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Segmentation of the Andaman–Sumatra forearc and implications for great-earthquake rupture

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Abstract

The Sunda subduction margin produced the great 2004 Mw 9.1–9.3 Sumatra–Andaman earthquake, whose trans-oceanic tsunami killed over 200,000 people. No self-consistent framework yet explains why co-seismic slip during this earthquake varied so dramatically along strike, or why neighbouring fault systems responded so differently to the resulting stress changes. Here, by jointly inverting GPS velocities and earthquake slip-vectors in a regional kinematic block model, we show that the rupture crossed a previously unrecognised plate boundary within the forearc, so that a single earthquake spanned two microplates loaded at different long-term slip rates and directions. This boundary, near $\sim 6\text{--}7^\circ\text{N}$ (which we term the Nicobar Neck), separates the Andaman and Sumatran segments of the rigid forearc microplate and coincides with a pronounced negative residual gravity anomaly, indicating a mechanically weaker zone. We further find that the offshore continuation of the Sumatran Fault (the Andaman–Nicobar Fault) accommodates ~ 39 mm/yr of trench-parallel slip (twice the onshore rate) yet has no record of large earthquakes, implying creep and/or distributed slip.

Introduction

The Andaman–Nicobar segment of the Sunda margin and the broader tectonic system surrounding it rank among the most consequential active plate-boundary zones on Earth. Within the past two decades this system has produced one of the largest earthquakes ever recorded, the 2004 Mw 9.1–9.3 Sumatra–Andaman event and one of the largest strike-slip earthquakes on record, the 2012 Mw 8.6 Wharton Basin event. The tsunami generated by the 2004 earthquake was trans-oceanic, with destructive waves reaching coastlines across the Indian Ocean. The region is structurally defined by large-scale interactions among major fault systems: the Sunda megathrust, the Sumatran Fault and its offshore continuation, the Andaman back-arc spreading system, the Sagaing Fault, and a region of diffuse deformation beneath the Indian Ocean^{1–3} (Fig. 1). The Andaman Sea itself is one of Earth's great tectonic stepovers, and an active subaerial-and-submarine volcanic arc lies along a major strike-slip fault zone within it⁴. Together, these systems partition the total relative plate motion along the western Sunda plate boundary. Earthquake behaviour across these interconnected systems is correspondingly complex: the 2004 event triggered widespread regional seismicity⁵, the Nicobar sector has hosted prolonged swarm activity⁶, and triggered or stress-modulated slip continues to be reported across the system. Understanding this region also bears directly on other poorly understood but high-risk fault systems, most notably the Rakhine megathrust to the north.

