**Earthquakes in Türkiye—Understanding Anatolian Plate Tectonics**

Animation can be watched on YouTube (<https://youtu.be/NDCrt1EaOPg>) or downloaded from InClass (www.iris.edu/hq/inclass/animation/858)

Many devastating earthquakes have occurred in Türkiye. This region is broken into microplates, including the Anatolian Plate that contains most of the country of Türkiye. As Arabia rotates counterclockwise into southern Eurasia, a continental collision zone builds between the Persian Gulf and Caspian Sea. By strike-slip motion along its northern and eastern boundaries, the Anatolian Plate moves west to escape this collision zone.

Potentially damaging shallow magnitude 5 and larger earthquakes are concentrated near plate boundaries. The North and East Anatolian Fault zones and West Anatolia Extension Zone are areas of high earthquake hazard in Türkiye.

The North Anatolian Fault Zone extends 1500 km from the Aegean Sea to its intersection with the East Anatolian Fault Zone. High-precision GPS data are available from over 800 stations in Turkey. If we nail down the Eurasian Plate and hold it fixed, we see how GPS velocities document the counterclockwise rotation of the Anatolian Plate. Now let’s zoom into a region straddling the fault. While the plates are locked by friction along the fault, the plate interiors are moving in a right-lateral sense parallel to the fault. The plate edges near the fault are bending and shear stress is building. If we collect GPS data from stations in a swath near the fault, we can see how velocities change across the fault. There is a gradual change from zero in the Eurasian Plate that we’re holding fixed, through the zone of deformation, and into the Anatolian Plate that is moving 22 mm/year at this location. GPS-determined rates of motion across the North Anatolian Fault Zone increase from 20 mm/yr in the east to 26 mm/yr in the west where the northern strand takes up most of the motion.

From 1939 through 1999, 12 major earthquakes occurred along the North Anatolian Fault Zone. Eight of these occurred in a westward progression demonstrating how one major earthquake can set up the next. Let’s look at a section of the North Anatolian Fault that has accumulated high shear stress. When an earthquake ruptures a segment of this fault, the opposite sides of the fault are displaced in a right-lateral sense. Notice that along and adjacent to the rupture, shear stress is decreased by the earthquake while shear stress increased in the area just beyond the rupture zone. The change-in-stress resulting from the earthquake looks like this. In 1939, a magnitude 7.9 earthquake ruptured a 300 km length of the fault with displacements up to 7 meters. That earthquake decreased shear stress along its rupture zone but increased stress on adjacent segments bringing them closer to failure in subsequent earthquakes. So, in 1942, a magnitude 6.9 earthquake ruptured the 40-km-long fault segment west of the 1939 rupture. Succeeding earthquakes in the westward progression occurred in 1943, ‘44, ’51, ’57, and ’67.

Historic records and earthquake geology indicate that the segment of the northern strand of the North Anatolian Fault Zone immediately west of the 1967 rupture had not experienced a major earthquake since 1878 and the next segment to the west had a major earthquake in 1719. So, these parts of the fault had been storing elastic energy for centuries. By 1997, geophysicists had early GPS observations of Eurasia – Anatolia plate motion and advancing knowledge of stress changes during earthquakes. This made it possible to issue an “earthquake forecast” indicating 12% probability of a major earthquake near Izmit during the 30-year interval starting in 1997. Just two years later, the magnitude 7.4 Izmit earthquake struck in August followed by the magnitude 7.2 Düzce earthquake in November. The Izmit and Dünze earthquakes caused at least 20,000 fatalities and widespread damage to buildings and infrastructure as well as liquefaction and subsidence. Affected areas included the eastern suburbs of Istanbul, Turkey’s largest city with a population of 16 million.

On the west side of the Marmara Sea, a major earthquake occurred in 1912 on the northern strand of the North Anatolian Fault Zone. A “seismic gap” is recognized in the east and central Marmara Sea where fault segments have not experienced a major earthquake since 1894 and 1766, respectively. A recent analysis forecast a 47% chance in the next 30 years of a major earthquake along one or both fault segments. So, Istanbul stands as one of the world’s megacities with very high earthquake hazard.

GPS observations indicate north – south extension at 33 mm/yr along the west coast of Türkiye and offshore Greek islands. This produces normal-faulting crustal earthquakes that pose hazards across the region. Examples include the 1970 magnitude 7.2 Gediz, Türkiye earthquake and 2020 magnitude 7.0 Samos Island, Greece earthquake.

The southeast boundary of the Anatolian Plate is the left-lateral East Anatolian Fault Zone. While the northeast half is a single strike-slip fault, the southwest half is part of a complex triple junction between the Nubian, Arabian, and Anatolian plates. GPS observations indicate rates of 10 mm/yr across the northeastern East Anatolian Fault Zone, 3 mm/yr across the Northern Strand, and 7 mm/yr across the Southern Strand. We will show that the Northern and Southern Strands of the East Anatolian Fault Zone and the Dead Sea Transform had no significant earthquakes in 500 years.

Historical records provide locations and approximate magnitudes of major earthquakes through the 19th and early 20th centuries. By the 1960s, data from seismic networks could accurately determine both earthquake epicenters and magnitudes. In this 200-year history, the Northern and Southern strands of the East Anatolian Fault Zone stand out as segments that did not host a major earthquake from 1800 through 2022. Earlier historic records suggest the Northern Strand experienced a major earthquake in 1544. And major earthquakes occurred on the Southern Strand in 1513 and 521. Indeed, earthquake scientists have, for several decades, forecast a major earthquake on the Southern Strand of the East Anatolian Fault Zone. So, the major earthquakes of February 6, 2023 were not a surprise.

On February 6, 2023, earthquake rupture started on a strand of the Dead Sea Transform, reached the southern strand of the East Anatolian Fault Zone in 10 seconds, then for 80 seconds spread northeast and southwest for a total length of 350 km with peak slip over 8 meters. This moment magnitude 7.8 earthquake ruptured across multiple fault segments displaced by historic earthquakes to become the strongest in Turkey in more than 80 years. The M7.8 earthquake decreased stress along **its** rupture zone but increased stress on the Northern Strand. Nine hours later, a magnitude 7.6 earthquake ruptured a 160-km-long segment of the Northern Strand in 40 seconds producing peak slip of 10 meters. These Kahramanmaraş earthquakes are the first great earthquake doublet with a combined moment magnitude of 8.0 recorded on a continental strike-slip fault system. The footprint of ground-shaking intensities from the two earthquakes on cities and towns of the region indicates over 8 million people experienced very strong, 2.1 million felt severe, and nearly a million people endured violent ground shaking. Impacts on southeastern Turkey and war-torn northwestern Syria were enormous. Over 300,000 buildings in Turkey were heavily damaged or collapsed and over 9,000 buildings in Syria collapsed. The resulting death toll was nearly 60,000 making the Kahramanmaraş earthquakes the fifth-deadliest of the 21st century. In the face of such destruction and human tragedy, it can be difficult to appreciate the successes of earthquake engineering and improved construction practices. But, of the 20,000 school buildings in the affected area built to Türkiye’s 2018 seismic code, only 5% collapsed or were severely damaged. Modern hospitals also performed well and were functioning to care for the more than 100,000 people injured.

Through this exploration of earthquakes in Türkiye, we learned how one earthquake can change stress and increase the likelihood of an earthquake on a nearby fault. That interaction is important for earthquake forecasts and often operates over years or decades. But, as in the February 2023 earthquake doublet, one earthquake can trigger another over a matter of hours or even minutes.