Turkish Journal of Earth Sciences

http://journals.tubitak.gov.tr/earth/

Research Article

Turkish J Earth Sci
(2023) 32: 320-329

doi:10.55730/1300-0985.1847

The role of stress barriers on the shape of future earthquakes in the Mentawai section of the Sunda megathrust

Süleyman S. NALBANT[1,*], **Mairéad Nic BHLOSCAIDH**[2], **John McCloskey**[2], **Cengiz İPEK**[3], **Murat UTKUCU**[4]
[1]Department of Geography, Faculty of Science and Literature, Iğdır University, Iğdır, Turkey
[2]School of Geosciences, the University of Edinburgh, Edinburgh, United Kingdom
[3]Department of Civil Engineering, Engineering Faculty, İstanbul Medeniyet University, İstanbul, Turkey
[4]Department of Geophysics, Engineering Faculty, Sakarya University, Sakarya, Turkey

Received: 12.05.2022 • **Accepted/Published Online:** 13.01.2023 • **Final Version:** 28.04.2023

Abstract: The underlying causes of apparent barriers to rupture propagation on earthquake faults that appear strongly to constrain rupture shape and slip distributions, are the ongoing subject of research. Preseismic stress shadows on the rupturing segment, resulting from the history of slip preceding a great earthquake, are proposed here as one possible cause of such barriers. We focus on the Mentawai section of the Sunda megathrust since it is unique in having its long seismic history recorded in shallow water corals, as well as detailed slip distributions for events in the last "seismic cycle", and modern geodetic information on the distribution of interseismic coupling. We show that stress shadows left by the moment magnitude (M) 8.7 1797 and M = 8.9 1833 earthquakes on the section persist up to today, and likely acted as barriers to the ruptures in 2007 (M = 8.4 and 7.9) and 2010 (M = 7.8), potentially resulting in much smaller earthquakes than would have occurred otherwise.

Key words: Earthquake stress interaction, barriers, Sunda megathrust, seismic hazard

1. Introduction

Having a complete picture of the stress evolution of a given fault segment, at least over a seismic cycle, is crucial if we are to make a meaningful forecast of the distribution of slip in a future rupture. This so-called preseismic stress map, in turn, might guide our efforts to mitigate the risk of future earthquakes and/or resulting tsunamis. A portion of the Sunda megathrust along the west coast of Sumatra has been a centre of focus for scientific studies (for example Stein and Okal 2005; Meltzner et al., 2015; Freitag and Okal, 2020) due to heightened great earthquake (M > 7.6) activity in the region following the M = 9.2 2004 Sumatra-Andaman earthquake. A further 450 km portion of the megathrust, southeast of the 2004 rupture, was ruptured by the M = 8.7 Nias earthquake three months later (Figure 1). Attention was then turned to the next adjoining southern section of the megathrust, beneath the Mentawai islands, since it is well advanced in its seismic cycle (Nalbant et al., 2005; Konca et al., 2008; Sieh et al., 2008; Wiseman & Bürgmann, 2011). Three large earthquakes partially ruptured this 700 km long section in 2007 and 2010 (Salman et al., 2017). On the 12th of September 2007, M = 8.4 and 7.9 earthquakes occurred 12 h apart from each other (Figure 1). In 2010, to the seaward of the Pagai Islands, where the 2007 M = 8.4 rupture had terminated, an M = 7.8 earthquake initiated and ruptured the shallow portion of the section (Lay et al., 2011).

Nalbant et al. (2013) construct a stress map on the Sunda megathrust, including models for both the interseismic loading and the coseismic stress changes associated with all seismicity (M ≥ 7.0) between 1797 and 2007 (Figure 2). Figure 2 shows the rupture planes of modelled earthquakes between 1797 and 2003 (a) and the coupling distribution estimated by Chlieh et al. (2008) (b). They sought to investigate whether preseismic coupling or preseismic stress is the primary control on the slip distribution of future large megathrust earthquakes. They concluded that the slip distributions of recent earthquakes are more consistent with the modelled stress field than with the coupling distributions. However, the study underlined that, in places, the stress pattern is strongly dependent on poorly constrained values of slip in historical earthquakes, specifically those for the 1797 and 1833 earthquakes. Here we revisit the 2013 study, overcoming that shortcoming by using the historical slip distributions obtained from modelling of vertical deformations recorded in the growth

