The September 2009 Padang earthquake

To the Editor — On 30 September 2009, the city of Padang in Indonesia was rocked by an earthquake with a moment magnitude of $M_w = 7.6$. Despite its size, the earthquake did not rupture the Sunda megathrust and did not significantly relax the 200 years of accumulated stress on the Mentawai segment. The megathrust strain-energy budget remains substantially unchanged and the threat of a great, $M_w > 8.5$, tsunamigenic earthquake on the Mentawai patch is unabated.

Padang, population 850,000, sits directly above the Sunda subduction zone where the Australian plate plunges beneath the Eurasian plate. Since late 2004, a series of earthquakes, the first of which triggered the 2004 Indian Ocean tsunami, has ruptured the plate boundary from the Andaman Islands to the Sunda Strait, a distance of nearly 2,500 km. Only some 300 km of the Sunda margin — the Mentawai segment — remains unbroken in the past five years (Fig. 1a); Padang lies broadside on to this segment.

Under Siberut, the biggest of the Mentawai Islands, the megathrust has not ruptured since the great 1797 earthquake ($M_w = 8.7$), when up to 10 m of slip produced a tsunami and inundated Padang and its adjacent coast. The megathrust is strongly coupled there (Fig. 1b) and stores almost all of the 5 cm or so of annual plate convergence. The strain released in 1797 has been more than replenished. Furthermore, recent earthquakes both to the north and to the south have loaded the locked segment and raised the risk of another great shock. The Mentawai segment is near failure. Forecasts have indicated that the next Mentawai earthquake will produce strong shaking along the Sumatran coast and will probably be tsunamigenic. There is potential for loss of life on the scale of the 2004 Indian Ocean tsunami.

Initial estimates located the hypocentre of the September 2009 Padang earthquake 60 km west-northwest of the city, on the eastern edge of the locked segment and at a depth of 80–90 km. The main shock was followed by a small number of locatable aftershocks. The plate geometry below Padang has been well characterized using data from a recently deployed, dense, temporary array of seismometers. The trench-perpendicular cross-section (Supplementary Fig. 1) shows that the hypocentres of the Padang event and its aftershocks lie within the lower part of the Wadati–Benioff zone of the subducting Australian slab; the upper limit of the zone is generally associated with the oceanic crust. Therefore, the Padang event probably ruptured the mantle of the Australian plate.

Although the centroid moment tensor solution indicates an oblique thrust event in map view, when viewed in the plane of the plate interface (Fig. 1c) the focal mechanism appears as a slightly oblique strike-slip event aligned with fractures zones of the incoming sea floor (Fig. 1a), with either right-lateral motion along an east–west plane or left-lateral motion along a north–south plane. It is difficult to discriminate between these planes seismologically; no pronounced directivity effects are observable and waveforms appear consistent with either. However, main-shock and aftershock relative locations are more elongated along the direction of the slip vector corresponding to the east–west plane (Supplementary Fig. 2), thus slightly favouring it. For this reason, here we assume that the event ruptured the east–west plane and show calculations for the conjugate plane where appropriate.

The source duration derived from inspection of body-wave displacement seismograms (Supplementary Fig. 3) indicates a rupture duration of only ~10 s, which is unusually short for an event of this magnitude. The short source duration would have enhanced high-frequency energy, producing accelerations greater than in other events of similar magnitude.

![Figure 1](image.png)
and possibly contributing to the devastation in Padang. We have calculated the vertical seafloor displacements and find that the maximum displacement for either mechanism was on the order of 9 cm, which is too small to have resulted in a large tsunami.

The Padang earthquake occurred between and down-dip of the 2005 and 2007 megathrust earthquakes, but the failure that caused it was only weakly encouraged by them; the interaction stress load on the hypocentre was only 0.05 bar in total (0.14 bar for the north–south plane). The back-loading of the megathrust by this event, however, was locally much stronger (Fig. 1c). Owing to differences in depth and orientation of the possible failure planes and the megathrust, the stress distribution is complex, spatially variable and locally strong at depth on the interface, but generally decreases towards the trench, where it is near zero and dominantly negative.

It is difficult to interpret such a variable stress field, as its potency depends on unknown details of the existing state of absolute stress on the fault, but for the megathrust in western Sumatra this state might be inferred to first order from the plate coupling distributions assuming uniform loading. By inspection of Fig. 1b, c, it is clear that where the interaction stresses calculated here are strong the plate interface is thought to be weakly coupled, implying a low earthquake nucleation threat and low triggering potential. Conversely, under Siberut, where coupling is strong, the megathrust is nearest to failure and the triggering potential is probably high, the interaction stress is weak and mostly negative. Stresses from an event on the conjugate plane (Supplementary Fig. 4) allow a broadly similar interpretation, although a small, strongly coupled area east of Siberut experiences a significant stress increase from this mechanism and probably represents the biggest change in triggering potential due to this event. In all cases the total interaction stress accumulated since 2005 is positive over the area and is strong under southern Siberut (Supplementary Fig. 5).

We conclude that the Padang earthquake did not rupture the Sunda megathrust and did not significantly relax the accumulated stress on the Mentawai segment. Therefore, the megathrust strain–energy budget remains substantially unchanged and the threat of a great tsunamigenic earthquake on the Mentawai patch is unabated. Down-dip, and possibly just east of Siberut, there is undoubtedly a locally greater chance of failure, but where the perceived threat is highest the interaction stresses from the Padang event are generally weak and negative.

Given the tragic loss of life resulting from the September 2009 Padang earthquake, the threat from such an event is clear and the need for urgent mitigating action remains extremely high. It is imperative that the Indonesian authorities, with the assistance of the international community and non-governmental organizations, ensure that they complete the relief effort and earthquake-resistant reconstruction following this earthquake, and work with the people in Padang to help prepare them for the next one.

References

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Additional information
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