SEISMOLOGY

Remote-controlled earthquakes

Large earthquakes cause other quakes near and far. Analyses of quakes in Pakistan and Chile suggest that such triggering can occur almost instantaneously, making triggered events hard to detect, and potentially enhancing the associated hazards.

Gavin Hayes

Seismologists are often asked whether a large earthquake can trigger a similarly sized event elsewhere on the planet. This question is difficult to answer quantitatively because the details of earthquake triggering are not completely understood. Fault rupture permanently alters static stresses in the surrounding crust, leading to more earthquakes — often observed as local aftershocks. Additionally, as seismic waves from an earthquake travel around the globe, they generate transient changes in stress that can promote small earthquakes dynamically, sometimes at distances far from the initial event. Regardless of the triggering mechanism, if two earthquakes occur close enough together in time and space, they will be hard to distinguish because it is difficult to isolate the second event from the seismic waves of the first. Writing in *Nature Geoscience*, Nissen and colleagues[1] and Hicks and Rietbrock[2] analyse earthquakes in Pakistan and Chile — each listed in global earthquake catalogues as single events — and show that both involved multiple episodes of slip, on independent faults, separated by a small distance and short amount of time.

In modern seismic hazard assessments, such as the Uniform California Earthquake Rupture Forecast[3], potential earthquakes are not confined to separate, individual faults, where their magnitude would be restricted by the size of that fault. Instead, quakes are assumed to sometimes rupture multiple faults simultaneously — but only if the offset between the neighbouring structures is less than 5 km. Given a global lack of evidence for stress transfer between large earthquakes far apart in space, and since observations of historic multi-fault ruptures reveal only small offsets between those structures, this seems to be a reasonable assumption. However, if earthquake ruptures can indeed jump across larger gaps, such assumptions may lead to an underestimated hazard assessment from large earthquakes.

In one study, Nissen and colleagues[1] use satellite-based geodetic data to analyse the characteristics of the magnitude 7.1 Harnai earthquake that occurred in Pakistan in 1997. These satellite interferograms, which map surface deformation, reveal two distinct patterns of faulting rather than a single lobe of deformation typically generated by slip on an individual fault. The researchers go on to use analyses of seismic data to show that the two deformation lobes were indeed not caused by one, but by two distinct and similarly sized earthquakes, 50 km and 19 seconds apart. Furthermore, they show that static stress transfer from the first event at the location of the second was insufficient to trigger the latter earthquake. The triggering mechanism may have therefore been dynamic, related to the passage of seismic waves from the earlier rupture.