* Correspondence: ssami.nalbant@igdir.edu.tr

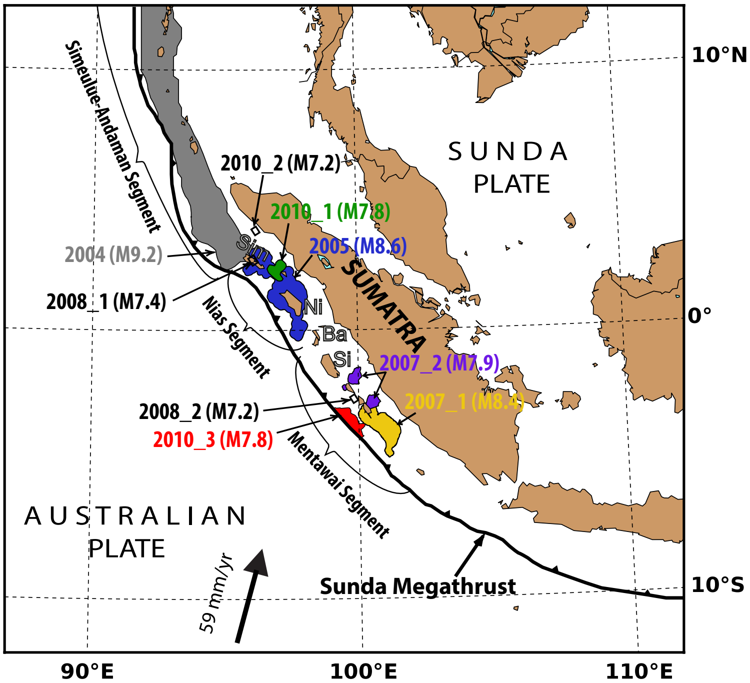


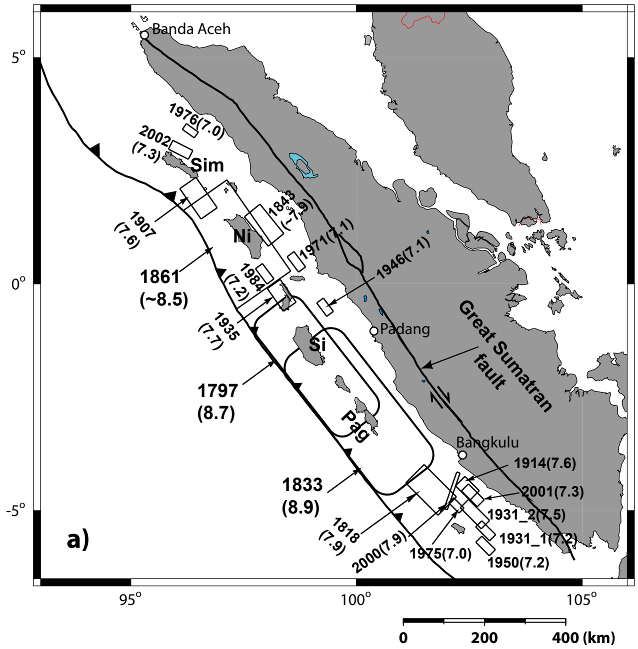
Figure 1. Map of the study area. Three segments of the Sunda megathrust are indicated based on rupture barriers suggested by Meltzner et al. (2015). Rupture areas associated with earthquakes since 2003 are indicated with different colours. The major islands are abbreviated as Sim (Simelue), Ni (Nias), Ba (Batu), and Si (Siberut). Note that the Mentawai segment is only partially ruptured in 2007 and 2010.

of shallow water corals on the islands along the west coast of Sumatra (Nic Bhloscaidh et al., 2015). We also added the 2010 events into our present modelling.

Along the Sumatran portion of the megathrust, two persistent barriers to rupture have been suggested: under the Batu Islands (Natawidjaja et al., 2006) and under the central Simeulue Island (Meltzner et al., 2012) (Figure 1). Based on this, Meltzner et al. (2015) divided the megathrust into three segments and suggest that the seismic behaviour of each segment is different. These are the Simeulue-Andaman segment located north of Simeulue Island, the Nias section between Simelue and the Batu Islands, and the Mentawai segment which is located south of the Batu Islands. The 2004 M = 9.2 event ruptured the Simeulue-Andaman segment, about 1300 km, in one go. It is not known whether this section has always ruptured with such great earthquakes in the past. However, the Nias section has ruptured in full twice, in 1861 and 2005, with similar magnitudes and arguably similar distributions of slip (Konca et al., 2008). It has been speculated (i.e. Meltzner et al., 2015) that earthquakes like the 2005 event may be a common feature of this section.

The picture for the Mentawai section is more complicated. It has been suggested that this section generally ruptures in two or more discrete events, in sequences which last several decades, about every two centuries. The pattern has been observed in seismicity for the past 700 years (Sieh et al., 2008; Meltzner et al., 2015). This section, for example, ruptured as a whole by a group of five earthquakes in 1597, 1613, 1631, 1658, and 1703. The following cycle involved only two large ruptures in 1797 and 1833 (Philibosian et al., 2017). These groups of events are referred to as supercycles by Sieh et al. (2008), and it has been further proposed that the 2007 sequence is the first episode of a new supercycle that will rupture all of the Mentawai section over the next two or three decades. Similarly, Philibosian et al. (2017) indicated that rupture cascades on the Mentawai segment occur approximately every 200 years. They also noted that the two largest events in each sequence have been separated by about 40 years in all three known supercycle cases (1350–1388, 1658–1703, and 1797–1833). Based on this, they forecast that the section will complete its cycle before 2047. We observe, however, that the sixteenth- to seventeenth-century cascade appears to have spanned approximately 105 years; even this quasi-periodic model is only complete in events above magnitude 7(?) and does not reflect the full complexity of earthquake sequences in this section of the megathrust.

Unlike the Nias segment, which has obvious candidates for persistent physical boundaries (in the



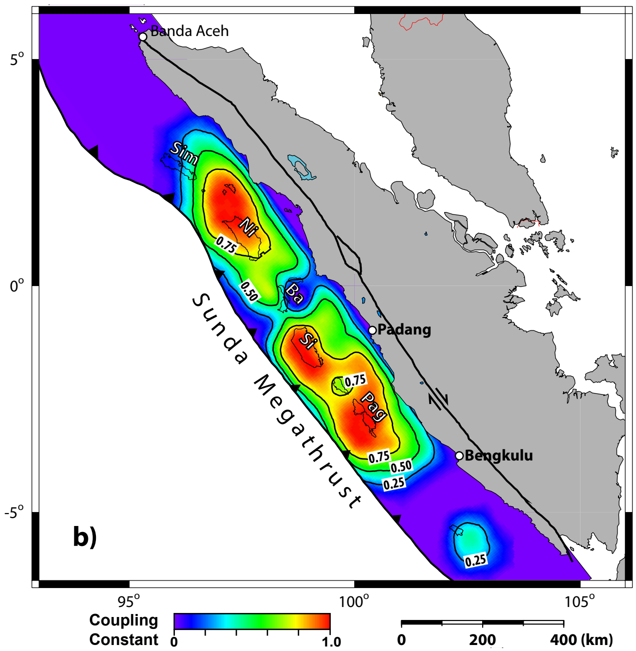


Figure 2. a) Rupture planes of modelled earthquakes (M ≥ 7.0) between 1797 and 2003. Approximate extent of rupture areas of the 1797 and 1833 events are shown as rounded rectangles (Natawidjaja et al., 2006). b) Distribution of coupling constants (from Chlieh et al., 2008). The major islands are abbreviated as Sim (Simelue), Ni (Nias), Ba (Batu), Si (Siberut), and Pag (Pagai).

changing fault geometry to the north, and the low interseismic coupling under the Batu islands to the south), there is no such obvious boundary within the Mentawai section. It is not clear why the Mentawai section should rupture only partially. Here we investigate this question by constructing a model of the stress evolution on this section of the megathrust since 1797, due to all recorded M ≥ 7 earthquakes as well as the secular stress loading. This model successfully explains the reasons for the partial rupture of the section in the modern sequence of events, strongly suggesting that coseismic slip on the Mentawai segment is controlled by stress shadows left over from previous ruptures. The results also support suggestions (Wiseman & Bürgmann, 2011) that the Siberut patch of the Mentawai section is the most likely candidate for a future great rupture.

2. Method

For an estimate of the distribution of stress prior to any great earthquake, we require; the coseismic slip distributions of the events which precede it, the interseismic loading rate, and the distribution of interseismic coupling coefficients. We follow Nalbant et al. (2013) using a planar fault geometry with uniform strike of 222° and uniform dip of 15° (Chlieh et al., 2008); stresses are resolved for a rake of 90°. We choose constant values in order to avoid features in the stress field related solely to changes in geometry, which are negligible on the Mentawai segment. An effective coefficient of friction of 0.4 is used, as this is a common value in the literature (King and Cocco, 2001).

