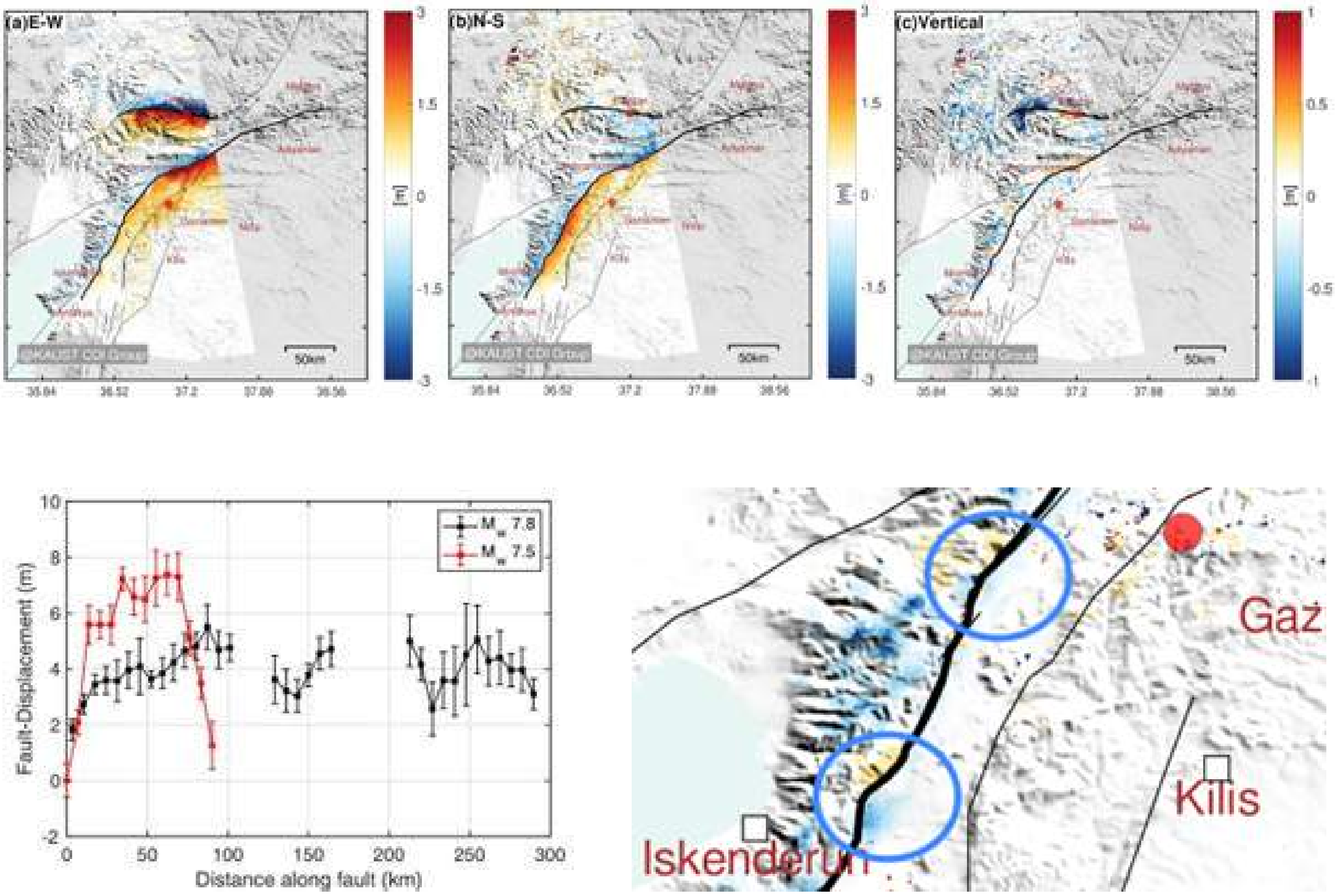

Figure 6. Top: East-West, North-South, and Up-Down ground displacement from pixel tracking in optical images in the source region of the two earthquakes, indicating left-lateral motion on both faults.