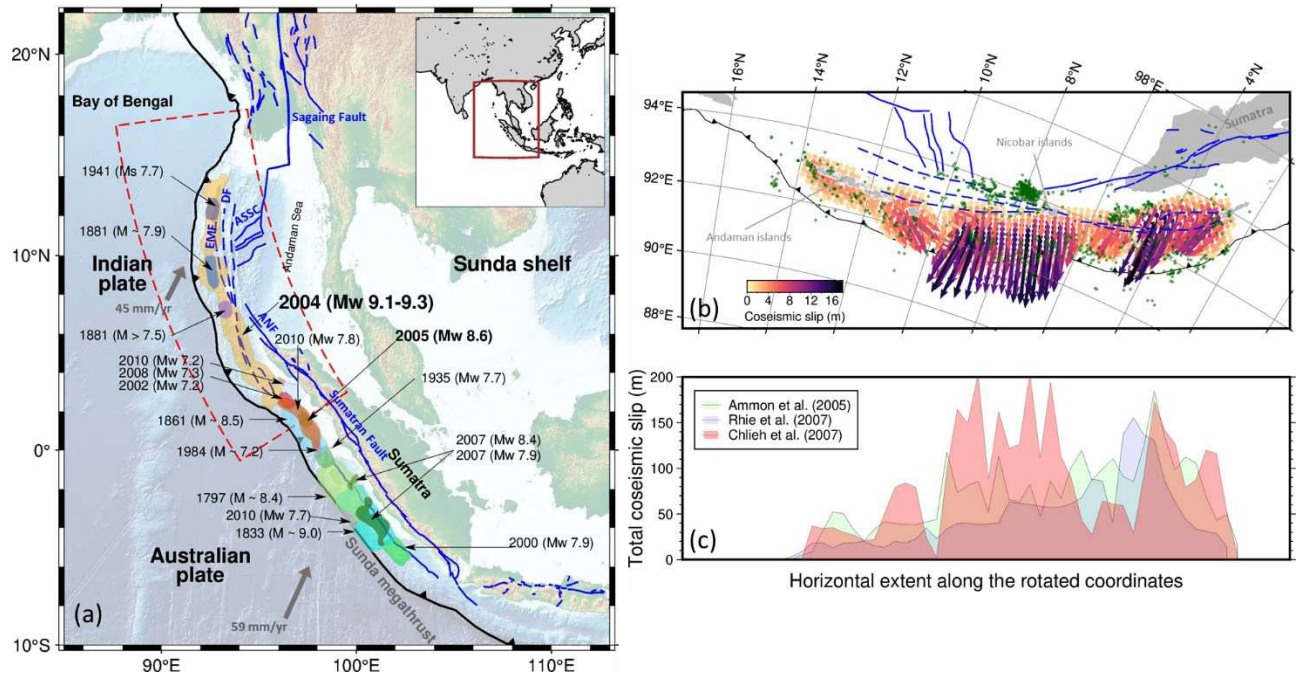


Figure 1: Tectonic setting of the Sunda subduction zone and seismicity along the western margin. a) Map showing the Sumatra-Andaman tectonic system. Trench is marked in black, while major upper plate faults are in blue, including the Sumatran Fault, Andaman Sea Spreading Centre (ASSC), Andaman Nicobar Fault (ANF). Other mapped faults (without concentrated seismicity) are in dashed lines. Plate motion vectors are from Shearer and Bürgmann⁷. Coloured patches along the forearc represent regions of inferred ruptures along the megathrust. Historical large earthquakes ($M_w \geq 7$) are labelled with year and magnitude, highlighting the highly active and segmented nature of the margin, including the 2004 Mw 9.1–9.3 Sumatra–Andaman earthquake (orange patch) and subsequent major events (e.g., 2005, 2007, 2010)^{8–10}. b) Coseismic slip of the 2004 Sumatra–Andaman earthquake and its aftershocks (from 26/12/2004 to 28/03/2005, before 2005 Nias earthquake). Contours show slip from Chlieh et al.¹¹, arrows show the rake (coloured and scaled for slip magnitude), green dots indicate aftershocks (from ISC-EHB catalogue¹²). c) Three different coseismic slip distributions^{11,13,14} are shown in rotated coordinates along trench (accumulated slip along horizontal extent in (b)) for the 2004 Sumatra–Andaman earthquake. These slip models were selected to represent the diversity of inversion datasets and methodologies, as well as their broad acceptance in the literature. Other published models are omitted for clarity, as they exhibit similar patterns of slip distribution and rake-angle variations (e.g. Bletery et al.¹⁵).

Despite two decades of intensive post-2004 observation, first-order questions about this margin remain unresolved. We do not know what controlled the >1500 km along-strike extent^{11,16} of the 2004 rupture or what produced its dramatic along-strike changes in slip magnitude, rake and rupture velocity (Fig. 1b, c); nor do we know why neighbouring fault systems responded so differently to the regional stress changes that the earthquake produced, with sustained postseismic deformation in the Andamans¹⁷ and prolonged swarm seismicity around the Nicobars⁴. We do not yet know how the strongly oblique India–Sunda convergence is partitioned among the megathrust, the back-arc spreading system, and the upper-plate strike-slip faults. These open questions prevent quantitative models of the earthquake cycle on the largest faults in the region, and they limit assessments of seismic and tsunami hazard along the entire eastern Indian Ocean rim.

These gaps have persisted in large part because no self-consistent kinematic model of the regional microplates yet exists. The prevailing plate organisation for the region is inherited from the global plate model¹⁸ which has been used as the structural starting point for subsequent seismotectonic studies, and remains unchanged in the updated global plate model¹⁹. In this configuration, a microplate boundary is

placed at the southern termination of the 2004 rupture, near Simeulue Island, even though this placement was explicitly assumed rather than independently resolved from data. Studies of along-strike variation in earthquake behaviour have further appealed to lower-plate causes (i.e., slab tears, slab geometry, downgoing-plate hydration), without simultaneously evaluating upper-plate kinematics or slip partitioning (e.g., refs.^{20,21}).