We use an interseismic stressing rate of 0.14 bars/yr on the interface, again following Nalbant et al. (2013). This is multiplied by the number of years in the time period of interest to obtain the interseismic loading. This change is then added to the coseismic Coulomb stress change due to earthquakes in the same period. The coupling data given by Chlieh et al. (2008) are used here as a linear multiplier for both coseismic and interseismic stresses (Figure 2b). The coupling data is usually scaled from 0 to 1, where 0 represents a freely slipping interface in the interseismic period whereas higher values indicate increasing locking of the plate interface. This linear scaling is consistent with our understanding of the accumulation of interseismic stress. However, this is less clear in the case of coseismic stress changes; here we are assuming that the subduction interface reacts similarly to coseismic stress steps as it does to slower tectonic loading (Nalbant et al., 2013). Changes in plate coupling over time have been also proposed (Uchida and Matsuzawa, 2013; Mavrommatis et al., 2014; Philibosian et al., 2014; Yokota and Koketsu, 2015). Nevertheless, here we assume that it is constant over the study period at least. We return to this in the discussion.

We have compiled a list of 30 earthquakes of M ≥ 7.0 on the megathrust between 1797 and 2022 (Table), and the stresses are calculated over the plates interface. The rupture areas of the earthquakes that occurred between 1797 and 2003 are shown in Figure 2a while events from 2004 onwards are in Figure 1. The events in 1797 of M = 8.7, and in 1833 of M = 8.9 on the Mentawai section are the largest events in the study period (Figure 2a). Hence knowledge of their slip distributions is very important in order to construct a meaningful stress map. Their slip distributions have been modelled by different research groups (i.e. Philibosian et al., 2014; Nic Bhloscaidh et al., 2015; Lindsay et al., 2016). The main features of the slip distributions are similar, though there are differences in details owing to the methodology used in their modelling. We use the slip distributions obtained by Nic Bhloscaidh et al. (2015) (Figure S1 in Appendix). They inverted slip distributions of the 1797 and 1833 megathrust earthquakes from paleogeodetic data (Natawidjaja et al., 2006) based on the Bayesian Monte Carlo methodology.

As in Nalbant et al. (2013), the location and magnitudes of the 1818 and 1843 events are estimated based on the tsunami inundation areas given by Newcomb and McCann (1987). The location and magnitudes of earthquakes between 1907 and 1984 are taken from Newcomb and McCann (1987). Data for events from 1984 to 2022 come from a variety of sources including Konca et al. (2007), Yue et al. (2014), and Hayes (2017). Where there is no available rupture geometry or slip distribution, we use the empirical relations of Wells and Coppersmith (1994) to estimate the widths, lengths, and average slips in order to be comparable to Nalbant et al. (2013). Similar scaling relations are suggested by Blaser et al. (2010), Strasser et al. (2010), and Leonard (2014). However, none of these would change the main conclusions of this paper. A triangular taper to the slip distributions is applied to remove unphysical edge effects while preserving the average slip; this has the effect of increasing the magnitude of the slip in the centre of the rupture, which may represent a more realistic slip distribution compared to a boxcar shape slip.

3. Results

It is important to underline that the stress levels discussed here are not absolute stresses. They are changes based on a zero stress baseline immediately prior to the occurrence of the first event, the 1797 earthquake in our case. Figure 3 shows the total accumulated Coulomb stress changes before 2007. Slip contours of the two future 2007 earthquakes are overlain on the stress maps for comparison (shown as black and purple colours). The M = 8.4 2007_1 rupture terminated to the northwest in a region of negative accumulated Coulomb stress change (shown prominently in Figures 3 and 4), which we will refer to as "stress scar", that is largely due to high slip in the 1833 event (see also Figures S1 and S2 in Appendix).

The M = 8.4 2007 event was followed some 12 h later by an aftershock, the M = 7.9 (2007_2) which nucleated very close to the termination of the M = 8.4 event though deeper on the megathrust. This event consists of two separate areas of rupture, each with more than 1 m of slip. The event nucleated to the northeast of the M = 8.4 event and propagated westward until it appears to have been terminated by the stress scar of the 1833 earthquake described above, about 25 s after nucleation. The moment rate function then shows very low energy release for the following 10 s or so, before the event accelerates again, producing more than 1 m of slip in the second lobe to the northwest. Both the moment rate function and the slip

Table. List of earthquakes which are used in our stress modelling. W & C (1994) stands for Wells and Coppersmith (1994), while N & M (1987) represents Newcomb and McCann (1987).

Earthquake	Magnitude	Rupture area (L × W in km)	Slip distribution source	Location
1797	8.7	480 × 240	Nic Bhloscaidh et al. (2015)	Nic Bhloscaidh et al. (2015)
1818	7.9	112 × 66	W & C (1994)	Natawidjaja et al. (2006)
1833	8.9	600 × 240	Nic Bhloscaidh et al. (2015)	Natawidjaja et al. (2006)
1843	7.8	93 × 51	N & M (1987)	N & M (1987)/ This study
1861	8.5	273 × 170	N & M (1987)	N & M (1987)/ This study
1907	7.8	130 × 65	W & C (1994)	Kanamori et al. (2010)
1914	7.6	60 × 40	W & C (1994)	N & M (1987)
1931_1	7.2	48 × 24	W & C (1994)	N & M (1987)
1931_2	7.5	55 × 35	W & C (1994)	N & M (1987)
1935	7.7	75 × 55	Rivera et al. (2002)	N & M (1987)
1946	7.1	41 × 25	W & C (1994)	N & M (1987)
1950	7.2	48 × 28	W & C (1994)	N & M (1987)
1971	7.1	41 × 25	W & C (1994)	N & M (1987)
1975	7.0	30 × 26	W & C (1994)	N & M (1987)
1976	7.0	30 × 26	W & C (1994)	N & M (1987)
1984	7.2	43 × 33	W & C (1994)	N & M (1987)
1998	7.0	30 × 26	W & C (1994)	USGS-NEIC
2000	7.9	95 × 40	Hayes (2017)	USGS-NEIC
2001	7.3	50 × 30	W & C (1994)	USGS-NEIC
2002	7.3	55 × 35	Hayes (2017)	USGS-NEIC
2004	9.2	1200 × 180	Ammon et al. (2005)	USGS-NEIC
2005	8.7	416 × 320	Konca et al. (2007)	USGS-NEIC
2007_1	8.4	400 × 368	Konca et al. (2008)	USGS-NEIC
2007_2	7.9	240 × 190	Konca et al. (2008)	USGS-NEIC
2007_3	7.1	41 × 25	W & C (1994)	USGS-NEIC
2008_1	7.4	55 × 35	Hayes (2017)	USGS-NEIC
2008_2	7.2	43 × 33	W & C (1994)	USGS-NEIC
2010_1	7.8	240 × 216	Hayes (2017)	USGS-NEIC
2010_2	7.2	90 × 90	Hayes (2017)	USGS-NEIC
2010_3	7.8	171 × 90	Yue et al. (2014)	USGS-NEIC