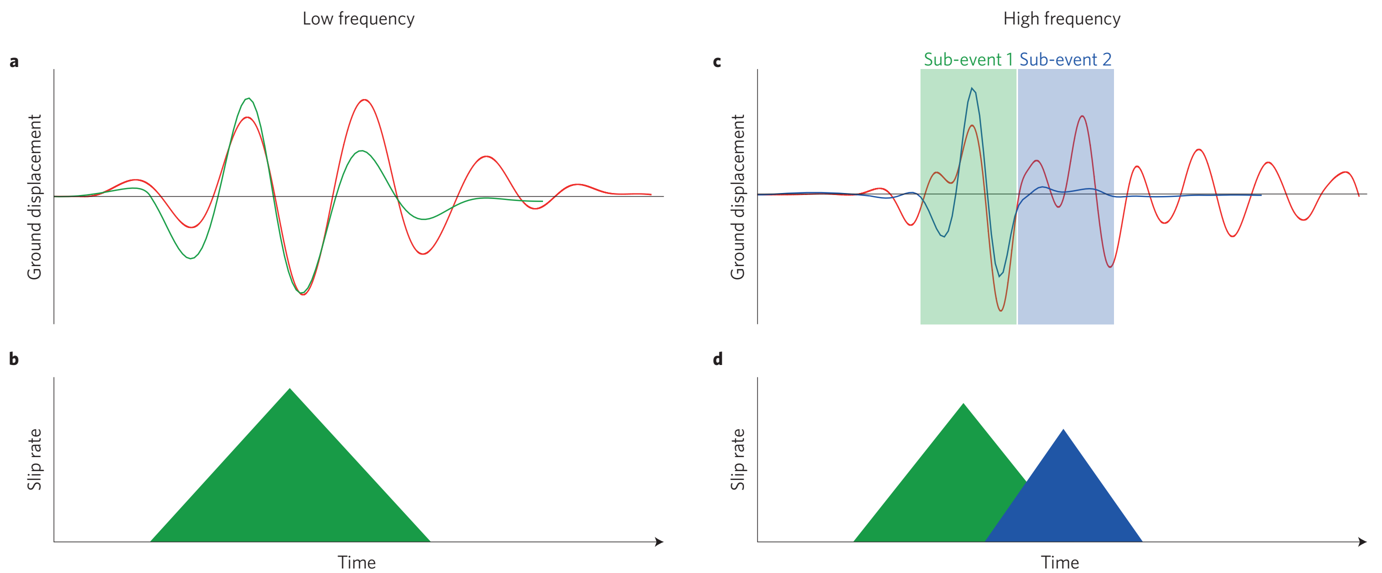

Figure 1 | Secondary earthquake masked by the time series of the first. **a**,**c**, Low frequency (**a**) and high frequency (**c**) seismograph records of the 2011 Araucania earthquake in Chile. Red lines represent data from the event, green and blue lines represent synthetic data generated using simulations of a single earthquake. **b**, For the low-frequency seismic record, the data are well fit by a single earthquake source. **d**, At higher frequencies, however, the single earthquake source approximation does not fit the data, and a second sub-event is evident. Nissen and colleagues[1] and Hicks and Rietbrock[2] suggest that these types of complex earthquakes, during which one large earthquake triggers a second nearby and in rapid succession, could lead to underestimation of seismic and tsunami hazards.

In a second study, Hicks and Rietbrock[2] analyse seismic data associated with the 2011 magnitude 7.1 Araucania earthquake — a large aftershock of the 2010 Maule earthquake in Chile. They find that the earthquake was composed of slip on two different faults: slip on the thrust fault that makes up the subduction zone plate interface was almost immediately followed by slip on a fault in the overriding plate. The second event was 30 km and 12 seconds removed from the first, and amounted to a distinct magnitude 6.7 earthquake — slightly smaller than the triggering event. Similar to Nissen and colleagues, they suggest the second earthquake could have been triggered by the passage of seismic waves from the first.

In global earthquake monitoring, such earthquake complexity can usually be identified by analysis of the seismic wave signals recorded at global seismograph stations (Fig. 1). However, for the Araucania event, seismic waves generated by the second episode of slip were essentially masked by seismic waves from the first, and thus unseen in standard global analyses. A more systematic study of regional seismic data was required to reveal the complexity of the event. If large enough, earthquakes in the upper plate of a subduction zone, at shallow depths beneath the ocean, have the potential to generate tsunamis[4,5]; thus, this type of rapid triggering of upper-plate fault slip presents a challenge to tsunami early-warning systems.

For both the Chile and Pakistan earthquakes, the distance between the two faults that slipped surpassed the 5 km limit for multiple-fault ruptures assumed in some standard seismic hazard assessments[3]. The studies suggest that the passage of seismic waves can almost instantaneously trigger secondary events beyond the rupture area of the first earthquake, increasing the region of significant shaking and thus the associated potential impact on population and infrastructure. This different class of dynamic, cascading rupture has not been considered in modern hazard analyses, and as such related hazards may be underestimated in regions of complex faulting[1].

Observationally, these studies reveal that we now have the tools to identify earthquake complexity at a level that has not been possible in the past. With the extensive availability of high-quality broadband seismic data at both global and regional scales, the systematic and regular collection of satellite imagery, and the expansion of real-time GPS networks, observations of faulting and related ground deformation are becoming more widespread, and the resolution is higher than ever before. Together with studies of other complex earthquakes[6–8], such analyses are paving the way toward routine and real-time identification in the future[9].

The processes that drive complex ruptures remain unclear, as do the details of earthquake triggering. However, Nissen and colleagues[1] and Hicks and Rietbrock[2] show that improved observational capacities can make it possible to distinguish between continuous earthquake rupture on a single fault, and separate but temporally and spatially proximate events. A goal now must be to understand what the implications of these complex earthquakes are for seismic and tsunami hazards, and how they can be considered in hazard assessments of the future. ❒

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