news & views

SEISMOLOGY

Unrushed megathrusts

Corals reveal that part of the plate-boundary fault near Sumatra slipped slowly and quietly for three decades before a large earthquake in 1861. The exceptional duration of this slip event has implications for interpreting deformation to assess seismic hazard.

Daniel Melnick

Subduction-zone megathrusts are large faults at the interface of tectonic plates where one plate slides beneath the other. Megathrusts are notorious for producing the largest earthquakes on Earth, but it was recently discovered that these faults don't always move in a hurry. Analyses of seismic and geodetic data have revealed diverse slip phenomena, ranging from tens of metres of sudden slip in a single giant (magnitude $M > 9$) earthquake to swarms of low-magnitude ($M < 5$) tremors and slow slip events, in which slow, largely steady and aseismic motion continues for weeks to years. Writing in *Nature Geoscience*, Mallick et al.[1] infer a slow slip event on the Sumatra part of the Sunda megathrust that lasted for approximately 32 years, much longer than others found before, and propose a mechanism to explain this event.

Slow slip events (SSEs) have been identified at most subduction zones from satellite geodetic measurements[2,3]. Most SSEs have been located deeper than the part of the megathrust that hosts great ($M > 8$) earthquakes[2], but some have been recognized shallower than this part, so far only off Ecuador, Japan and New Zealand. These shallow SSEs lasted a few weeks to months[4], whereas deep SSEs include the longest previously found, one in Alaska that lasted nine years[5] and a decade-long event in Japan[6]. While several SSEs have been directly associated with subsequent great earthquakes[6–11], our understanding of the duration, location and physics of SSEs is insufficient to include them in current probabilistic hazard models of megathrust earthquakes. Investigating historical SSEs may provide insights, but this has been challenging because geodetic data that extend for several decades (such as levelling lines and tide gauges) are available for only parts of a few subduction zones.

Mallick et al. investigate one long-term geodetic record, the growth patterns of coral microatolls (Fig. 1) — natural tide gauges — on Simeulue Island, offshore of northern Sumatra. These corals started recording relative subsidence in 1740, experienced a shift to faster subsidence in 1829, and died by sudden emergence in 1861, coincident with a $M \approx 8$ earthquake. Because the magnitude of these relative elevation changes is larger than those associated with climatic or oceanographic processes, the most likely explanation for them is variations in land level caused by slip of the underlying megathrust. From numerical simulations, Mallick et al. show that the coral data require an SSE from 1829 to 1861 on a shallow portion of the megathrust, located above where the 1861 $M \approx 8$ earthquake occurred. The ~32-year duration of this purported SSE is all the more exceptional given its shallow depth, at which the SSEs found previously lasted only up to a few months[4].

Fig. 1 | Coral microatoll killed by emergence due to an earthquake in Sumatra. Mallick et al.[1] analyse elevation changes during the nineteenth century recorded by such fossils, and find that the changes require a ~32-year-long slow slip event on the underlying megathrust. Credit: Aron Meltzner / Earth Observatory of Singapore

Supported by a numerical model of fault frictional behaviour, Mallick et al. propose that this SSE resulted from a stable area of the megathrust being destabilized by migration of fluids sourced from oceanic sediments that are dragged down with the subducting plate. Previously, SSEs had been thought not to nucleate where megathrusts are stable; instead, they have primarily been attributed to sectors with transitions in frictional behaviour, from unstable to stable sliding. The transition will develop as a function of the slip rate of the fault[12], as faults become weaker when slipping faster. The frictional behaviour of a fault is determined by its structure, rock properties, and/or fluid pressure[2,3]. Transitions in the frictional behaviour of megathrusts have been associated with observed changes in their slip style, from SSEs to large earthquakes[2,3], as well as in the recurrence interval of great earthquakes[13], and are thus important in seismogenesis.

The findings of Mallick et al. have implications for the inference of megathrust slip behaviour and seismic hazard from geodetic measurements and records. The authors exemplify this by examining ground deformation recorded by a GPS station at Enggano Island, offshore of southern Sumatra in a similar position relative to the subduction zone as Simeulue Island. Previously, the negligible landward motion detected there has been assumed to indicate that the megathrust is not locked, and so that there is a low likelihood of large earthquakes. The island is subsiding rapidly, however; hence Mallick et al. argue that the deformation indicates an ongoing shallow long-duration SSE that is cancelling out landward motion from the megathrust being locked at greater depth, and thus that the seismic hazard has been underestimated. Long-duration SSEs are probably not limited to Sumatra; they could explain signals in palaeogeodetic data prior to great earthquakes in Cascadia and Alaska[14], for example.