Several developments since 2004 now make a regional kinematic budget achievable. The great 2004 earthquake triggered a regional sequence of moderate-to-large earthquakes, many with well-determined focal mechanisms, expanding the slip-vector azimuth (SVA) dataset available for constraining relative block motions^{22,23}. Geodetic observation has also matured with GNSS networks across Sumatra, the Andaman and Nicobar Islands, Myanmar and Thailand recording both interseismic and postseismic motion^{24,25}. The 2012 Wharton Basin earthquake spurred a series of regional marine geophysical surveys that have illuminated the role of distributed deformation in the offshore areas²⁶ and slab geometries and regional tomography are better constrained than they were two decades ago^{27,28}. Collectively these datasets make it possible to construct, and independently validate, the regional kinematic framework.

Here we perform an arc-scale kinematic block inversion from southern Myanmar to Java, jointly fitting GNSS velocities and earthquake SVAs to estimate block rotations and slip rates on the major faults. We validate the resulting slip rates against independent geological observations where available (e.g., the Sumatran and Sagaing faults), then compare the results with the residual Bouguer gravity anomaly field. The principal forearc plate boundary is found to lie at the Nicobar Islands near $\sim 6\text{--}7^\circ\text{N}$ (referred to as Nicobar Neck hereafter) rather than at Simeulue, and within this framework the 2004 earthquake is best understood not as a single rupture but as a compound event that crossed two kinematically distinct plate boundaries loaded at different long-term rates and in different directions. The block model thus provides the missing kinematic baseline from which the dynamics, segmentation and hazard of this margin can be quantitatively reassessed.

Results

A regional kinematic block model for the Sunda–Andaman margin

We construct a kinematic model of the Sunda–Andaman margin by jointly inverting 183 published GNSS velocities spanning Java, Sumatra, the Andaman Sea and Myanmar, together with 1,039 earthquake SVAs, within an elastic block model that solves simultaneously for block rotations and interseismic fault coupling (see Data and Methods section). The region is partitioned into 11 blocks separated by the Sunda megathrust, the Sumatran and Sagaing fault systems, and their offshore continuation through the Andaman Sea. Our preferred model fits both datasets well (Fig. 2), reproducing the horizontal velocity field with a weighted root-mean-square residual of 3.4 mm yr^{-1} and the SVAs to $\sim 13^\circ$, for a normalised χ^2 of 2.35. Modelled and observed velocities cluster around a 1:1 relationship (in both north and east components) with no systematic spatial bias (Fig. 2c), indicating that the block geometry captures the first-order kinematics.

Modelled fault slip rates (Fig. 2a) agree with independent geodetic and geological estimates along the length of the margin. Along the Sumatran Fault we recover $\sim 18\text{ mm yr}^{-1}$, comparable to the near-constant $\sim 15 \pm 3\text{ mm yr}^{-1}$ long-term rate inferred from offset river channels²⁴. On the Sagaing Fault we obtain a slip rate of $\sim 20\text{ mm yr}^{-1}$, matching the $20\text{--}23\text{ mm yr}^{-1}$ dextral rate resolved by the previous dense-network geodetic block model²⁵ and consistent with geological offset estimates. Present-day

geodetic rates match the long-term geological record across contrasting kinematic regimes, indicating that the region's fault kinematics have been stable over many earthquake cycles. The large northward GNSS velocities of the Andaman forearc, and the nearly trench-perpendicular slip vectors of plate interface earthquakes, together require a fast slip rate on the Andaman-Nicobar Fault (the offshore continuation of the Sumatran Fault) to accommodate the trench-parallel motion of the Andaman sliver relative to the Sumatran sliver. This requires the Andaman–Nicobar Fault to carry $\sim 39 \text{ mm yr}^{-1}$ of trench-parallel slip, roughly twice the rate of the onshore Sumatran Fault.