distribution are consistent with the 1833 stress scar exerting significant control on the rupture of this event almost 200 years later. Figure 4a illustrates the accumulated Coulomb stress changes immediately before 2010. The M7.8 2010_3 generated 3 to 9 m of tsunami run-up along the southwestern coasts of the Pagai Islands that took at least 431 lives (Lay et al., 2011). Its rupture initiated in a highly stressed area, updip adjacent to the M = 8.4 2007_1 rupture termination towards the trench. Both Lay et al. (2011) and Yue et al. (2014) have studied the rupture process of the 2010_3 earthquake and modelled its slip distribution. While the model of Lay et al. (2011) shows slip up to 4 m, the model presented by Yue et al. (2014) indicates much larger slips, of more than 24 m, which are concentrated on shallower parts of the megathrust towards the trench line (Figure 4a). We preferred the model of Yue et al. (2014) in this study since their finite-fault rupture model contains more data sets as input, though the difference does not significantly change the results of this paper. The coupling ranges between 0.5 and 0.9 in the rupture area (see Figure 2b).

It is worth mentioning that the 2007 earthquakes transferred about 0.8 bars of stress onto the hypocentral

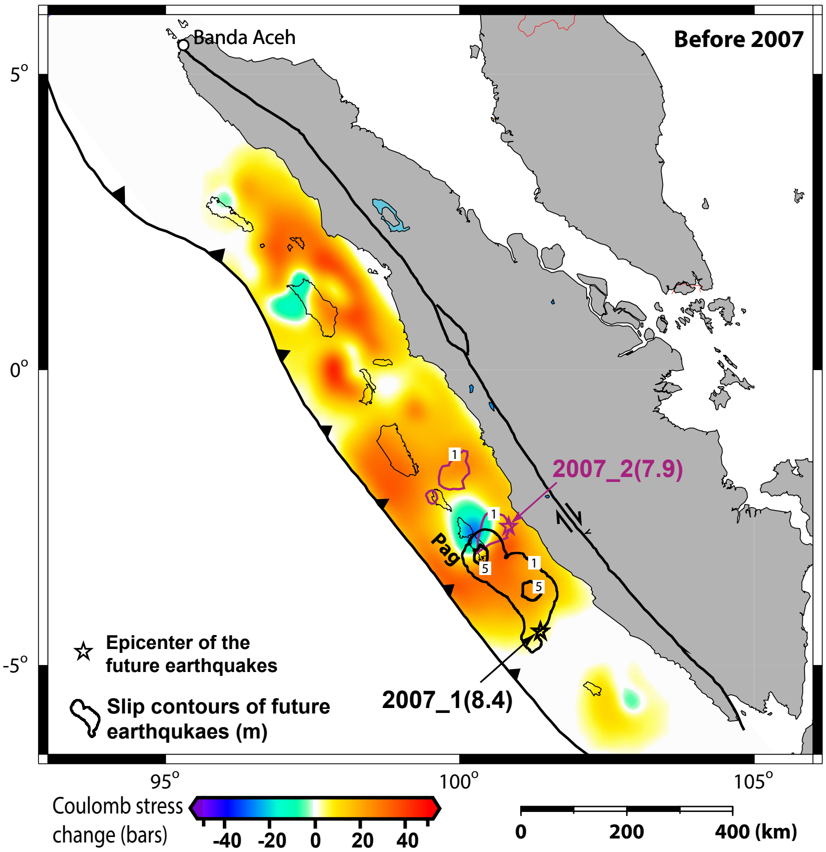


Figure 3. Cumulative Coulomb stress change due to earthquakes M > 7 and tectonic loading between 1797 and 2007 just before the 2007 earthquakes. Slip contours (in metres) of the future 2007 events are overlaid for comparison (shown in black and purple colours). Note the stress scar below the Pagai Islands (Pag) which we suggest acted as a barrier to the 2007_1 rupture. See the text for a discussion.

area of this earthquake, which likely promoted its occurrence. Similarly, another M = 7.8 2010_1 earthquake occurred in a region of large Coulomb stress accumulation in the north (Figure 4a) within the boundaries of 5 m slip contour of the M = 8.5 2005 rupture. Its epicentre was close to the 10 m slip contour of the 2005 event, which may indicate that, during the rupture process, areas of high slip load areas of low slip within the rupture, in some cases producing higher stresses than before the rupture itself. This could be a mechanism for producing large aftershocks within the rupture area of great earthquakes. Therefore, after a large rupture, we cannot confidently rule out the near future occurrence of a damaging earthquake in the same area.

Figure 4b shows the stress state in 2022. The stress accumulation over the Siberut patch ranges from 11 and 38 bars and the coupling is more than 0.75 (Figure 2b). After careful examination of the stress map, we can conclude that this patch of the Mentawai segment is a likely site for a future event.

4. Discussion and conclusions

The stress scar caused by the repeated slip in 1797 and 1833 beneath southern Pagai Island is a prominent feature in modern stress distribution. It clearly acted as a relaxation barrier (Aki, 1979) to the northward propagation of the 2007_1 (M = 8.4) event, and can also explain the two distinct patches of slip associated with the 2007_2 (M= 7.9) earthquake, as suggested by Konca et al. (2008) and Nalbant et al. (2013). The preseismic stress values in this area are well constrained due to the good coral data coverage surrounding the Pagai Islands used in the slip modelling by Nic Bhloscaidh et al. (2015). We can, therefore, be confident in the broad features of the stress map presented. The 2007 ruptures contributed to the widening and magnitude of this stress scar under the south Pagai Islands (Figure 4a). As discussed by Scholz (2019) relaxation barriers, such as these "stress scars" we have described, do not need to be a permanent feature; they could even act as asperities in the next future ruptures, resulting in earthquakes that are not characteristic in