Mallick et al. show that SSEs on megathrusts can last much longer than found previously, and that shallow SSEs can last as long, if not longer than deep events. Application of their method to other megathrusts could reveal further multi-decadal or ongoing shallow SSEs and prompt revisions to hazard assessments. ❐

Daniel Melnick[1,2] ✉
[1]Instituto de Ciencias de la Tierra, Universidad Austral de Chile, Valdivia, Chile. [2]Núcleo de Estudios Transdisciplinarios del Cuaternario del Sur de Chile, Universidad Austral de Chile, Valdivia, Chile.
✉e-mail: daniel.melnick@uach.cl

Published online: 3 May 2021
https://doi.org/10.1038/s41561-021-00750-z

References

1. Mallick, R. et al. *Nat. Geosci.* https://doi.org/10.1038/s41561-021-00727-y (2021).
2. Schwartz, S. Y. & Rokosky, J. M. *Rev. Geophys.* **45**, RG3004 (2007).
3. Bürgmann, R. *Earth Planet. Sci. Lett.* **495**, 112–134 (2018).
4. Wallace, L. M. *Annu. Rev. Earth Planet. Sci.* **48**, 175–203 (2020).
5. Li, S., Freymueller, J. & McCaffrey, R. *J. Geophys. Res. Solid Earth* **121**, 1060–1079 (2016).
6. Mavrommatis, A. P., Segall, P. & Johnson, K. M. *Geophys. Res. Lett.* **41**, 4486–4494 (2014).
7. Dixon, T. H. et al. *Proc. Natl Acad. Sci. USA* **111**, 17039–17044 (2014).
8. Radiguet, M. et al. *Nat. Geosci.* **9**, 829–833 (2016).
9. Socquet, A. et al. *Geophys. Res. Lett.* **44**, 4046–4053 (2017).
10. Ruiz, S. et al. *Science* **345**, 1165–1169 (2014).
11. Segou, M. & Parsons, T. *Geophys. Res. Lett.* **47**, e2019GL086640 (2020).
12. Im, K., Saffer, D., Marone, C. & Avouac, J.-P. *Nat. Geosci.* **13**, 705–710 (2020).
13. Moreno, M. et al. *Nat. Geosci.* **11**, 285–290 (2018).
14. Bourgeois, J. *Nature* **440**, 430–431 (2006).

Acknowledgements

This work was partly supported by the Millennium Scientific Initiative (ICM) of the Chilean government through grant NC160025 "Millennium Nucleus CYCLO The Seismic Cycle Along Subduction Zones", FONDECYT grants 1181479 and 1190258, the ANID PIA Anillo ACT192169. This is a contribution to International Geoscience Programme (IGCP) project 639.

Competing interests

The author declares no competing interests.

GEOMORPHOLOGY

Stressed rocks cause big landslides

Near-surface stress patterns, influenced by topography, control the size and location of the largest landslides — but not necessarily smaller ones — according to a study of mountains at the eastern edge of the Tibetan Plateau.

Peter van der Beek

Landslides constitute a major natural hazard, causing thousands of casualties and billions of dollars in damages every year[1]. Landslides commonly occur in hazard cascades; they can be triggered in abundance by severe storms or earthquakes, such as in Nepal in 2015[2], and can themselves cause flooding and debris flows down-valley, as exemplified by the recent Chamoli (Uttarakhand, India) disaster. On longer timescales, landslides are the main process transporting material from hillslopes to rivers in tectonically active landscapes[3] and they place limits on the relief that mountain belts can attain[4]. By making fresh rock available for weathering[5] and stripping hillslopes of vegetation[6], landslides also play a key role in modulating Earth's long-term carbon cycle. Despite the importance of landslides in landscape evolution and as natural hazards, what determines their size and occurrence is not well understood. Writing in *Nature Geoscience*, Li and Moon[7] report a correlation between near-surface stress-field metrics and maximum landslide size, and propose a causal link.

We understand the mechanisms that trigger landslides: earthquakes can destabilize hillslopes by ground acceleration and by damaging rocks, and strong precipitation can increase fluid pressure in rock fractures, making a rock mass more susceptible to sliding. However, we don't understand well what controls the number or size of landslides that result from particular seismic or precipitation events. One complicating factor is that the abundance and size of landslides depend not only on the properties of the triggering event, but also on pre-disposing factors relating to, for instance, regional climate, topography and lithology[8–11]. Another factor is that landslides (and other surface processes) 'feel' a rock strength that is variably reduced by weathering and fractures[4,8] and so is difficult to quantify.

It has long been hypothesized that topographic stress, the perturbation of regional tectonic stress fields by topography, may affect near-surface fracturing and rock strength[12]. More recently, computational advances have made it possible to predict topographic stress fields from real-world topography. These predictions can be compared to geophysical imaging proxies of near-surface rock strength, such as those derived from seismic waves, which travel through damaged and weathered rock slower than through intact rock. Such comparisons have verified that rocks are more deeply and pervasively damaged and weathered in locations where topographic stress models predict they would be[13]. It has also been hypothesized that deep bedrock fracturing permits larger landslides[14], but it has been difficult to extend geophysical imaging techniques beyond the scale of a single hillslope to test this hypothesis.