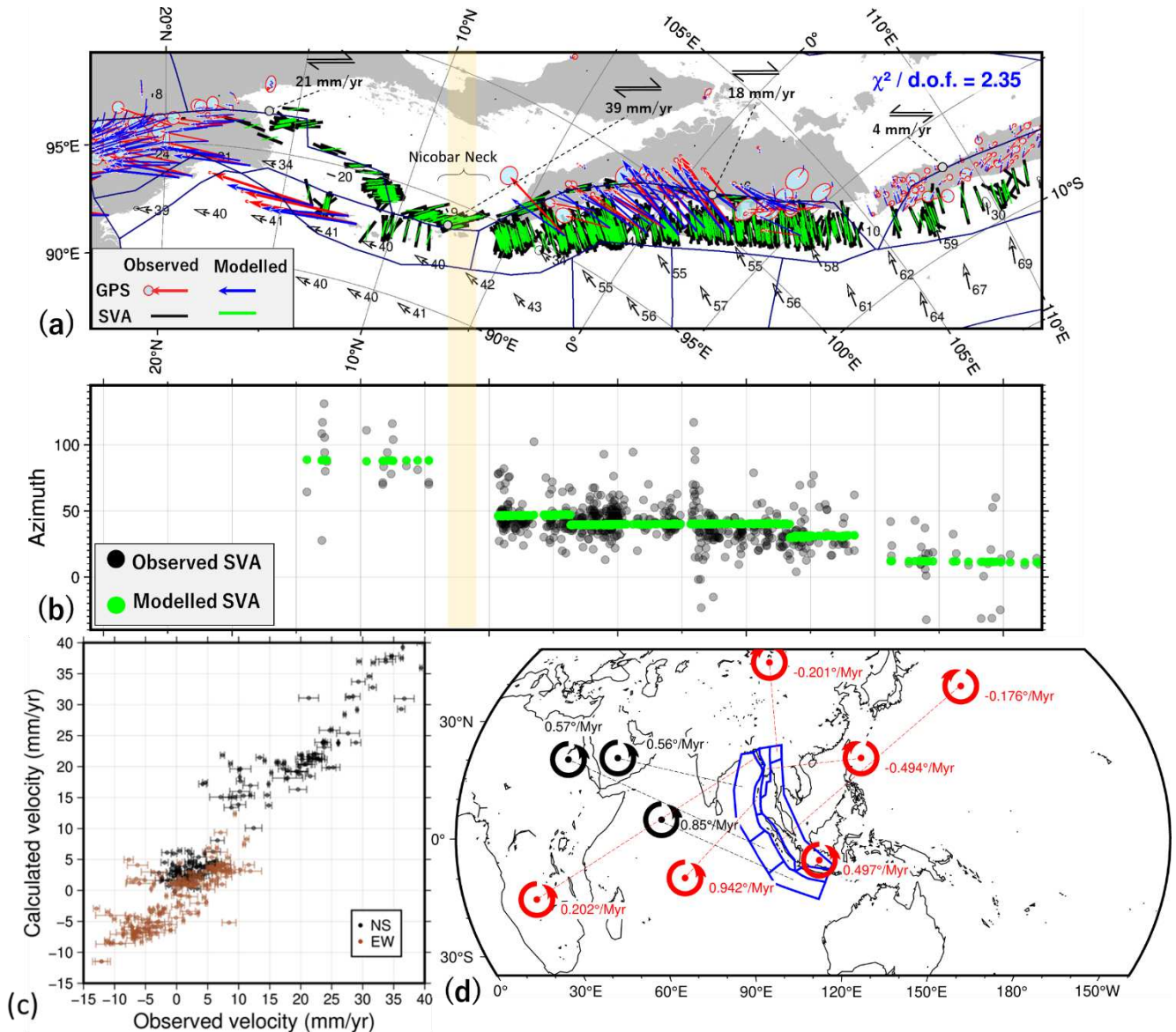


Figure 2. Regional block model results. (a) Map of observed and modelled GPS velocities across the Burma-Andaman-Sumatra-Java margin, with earthquake slip-vector azimuth (SVA) fits. Arrows with numbers are calculated surface velocity vectors (mm/yr). Strike-slip symbols with numbers are fault slip rates. The block boundaries are plotted in dark blue lines. (b) Along-strike variation in SVA. Annotated shift near Nicobar Neck ($\sim 6\text{--}7^\circ\text{N}$) marks the kinematic transition between the Sumatran and Andaman segments. (c) Comparison of calculated versus observed GPS velocities for both north-south (NS) and east-west (EW) components. (d) Euler poles of relative rotation for the block model with reference to the Sunda block. Poles shown in black are fixed and obtained from Bradley et al. ²⁴, the poles in red are inversion results with the corresponding blocks joined using dashed line.