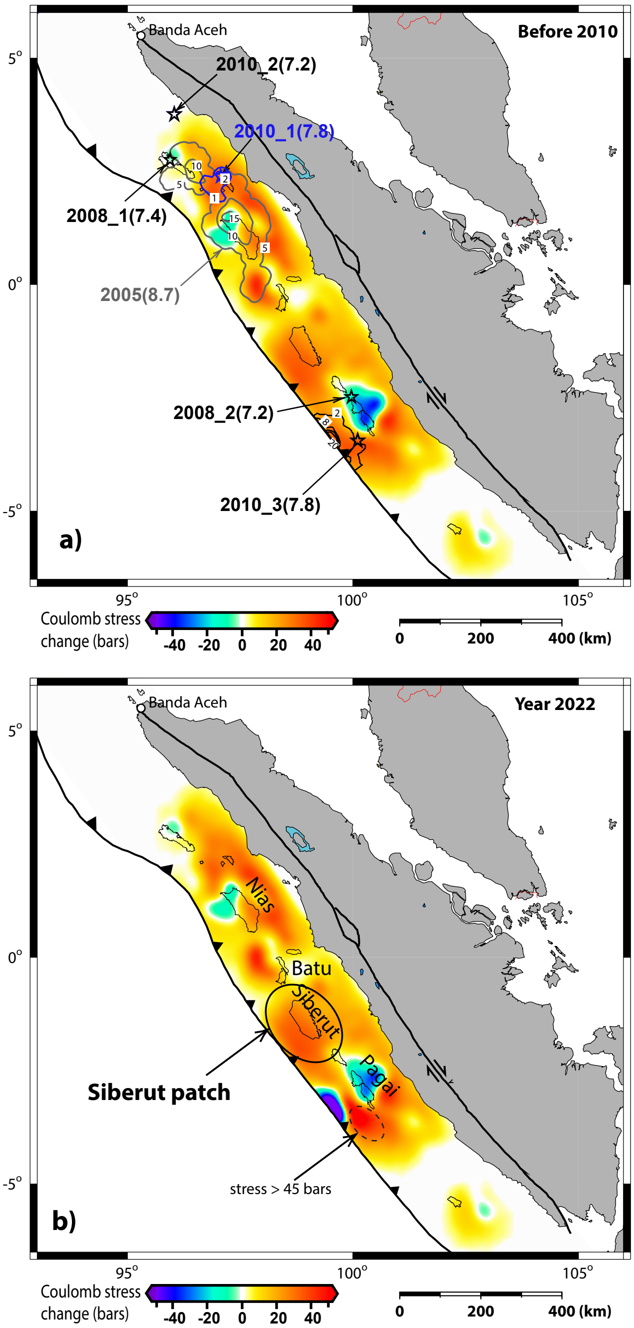


Figure 4. a) The Coulomb stress change just before the 2010 earthquake in the megathrust. Note that the slip in the 2010_1 and 2010_3 earthquakes was primarily on regions of large accumulated stress areas. The 2010_1 earthquake occurred between the 10m slip contours associated with the 2005 event (grey slip contours). The slip model of the 2010_3 is from Yue et al. (2014). Stars indicate the epicentres of the events. b) Current stress map in 2022. The stress scars caused mainly by the 1797, 1833, 2007, and 2010 earthquakes in the Mentawai section will have an impact on the shape and size of future megathrust earthquakes.

nature, i.e. that are neither predictable in their spatial extent, nor quasi-periodic in their timing.

Just before the M = 7.8 2010_3 event the stress on its hypocentral area earthquake was increased by the 2007 events. The slip during the 2010_3 event was confined mostly within the stress-enhanced area (Figure 4a), where the coupling is larger than 0.6 over most of the rupture area. Meltzner et al. (2015) speculated that a change in the state of coupling on the megathrust following the major earthquakes may significantly influence the propagation of subsequent ruptures. Our results, however, show that the preseismic stress on the Mentawai section, as shaped by interseismic coupling and the history of coseismic slip in previous events, is sufficient to explain the main features of the current slip distributions; this preseismic stress could therefore be the primary controlling factor for future ruptures, rather than the coupling alone. Coupling is a necessary factor for identifying which areas are accumulating stress, but not sufficient to forecast future ruptures. A similar conclusion was also reached by Lorito et al. (2011). They studied the great (M = 8.8) 2010 Maule, Chile earthquake which occurred in a previously identified seismic gap. However, the largest slip area took place outside the gap and the highly coupled region with the largest slip deficit experienced a relatively small slip, resulting in only a partial filling of the seismic gap. Based on the comparison of coupling and slip distribution for the Maule earthquake, they concluded that coupling on its own provides a poor forecast of future slip, but is required for identifying areas of accumulating stresses.

The area just southeast of the 2010_3 rupture (marked by a dashed circle in Figure 4b) is one of the most likely locations for the occurrence of a future tsunamigenic earthquake due to its accumulated stress change (>45 bars) and its proximity to the trench line. The area under Siberut Island (Siberut patch) is also highly stressed (between 11 and 38 bars), so it is at extremely high risk of a large, megathrust event. Nevertheless, it is not clear that a future rupture should be confined to this patch solely (i.e. the area from 2.5 °S to 1 °S). While low coupling in the region of the Batu Islands (Figure 2b) does contribute to generally low stress in that area, coseismic stress from the 2005 Nias event has increased the stress north of the Batu Islands and might allow a future Siberut event to propagate across the Batu Island barrier. Similarly, depending on the future stress distribution on the Mentawai segment, the segment could rupture completely in one great earthquake in a future cycle.

Another region where this result might have relevance is the Nankai Trough. It has an unusually long and well-documented seismic history (Scholz, 2019). This approximately 700 km long plate boundary, has been proposed as divided into three segments, generally referred to as Nankai, Tonankai, and Tokai (Ando, 1975). The earthquake repeat intervals are considered to be in the range of 90–200 years (Hori, 2006). The boundary in the past has ruptured with two earthquakes separated by several years. However, it ruptured completely with a single event in 887 and 1707 (Hori, 2006). The 2011 Tohoku earthquake is another example that involved multiple asperities that commonly rupture independently (Philibosian and Meltzner, 2020). In their review paper, Philibosian and Meltzner (2020) have compiled rupture chronologies for major faults worldwide to analyse patterns of earthquake clustering in space and time. They emphasised that different behaviours such as rupture cascades, superimposed cycles, and quasi-periodic similar ruptures are common features of most major faults, but clustered similar ruptures are not common features in these faults. Ye et al. (2018) attribute these complex rupture patterns in megathrust earthquakes to persistent geological factors, such as subducting seafloor relief or fault trace discontinuities, and proposed that rupture models are primarily influenced by two parameters; fault interface roughness and barrier/asperity size. Here our results, however, show that large stress scars can act like 'ephemeral barriers' (Lay and Kanamori, 1981), indicating a barrier does not necessarily have to be a static structural factor but might be a transient, dynamic feature of a complex system, leading to a much more complicated series of earthquakes of all sizes.

In conclusion, our study indicates that stress scars such as those left over by the 1797 and 1833 ruptures indeed do behave like transient barriers to rupture propagation that influence the extent and magnitude of future earthquake ruptures. Such barriers, though transient, may persist for hundreds of years.

Acknowledgements
We thank the editor Dr. Uçarkuş and Dr. Matthieu Ferry for their thoughtful reviews which clarified the manuscript significantly. This work was supported by the Natural Environment Research Council (NERC) (grant numbers NE/D006678/1, NE/F01161X/1, NE/H008519/1, NE/F245444/1 and NE/S009000/1).

