News and Views

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Seismology: Greatness thrust upon them

James F. Dolan[1] (#a1)

Abstract

The latest research seems to imply that all earthquakes are born equal. But combining that insight with earlier, seemingly contradictory, work could help us to tell which tremors grow to become more equal than others.

In an analysis on **page 358** (/nature/journal/v444/n7117/full/nature05275.html) of this issue[1] (/nature/journal/v444/n7117/full/444276a.html#B1), Steven Wesnousky provides strong evidence that the ultimate size of a seismic rupture is largely controlled by the structure of the underlying fault, and therefore that big earthquakes do not differ from small earthquakes in their beginnings. These data might seem to conflict with earlier observations implying that the size of an earthquake is determined by the dynamics of rupture onset. In fact, both conclusions could be true, and combining these two data sets in future analyses of seismic hazards might result in a better prediction of the eventual size of an earthquake before the shaking stops.

Many Earth scientists have long suspected that the limit of an earthquake rupture, and therefore the magnitude of an event, is largely controlled by the structure of the fault zone and variations in stress along the fault itself[2,] (/nature/journal/v444/n7117/full/444276a.html#B2) [3,] (/nature/journal/v444/n7117/full/444276a.html#B3) [4] (/nature/journal/v444/n7117/full/444276a.html#B4). In this view, all earthquakes begin in the same way, and continue to propagate until they reach a barrier, in the form of a structural complexity or a part of the fault on which the stresses are sufficiently low to stop rupture. But the alternative standpoint — that large earthquakes are in some way born differently from their smaller brethren[5,] (/nature/journal/v444/n7117/full/444276a.html#B5) [6] (/nature/journal/v444/n7117/full/444276a.html#B6) — is attractive because it holds the promise of determining the eventual size of an earthquake during the first few seconds of the rupture. That could provide the basis for an effective early-warning system.

Wesnousky's contribution[1] (/nature/journal/v444/n7117/full/444276a.html#B1) to this debate is to examine the end-points of 22 surface-rupturing earthquakes of moderate to large magnitude (M = 6.1–7.9) from the past 150 years. He found that approximately two-thirds of all ruptures terminated at either a structural 'step' in the fault or at an intersection with a second fault. Moreover, he found that no ruptures, regardless of their magnitude, were able to propagate through structural steps wider than 3–4 kilometres. Collectively, these observations demonstrate the fundamental role played by the structure of the fault in stopping a seismic rupture, and imply forcefully that an earthquake cannot 'know' how large it is destined to be until forced to stop at a structural or stress barrier.

These observations are in apparent conflict with results showing that the predominant frequency of the waves of seismic energy radiated during the first few seconds of a rupture differs for large and small earthquakes. Olsen and Allen[6] (/nature/journal/v444/n7117/full/444276a.html#B6), for example, examined the frequency content of the early stages of 71 seismic ruptures from M = 3 to M = 8.3. The predominant frequency of these earthquakes decreased with increasing magnitude; in other words, small earthquakes released a higher proportion of their energy as higher-frequency waves than did large earthquakes. That seemed to indicate that the final magnitude of an earthquake is determined before the end of the event, and so is at least partially controlled by the rupture initiation process.

An explanation for the seeming contradiction of these conclusions[1,] (/nature/journal/v444/n7117/full/444276a.html#B1) [6] (/nature/journal/v444/n7117/full/444276a.html#B6) could lie in the detailed structure of the fault planes themselves. Earlier research, much of it by Wesnousky and colleagues[7,] (/nature/journal/v444/n7117/full/444276a.html#B7) [8] (/nature/journal/v444/n7117/full/444276a.html#B8), showed that the more a fault slips over its lifetime, the smoother the slip surface becomes. The structure of faults with small displacements is therefore likely to be much more complex than that of faults that have accommodated tens to hundreds of kilometres of displacement.

It is not surprising that earthquakes nucleated on smooth faults generate less energy at high frequencies right from the start than do earthquakes nucleated on rougher, less-developed faults. Each small-scale structural feature of a fault acts as a separate source of high-frequency energy. Olsen and Allen's correlation[6] (/nature/journal/v444/n7117/full/444276a.html#B6) might thus simply reflect the fact that small earthquakes can occur on small faults that have not accommodated significant displacements over their lifetimes. Many of these earthquakes may occur in the zone of damaged rock surrounding large faults.

Large earthquakes, by contrast, necessarily occur on large faults — the largest earthquake examined in Wesnousky's study[1] (/nature/journal/v444/n7117/full/444276a.html#B1), an event of M = 7.8 in 2001, ruptured the Kunlun fault on the Tibetan plateau for a distance of more than 400 kilometres (**Fig. 1** (#f1)). Such large faults are much more likely to have accommodated significant displacements, and are likely to be much smoother than the innumerable small faults that generate the earthquakes of M <5.5 that are ubiquitous features of Earth's crust.

Figure 1: At fault. (/nature/journal/v444/n7117/fig_tab/444276a_F1.html)

 (/nature/journal/v444/n7117/fig_tab/444276a_F1.html)

The 400-km-long rupture along the Kunlun fault on the Tibetan plateau that occurred in 2001 was the longest of those studied by Wesnousky[1] (/nature/journal/v444/n7117/full/444276a.html#B1). According to his analysis, the ultimate size of an earthquake is primarily determined by the local fault structure. Image: HOU DEQIANG/XINHUA

High resolution image and legend (126K) (/nature/journal/v444/n7117/fig_tab/444276a_F1.html)

Interestingly, although the relationship between magnitude and wave frequency noted by Olsen and Allen[6] (/nature/journal/v444/n7117/full/444276a.html#B6) is quite pronounced for smaller magnitudes between 3 and 5.5, there is no obvious variation in the predominant frequency of energy radiated in the first few seconds of $M > 6$ earthquakes. The radiation of energy at relatively low frequencies for these larger earthquakes could tell us which of the ruptures are starting on large, smooth faults, and therefore might be capable of generating large earthquakes — if the structural and stress conditions of the fault are favourable.

Wesnousky's data[1] (/nature/journal/v444/n7117/full/444276a.html#B1), on the other hand, show that the ultimate size of the earthquake is largely controlled by the structure of the fault zone, rather than by the dynamics of the rupture nucleation. They thus validate the continued use of mapped structural complexities (steps and bends in the fault surface, intersections with other faults) in forward modelling of the potential limits of future ruptures. Such data are the basis for many seismic-hazard models in use today[9] (/nature/journal/v444/n7117/full/444276a.html#B9).

Thus, combining these two sets of observations[1,] (/nature/journal/v444/n7117/full/444276a.html#B1) [6] (/nature/journal/v444/n7117/full/444276a.html#B6) in automated form could result in more accurate assessments of likely earthquake size before the shaking stops. The frequency content would identify an earthquake that could grow large, and the structure of the fault would identify the likely end-point of the rupture. Knowing in real time the difference between a moderate magnitude-6 earthquake and a truly destructive magnitude-8 one on the San Andreas fault near Los Angeles, for example, could be important indeed.

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