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Not My Fault: Complications in a plate boundary - the October 30th Aegean Sea earthquake

Lori Dengler/For the Times-Standard
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Before I retired, I would often take school groups on tours of the HSU Geology Department's seismograph. We'd start out in front of the drum on display in Van Matre Hall and talk about how seismographs work. They loved making their own earthquake by jumping up and down next to the sensor in the Founders Hall vault.

I would often ask them what caused earthquakes. Up shot up the hands responding "plate tectonics" with satisfied smiles. They had learned how earthquakes and volcanic activity were concentrated along plate boundaries. "Well it's a little more complicated," was my answer.

Earthquakes don't occur because of plate tectonics. They happen because of forces in the earth cause rock to rupture, releasing seismic waves that we experience as ground shaking. Plate tectonics is a model that explains why most (but not all) earthquake epicenters are concentrated in narrow bands on the earth's surface.

It's all about how the planet is cooling down. Convection is a much more efficient way of moving heat than conduction and in the earth, takes form as narrow zones of heat upwelling along ridges and hot spots. As the material cools, it becomes heavier and succumbs to gravity creating downwelling along subduction zones. The push and pull of heat and gravity causes the outer part of the earth to be in continuous motion. Because the earth is a sphere, spreading centers and subduction zones need areas of horizontal movement (transform boundaries) to accommodate all the possible movements between plates. Certain types of earthquakes tend to be associated with different boundaries – compressive or thrust quakes in subduction zones, extensional or normal faulting at ridges, and strike-slip earthquakes along transforms.

Unlike the textbook images that many of my school groups had seen, plate boundaries are not simple lines where on them, you get earthquakes and off them is earthquake free. In some places like along ocean ridges, almost all earthquakes are close to the boundary. But not always, and when plate boundaries involve continental material, it always gets much more complicated.

The October 30th M7 earthquake in the Aegean Sea is a good example. A typical 5th grade textbook will show a long line with teeth on it through the middle of the Mediterranean Sea, marking it as a convergent plate boundary. The African plate is moving to the north and colliding into the European plate. As a result, the Mediterranean is compressed and growing smaller. The Aegean Sea quake was centered just off the west coast of Turkey, and looking at a global map of plate boundaries, is in the zone of convergence between the two plates. So the earthquake faulting should be E-W oriented thrust faulting, right?

Wrong. The E-W orientation is right, but the faulting was the exact opposite. It was on a normal fault, involving extension instead of compression. Zooming into a geologic map, the major plate boundary is no longer a straight line and many other adjacent fault systems appear. Blocks of relatively more resistant materials respond to the ever-tightening compressive vise of the African plate motion by rotating. Most of Turkey is on the Anatolian block, one of these more resistant units, and is slowly rotating counter clock-wise in response to the northward movement of Africa.

The geology of the Anatolian block on land is complex, but has been studied by many geologists and the fault zones are well defined. It gets much messier offshore where direct observation is difficult and faulting becomes more diffuse. Earthquakes like the M7 help to clarify the story.

As the Anatolian block rotates, it creates areas of tension in the Aegean Sea. This is one of the reasons the Sea exists - the entire area between Greece and Turkey is being stretched, locally thinning the crust. Another consequence of the extensional stress is earthquakes. The USGS catalog includes 25 earthquakes of magnitude 6 and larger in the Aegean Sea since 1950. The October 30th is the largest.

A large magnitude normal faulting earthquake beneath the seafloor and close to populated areas has consequences. The Aegean Sea earthquake produced strong ground shaking in much of Western Turkey and in the Greek Islands near the epicenter. The USGS estimates that nearly 4 million people were exposed to strong to very strong ground shaking. Dozens of buildings were severely damaged or collapsed and 116 people died. It is the deadliest earthquake of 2020 to date.

The built environment in Turkey is a mix of traditional structures with no reinforcement, multistory concrete buildings constructed in the latter half of the 20th century to differing and sometimes lax building standards, and modern well-built structures that are as safe as anything built recently in California. The details of why which buildings failed or survived is currently being investigated by Turkish and International earthquake engineers; a quick glance at damage photos gives the tragic answer of almost every recent earthquake. Structures with inadequate resistance to the strong side-to-side motion in earthquakes become death traps.

Another consequence of the earthquake was a tsunami. Most major tsunamis are caused by thrust faulting where the motion is compressive and one side of the fault moves up and over the other. But normal faults are steeper than thrust faults and produce more vertical displacement for the same magnitude. They don't get as much attention in the tsunami community because very large submarine normal faulting earthquakes are rare. But October 30th is a reminder not to ignore them. The tsunami was less than a foot high in most areas where it was observed, but reached over three feet in several locations in Turkey. But it's not just the height of a tsunami that is important. Even a very small tsunami can produce strong currents and in this case, strong enough to pull at least one person to their death.

Bottom line – plate boundaries are complex and every earthquake has a lesson to teach. We just need to make sure to learn it.

Note: Thanks to Horst Rademacher's Berkeley Seismology Lab's Seismo Blog for the tectonic background of the Aegean Sea earthquake –
http://seismo.berkeley.edu/blog/index.html

Lori Dengler is an emeritus professor of geology at Humboldt State University, an expert in tsunami and earthquake hazards. All Not My Fault columns are archived at
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