References

Aki K (1979). Characterization of barriers on an earthquake fault. Journal of Geophysical Research: Solid Earth 84 (B11): 6140–6148. https://doi.org/10.1029/JB084iB11p06140

Ando M (1975). Source mechanisms and tectonic significance of historical earthquakes along the Nankai trough, Japan. Tectonophysics 27 (2): 119–140. https://doi.org/10.1016/0040-1951(75)90102-X

Blaser L, Krüger F, Ohrnberger M, Scherbaum F (2010). Scaling Relations of Earthquake Source Parameter Estimates with Special Focus on Subduction Environment. Bulletin of the Seismological Society of America 100 (6): 2914–2926. https://doi.org/10.1785/0120100111

Chlieh M, Avouac JP, Sieh K, Natawidjaja DH, Galetzka J (2008). Heterogeneous coupling of the Sumatran megathrust constrained by geodetic and paleogeodetic measurements. Journal of Geophysical Research: Solid Earth 113 (B5). https://doi.org/10.1029/2007JB004981

Freitag L, Okal EA (2020). Preliminary Results from a Prototype Ocean-Bottom Pressure Sensor Deployed in the Mentawai Channel, Central Sumatra, Indonesia. Pure and Applied Geophysics 177 (11): 5119–5131. https://doi.org/10.1007/s00024-020-02561-6

Hayes GP (2017). The finite, kinematic rupture properties of great-sized earthquakes since 1990. Earth and Planetary Science Letters 468: 94–100. https://doi.org/10.1016/j.epsl.2017.04.003

Hori T (2006). Mechanisms of separation of rupture area and variation in time interval and size of great earthquakes along the Nankai Trough, southwest Japan. Earth Simulator 5: 8–19.

King GCP, Cocco M (2001). Fault interaction by elastic stress changes: New clues from earthquake sequences (R. Dmowska & B. B. T.-A. in G. Saltzman (Eds.): 44, pp. 1–VIII). Elsevier. https://doi.org/10.1016/S0065-2687(00)80006-0

Konca AO, Avouac JP, Sladen A, Meltzner AJ, Sieh K et al. (2008). Partial rupture of a locked patch of the Sumatra megathrust during the 2007 earthquake sequence. Nature 456 (7222): 631–635. https://doi.org/10.1038/nature07572

Konca, AO, Hjorleifsdottir V, Song TRA, Avouac JP, Helmberger DV et al. (2007). Rupture kinematics of the 2005 Mw 8.6 m Nias-Simeulue earthquake from the joint inversion of seismic and geodetic data. Bulletin of the Seismological Society of America 97 (1): 307–322. https://doi.org/10.1785/0120050632

Lay T, Ammon CJ, Kanamori H, Yamazaki Y, Cheung KF et al. (2011). The 25 October 2010 Mentawai tsunami earthquake (Mw 7.8) and the tsunami hazard presented by shallow megathrust ruptures. Geophysical Research Letters 38 (6). https://doi.org/10.1029/2010GL046552

Lay T, Kanamori H (1981). An asperity model of large earthquake sequences. In D. W. Simpson & P. G. Richards (Eds.), Earthquake prediction, an international review, Maurice Ewing series (pp. 579–592). American Geophysical Union. https://doi.org/10.1029/ME004p0579

Leonard M (2014). Self-Consistent Earthquake Fault-Scaling Relations: Update and Extension to Stable Continental Strike-Slip Faults. Bulletin of the Seismological Society of America 104 (6): 2953–2965. https://doi.org/10.1785/0120140087

Lindsay A, McCloskey J, Nic Bhloscaidh M (2016). Using a genetic algorithm to estimate the details of earthquake slip distributions from point surface displacements. Journal of Geophysical Research: Solid Earth 121 (3): 1796–1820. https://doi.org/10.1002/2015JB012181

Lorito S, Romano F, Atzori S, Tong X, Avallone A et al. (2011). Limited overlap between the seismic gap and coseismic slip of the great 2010 Chile earthquake. Nature Geoscience 4 (3): 173–177. https://doi.org/10.1038/ngeo1073

Mavrommatis AP, Segall P, Johnson KM (2014). A decadal-scale deformation transient prior to the 2011 Mw 9.0 Tohoku-Oki earthquake. Geophysical Research Letters 41 (13): 4486–4494. https://doi.org/10.1002/2014GL060139

Meltzner AJ, Sieh, K, Chiang HW, Shen C-C, Suwargadi BW et al. (2012). Persistent termini of 2004- and 2005-like ruptures of the Sunda megathrust. Journal of Geophysical Research: Solid Earth 117 (B4). https://doi.org/10.1029/2011JB008888

Meltzner AJ, Sieh, K, Chiang HW, Wu CC, Tsang LL et al. (2015). Time-varying interseismic strain rates and similar seismic ruptures on the Nias-Simeulue patch of the Sunda megathrust. Quaternary Science Reviews 122: 258–281. https://doi.org/10.1016/j.quascirev.2015.06.003

Nalbant S, McCloskey J, Steacy S, Nicbhloscaidh M, Murphy S (2013). Interseismic coupling, stress evolution, and earthquake slip on the Sunda megathrust. Geophysical Research Letters 40 (16): 4204–4208. https://doi.org/10.1002/grl.50776

Nalbant SS, Steacy S, Sieh K, Natawidjaja D, McCloskey J (2005). Earthquake risk on the Sunda trench. Nature 435 (7043): 756–757. https://doi.org/10.1038/nature435756a

Natawidjaja DH, Sieh K, Chlieh M, Galetzka J, Suwargadi BW et al. (2006). Source parameters of the great Sumatran megathrust earthquakes of 1797 and 1833 inferred from coral microatolls. Journal of Geophysical Research: Solid Earth 111 (B6). https://doi.org/10.1029/2005JB004025

Newcomb KR, McCann WR (1987). Seismic history and seismotectonics of the Sunda Arc. Journal of Geophysical Research: Solid Earth 92 (B1): 421–439. https://doi.org/10.1029/JB092iB01p00421

Nic Bhloscaidh M, McCloskey J, Naylor M, Murphy S, Lindsay A (2015). Reconstruction of the slip distributions in historical earthquakes on the Sunda megathrust, W. Sumatra. Geophysical Journal International 202 (2): 1339–1361. https://doi.org/10.1093/gji/ggv195

Philibosian B, Meltzner AJ (2020). Segmentation and supercycles: A catalog of earthquake rupture patterns from the Sumatran Sunda Megathrust and other well-studied faults worldwide. Quaternary Science Reviews 241: 106390. https://doi.org/10.1016/j.quascirev.2020.106390

