The geology of earthquake swarms

Differences between earthquake sequences in the crust and adjacent uppermost mantle at oceanic transform faults are revealed by a seafloor seismic experiment at the Blanco Transform Fault.

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Plate boundary faults can fail over a range of timescales. In regular earthquakes, rupture occurs in seconds. Slow slip events, by contrast, take between tens of seconds and years, and do not produce seismic shaking. The geological conditions that demarcate slow slip from earthquakes and the ability of slow slip to trigger large earthquakes are both poorly constrained. As they report in *Nature Geoscience*, Kuna et al. investigated earthquake clustering on the Blanco Oceanic Transform Fault offshore of Oregon. They demonstrate that the crustal part of this fault is dominated by mainshock–aftershock sequences, whereas the mantle portion produces earthquake swarms.

Most fault systems are dominated by mainshock–aftershock sequences, where large ruptures are followed by a vigorous but rapidly decaying series of smaller aftershocks. However, seismologists have long been interested in unusual sequences known as earthquake swarms, where multiple similar-sized earthquakes occur over periods of hours to days. Recently, swarms have received particular attention because of the occurrence of migrating microearthquakes before the 2011 Mw 9.0 Tohoku and 2014 Mw 8.2 Iquique earthquakes, probably in association with aseismic fault slip before the mainshocks. In contrast to most fault systems, oceanic transform faults produce abundant Mw 5–7 seismicity but typically not larger earthquakes that would rupture the entire fault. Instead, they accommodate plate motion primarily by aseismic fault slip. Mainslips on oceanic transform faults have unusually high rates of foreshocks and often occur as part of migrating earthquake swarms. Nevertheless, oceanic transform faults are still relatively poorly understood because they are so inaccessible.

Kuna et al. present data from the largest deployment of ocean-bottom seismometers to date at an oceanic transform fault. These provide a high-resolution view of microearthquake behaviour in a region with regular Mw 6 earthquakes. Remarkably, the compositional difference between the crust and mantle portions of the fault results in an almost complete dichotomy of earthquake behaviour over only a few kilometres: mainshock–aftershock sequences in the crust and earthquake swarms in the mantle.

Kuna et al. also show that the depth extent of seismicity requires significant hydrothermal circulation within the fault zone, lowering the temperature and so increasing the depth of the brittle–ductile transition to 13 km below the seafloor. This hydrothermal circulation probably alters the composition of the mantle portion of the fault from peridotite to serpentinite, which is known to favour aseismic slip. They suggest that slow slip events cause earthquake swarms to migrate along the mantle portion of the fault and may occasionally trigger large earthquakes that rupture the entire fault zone. This plausible conclusion will require seafloor geodetic data to verify, but the data indicate a systematic behaviour that constrains the role of aseismic slip and fault-zone geology in earthquake swarms.

The inference of pervasive mantle serpentinization suggests a hydrological system that circulates seawater down to the brittle–ductile transition along the Blanco Transform Fault. This matches well with seismic images of the Gofar Transform Fault on the East Pacific Rise, which imply high porosities down to the brittle–ductile transition, as well as with the routine recovery of serpentinite samples from the seafloor at Atlantic transform fault zones.

There have been very few observations that quantify the extent of fluid circulation within active oceanic transform faults. This field has immense potential for fundamental insights into fault and earthquake mechanics. Together, these observations imply that thousands of kilometres of the seafloor (Fig. 1) are potential sites of active water–rock interaction. Future seafloor surveys with robotics and perhaps scientific drilling expeditions should consider targeting these fault zones.

Data on the role of aseismic slip in triggering large earthquakes remain limited.
The most comprehensive attempt to capture a specific earthquake to date, the Parkfield prediction experiment, did not record any evidence of a foreshock sequence or aseismic slip before the 2004 $M_w$ 6.0 event on the San Andreas Fault\(^{13}\). However, there may have been deep aseismic deformation in the months before this earthquake, which would have been difficult to detect at the surface\(^{14}\). Perhaps the earthquake science community should consider designing new long-term monitoring experiments to capture or rule out any aseismic signals during the lead up to moderate earthquakes. Such experiments would need to place strain sensors close enough to the fault to detect the expected aseismic signals, a scenario that was recently discussed at a fault-zone drilling workshop\(^{15}\).

The systematic behaviours found by Kuna et al.\(^{4}\) on the Blanco Transform Fault suggest this fault zone is a natural target for clarifying the role of aseismic slip, both in triggering frequent earthquake swarms and in loading fault segments that rupture in periodic large earthquakes.

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