Bottom left: Distribution of displacement along the fault for each event. Source: Milliner (2023).

Bottom right: Circles highlight uplifts on the north side of the fault near Iskenderun due to fault bends. Source: Liu, 2023).

SURFACE FAULTING

Surface faulting across roads near Kahramanmaras, across a railway line in Narli near Pazarck, and across a town street in Hassa near Iskenderun are shown in Figures 7, 8 and 9 respectively. In each case the sense of fault motion is left-lateral.

Figure 7. Aerial view of surface rupture crossing roads with left-lateral displacement near Kahramanmaras (location shown in Figure 2). Source: TRT Haber.

Figure 8. Offset railway in Narlı (located near Pazarck, southeast of Kahramanmaras in Figure 2). Fault strands appear to run across the railway in the near and middle distance, with left-lateral displacement. A strong ground motion recording in Pazarck (near this railway) is shown in Figure 10. Source: H. Serdar Akyuz (2023).

Figure 9. Surface rupture at Hassa (located near Iskenderun in Figure 2), showing left-lateral offset of the centreline of the road. Source: Ozdemir Alpay (2023).

STRONG GROUND MOTION RECORDING

The north-south component of horizontal ground motion recorded at Pazarck during the Mw 7.8 earthquake is shown in Figure 10.

The large velocity pulse (centre trace) has a peak ground velocity of 1.85 metres per second, comparable to the largest ground motions recorded close to large earthquakes. This pulse may have been caused by the propagation of fault rupture towards the recording station at close to the shear wave velocity, generating incipient shock wave conditions (Somerville et al., 1997). Pazarck is in the same region as the offset railway in Narlı shown in Figure 8.

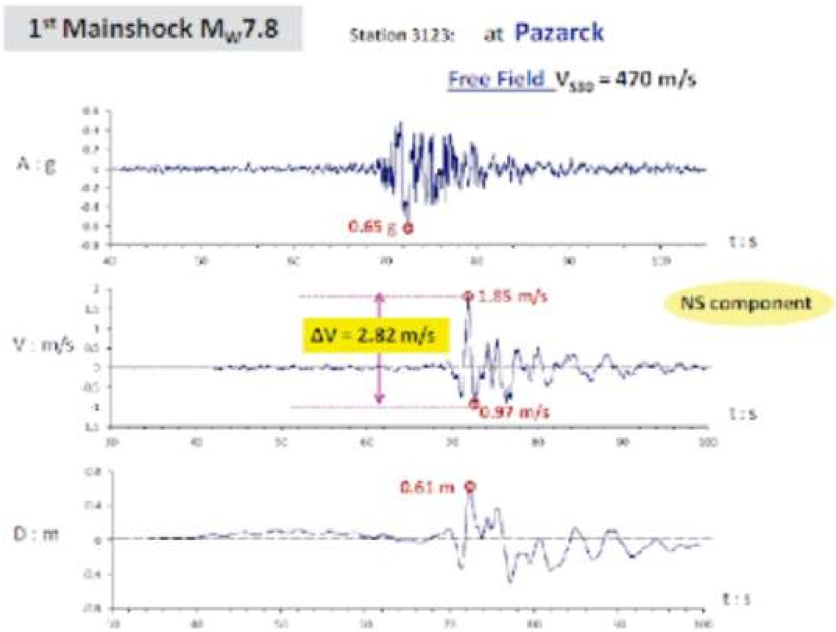

Figure 10. Horizontal ground motion recorded at Pazarck during the Mw 7.8 earthquake. Top: acceleration in g's; Centre: velocity in metres/sec; and Bottom: displacement in metres. Source: Garini and Gazetas (2023).

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Paul is Chief Geoscientist at Risk Frontiers. He has a PhD in Geophysics, and has 45 years experience as an engineering seismologist, including 15 years with Risk Frontiers. He has had first hand experience of damaging earthquakes in California, Japan, Taiwan and New Zealand. He works with Valentina Koschatzky in the development of QuakeAUS and QuakeNZ.

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