Philibosian B, Sieh K, Avouac JP, Natawidjaja DH, Chiang HW et al. (2017). Earthquake supercycles on the Mentawai segment of the Sunda megathrust in the seventeenth century and earlier. Journal of Geophysical Research: Solid Earth 122 (1): 642–676. https://doi.org/10.1002/2016JB013560

Philibosian B, Sieh K, Avouac JP, Natawidjaja DH, Chiang HW et al. (2014). Rupture and variable coupling behavior of the Mentawai segment of the Sunda megathrust during the supercycle culmination of 1797 to 1833. Journal of Geophysical Research: Solid Earth 119 (9): 7258–7287. https://doi.org/10.1002/2014JB011200

Salman R, Hill EM, Feng L, Lindsey EO, Mele Veedu D et al. (2017). Piecemeal Rupture of the Mentawai Patch, Sumatra: The 2008 Mw 7.2 North Pagai Earthquake Sequence. Journal of Geophysical Research: Solid Earth 122 (11): 9404–9419. https://doi.org/10.1002/2017JB014341

Scholz CH (2019). The Mechanics of Earthquakes and Faulting. Cambridge University Press.

Sieh K, Natawidjaja DH, Meltzner AJ, Shen CC, Cheng H et al. (2008). Earthquake supercycles inferred from sea-level changes recorded in the corals of west Sumatra. Science 322 (5908): 1674–1678. https://doi.org/10.1126/science.1163589

Stein S, Okal EA (2005). Speed and size of the Sumatra earthquake. Nature 434 (7033): 581–582. https://doi.org/10.1038/434581a

Strasser FO, Arango MC, Bommer JJ (2010). Scaling of the Source Dimensions of Interface and Intraslab Subduction-zone Earthquakes with Moment Magnitude. Seismological Research Letters 81 (6): 941–950. https://doi.org/10.1785/gssrl.81.6.941

Uchida N, Matsuzawa T (2013). Pre- and postseismic slow slip surrounding the 2011 Tohoku-Oki earthquake rupture. Earth and Planetary Science Letters 374: 81–91. https://doi.org/10.1016/j.epsl.2013.05.021

Wells D, Coppersmith K (1994). New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. Bulletin of the Seismological Society of America 84: 974–1002.

Wiseman K, Bürgmann R (2011). Stress and seismicity changes on the Sunda megathrust preceding the 2007 Mw 8.4 earthquake. Bulletin of the Seismological Society of America 101 (1): 313–326. https://doi.org/10.1785/0120100063

Ye L, Kanamori H, Lay T (2018). Global variations of large megathrust earthquake rupture characteristics. Science Advances 4 (3): eaao4915.

Yokota Y, Koketsu K (2015). A very long-term transient event preceding the 2011 Tohoku earthquake. Nature Commination **6**, 5934. https://doi.org/10.1038/ncomms6934

Yue H, Lay T, Rivera L, Bai Y, Yamazaki Y et al. (2014). Rupture process of the 2010 Mw 7.8 Mentawai tsunami earthquake from joint inversion of near-field hr-GPS and teleseismic body wave recordings constrained by tsunami observations. Journal of Geophysical Research: Solid Earth 119 (7): 5574–5593. https://doi.org/10.1002/2014JB011082

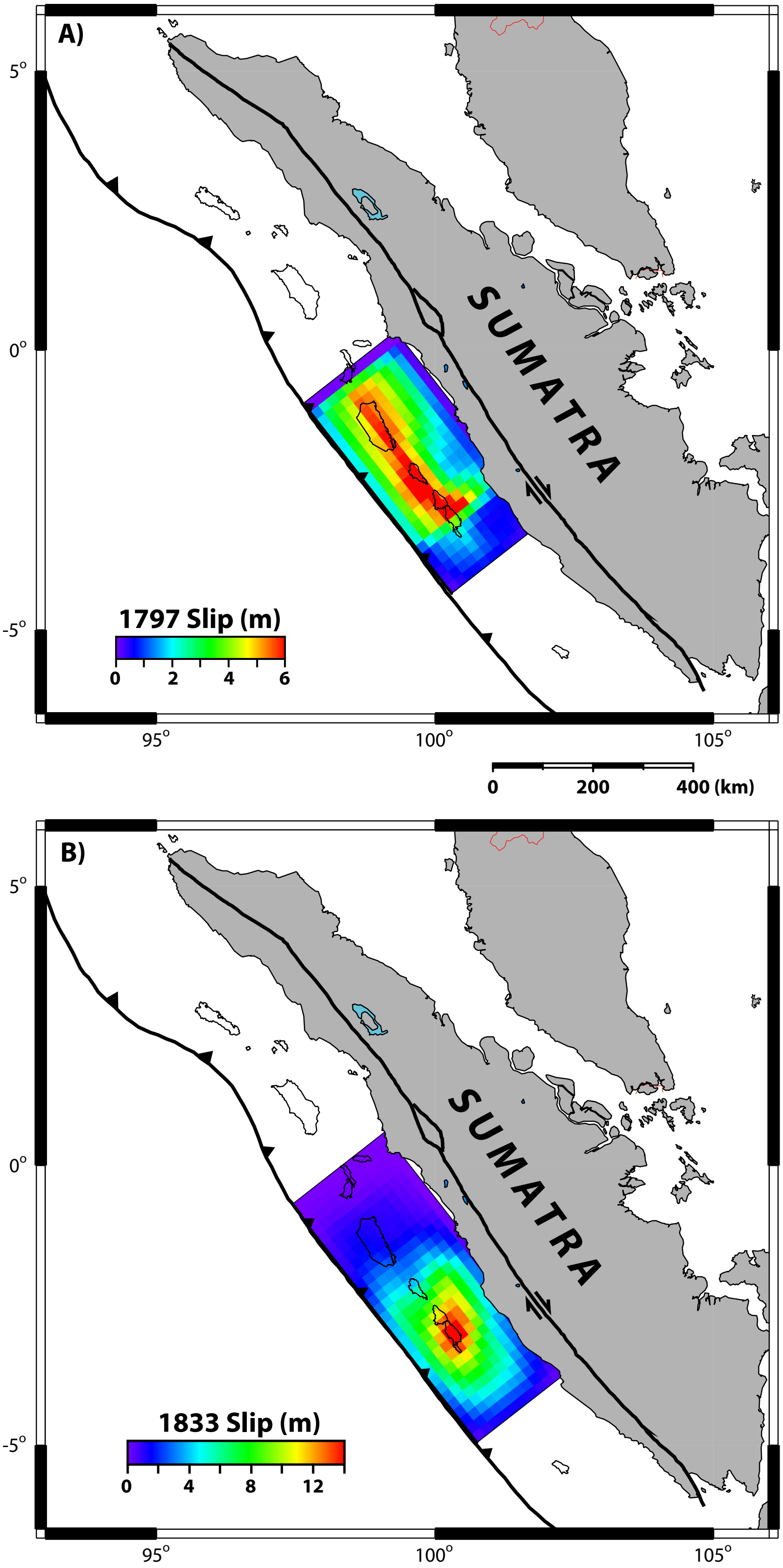


Figure S1. Slip distributions of 1797 (a) and 1833 (b) historical earthquakes. They are obtained from modelling of vertical deformations recorded in the growth of shallow water corals on the islands along the west coast of Sumatra (from Nic Bhloscaidh et al., 2015).

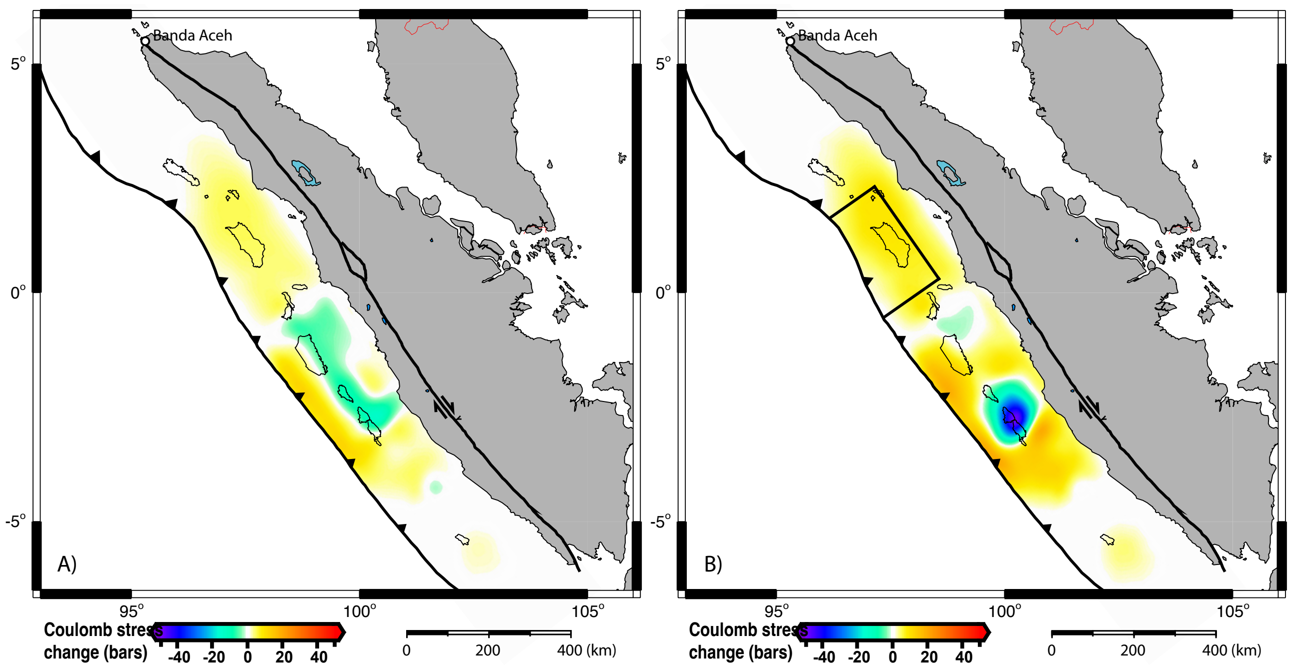


Figure S2. (A) Total Coulomb stress change (coseismic + tectonic loading) between 1797 and just before the 1833 earthquake. During this period, coseismic stress changes are due to the 1797 and 1818 events. (B) Again total Coulomb stress changed between 1797 and before the 1861 event. The rupture area of the 1861 earthquake is shown as a rectangular area. Note that stress scar caused mostly by the 1833 event with more than 12m slip is a dominant feature which will influence the rupture area of the future 2007_1 and 2007_2 earthquake sequence and their magnitude as a consequence. Please see the text for further discussion.

References

Hayes GP (2017). The finite, kinematic rupture properties of great-sized earthquakes since 1990. Earth and Planetary Science Letters 468: 94–100. https://doi.org/10.1016/j.epsl.2017.04.003

Kanamori H, Rivera L, Lee WHK (2010). Historical seismograms for unravelling a mysterious earthquake: The 1907 Sumatra Earthquake, Geophysical Journal International 183 (1): 358–374. https://doi.org/10.1111/j.1365-246X.2010.04731.x

Konca AO, Avouac JP, Sladen A, Meltzner AJ, Sieh K et al. (2008). Partial rupture of a locked patch of the Sumatra megathrust during the 2007 earthquake sequence. Nature 456 (7222): 631–635. https://doi.org/10.1038/nature07572

Konca, AO, Hjorleifsdottir V, Song TRA, Avouac JP, Helmberger DV et al. (2007). Rupture kinematics of the 2005 Mw 8.6 m Nias-Simeulue earthquake from the joint inversion of seismic and geodetic data. Bulletin of the Seismological Society of America 97 (1): 307–322. https://doi.org/10.1785/0120050632

Natawidjaja DH, Sieh K, Chlieh M, Galetzka J, Suwargadi BW et al. (2006). Source parameters of the great Sumatran megathrust earthquakes of 1797 and 1833 inferred from coral microatolls. Journal of Geophysical Research: Solid Earth 111 (B6). https://doi.org/10.1029/2005JB004025

Newcomb KR, McCann WR (1987). Seismic history and seismotectonics of the Sunda Arc. Journal of Geophysical Research: Solid Earth 92 (B1): 421–439. https://doi.org/10.1029/JB092iB01p00421

Nic Bhloscaidh M, McCloskey J, Naylor M, Murphy S, Lindsay A (2015). Reconstruction of the slip distributions in historical earthquakes on the Sunda megathrust, W. Sumatra. Geophysical Journal International 202 (2): 1339–1361. https://doi.org/10.1093/gji/ggv195

Rivera L, Sieh K, Helmberger D, Natawidjaja D (2002). A Comparative Study of the Sumatran Subduction-Zone Earthquakes of 1935 and 1984. Bulletin of the Seismological Society of America 92 (5): 1721–1736. https://doi.org/10.1785/0120010106

Wells D, Coppersmith K (1994). New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. Bulletin of the Seismological Society of America 84: 974–1002.

Yue H, Lay T, Rivera L, Bai Y, Yamazaki Y et al. (2014). Rupture process of the 2010 Mw 7.8 Mentawai tsunami earthquake from joint inversion of near-field hr-GPS and teleseismic body wave recordings constrained by tsunami observations. Journal of Geophysical Research: Solid Earth 119 (7): 5574–5593. https://doi.org/10.1002/2014JB011082