SVAs are reproduced with high fidelity (Fig. 2b). A pronounced shift occurs at the Nicobar Neck (south of the Nicobar Islands, $\sim 6\text{--}7^\circ \text{N}$), marking the transition from trench-normal convergence in the Sumatran segment to increasingly oblique, margin-parallel motion in the Andaman sector. This rotation cannot be accommodated by a single rigid sliver plate and requires a break in the sliver plate separating the Sumatran and Andaman domains. The boundary is demanded directly by the data: we cannot fit the combined slip-vector and GNSS observations with a continuous sliver plate, with the boundary placed further south, or with the obliquity gradient taken up by the downgoing plate (see alternative models in the Data and Methods section as well as in supplementary material). Block rotations are described by the recovered Euler poles (Fig. 2d), which are well separated between the forearc slivers, especially the Andaman and Sumatra. The transition is therefore a robust, data-required feature, separating two forearc blocks that move at distinctly different rates and directions.

A weak forearc plate boundary: confirmation from residual Bouguer gravity

We compare the block-model boundary against an independent geophysical observable: the along-trench residual Bouguer gravity anomaly field. Following the approach of Bassett and Watts²⁹, the residual is obtained by removing an average trench-normal profile from the Bouguer-corrected gravity field, which suppresses the long-wavelength slab signal and isolates short-wavelength variations in forearc density. The residual field is strongly variable along strike and plotted separately for landward and seaward across-arc profiles (Fig. 3a,b).

Two prominent negative anomalies occur in the forearc: one at the Nicobar Neck and one at the Sunda Strait, between Sumatra and Java. Both reach amplitudes of $\sim 100 \text{ mGal}$, are confined to the landward side of the trench, and coincide with inward curvature of the trench (Fig. 3b). The Nicobar low is co-located with the kinematic boundary identified in the block model. Likewise, the region around the Sunda Strait has a trans-tensional boundary between the Sumatran and Javan forearc slivers³⁰.

Residual forearc gravity lows are widely interpreted in terms of upper-plate density structure linked to forearc segmentation²⁹. An anomaly of this amplitude has two principal explanations. The first is anomalously thick, low-density forearc sediment: a Bouguer slab calculation shows that $\sim 100 \text{ mGal}$ requires the equivalent of $\sim 12 \text{ km}$ of material at a density contrast of $\sim 200 \text{ kg m}^{-3}$ relative to surrounding crust, or a thinner layer at a correspondingly larger contrast. Although the Andaman accretionary prism is among the widest globally³¹, the sediment column at the Nicobar Neck is too thin to account for the anomaly: seismic-reflection imaging shows sediment thicknesses of $\sim 2\text{--}6 \text{ km}$ along this part of the margin²⁶. The second, and our preferred, interpretation is low-density material in the upper-plate lower crust or mantle, produced by fluid-driven serpentinisation or by mechanical weakening within a long-lived, fluid-infiltrated fault zone^{32–34}. Serpentinised mantle carries a larger density contrast ($\sim 300\text{--}600 \text{ kg m}^{-3}$) and would generate the same anomaly with only $\sim 4\text{--}8 \text{ km}$ of affected material.

Convergence obliquity and forearc seismicity

Our block model yields the convergence obliquity, the angle between the plate-convergence vector and the trench-normal direction, continuously along the margin (Fig. 3c). Trench-parallel motion exceeds trench-normal convergence beyond 45° obliquity, a crossover reached near the Nicobar Neck and exceeded northward, where obliquity approaches margin-parallel ($>70^\circ$). To demonstrate this kinematic gradient seismically, we classified earthquakes within $\pm 10 \text{ km}$ of the Slab2.0 plate interface²⁷ into interface (megathrust-style thrust) and off-slab (forearc and upper-plate) populations, and computed the fraction of each in 1° along-strike bins with binomial confidence intervals (Fig. 3c).

The seismicity tracks the obliquity structure closely. In the Sumatran sector, where trench-perpendicular convergence is the dominant component (obliquity $<45^\circ$), seismicity is dominated by interface-thrust earthquakes (thrust fraction ~ 0.69), consistent with a strongly coupled megathrust accommodating trench-normal shortening. Across the Nicobar Neck, where obliquity passes beyond 45° , the thrust fraction drops abruptly to ~ 0.11 while the off-slab forearc fraction rises from ~ 0.15 to ~ 0.76 , marking a transition to a margin-parallel-dominated regime. Farther north, where obliquity exceeds $\sim 70^\circ$ and motion is nearly margin-parallel, normal-faulting earthquakes become the dominant population (~ 0.43), reflecting back-arc extension and seafloor spreading in the Andaman Sea. The seismic record therefore reproduces the same first-order transition as the slip vectors and the residual gravity field, with the mechanism style changing where the obliquity geometry changes.

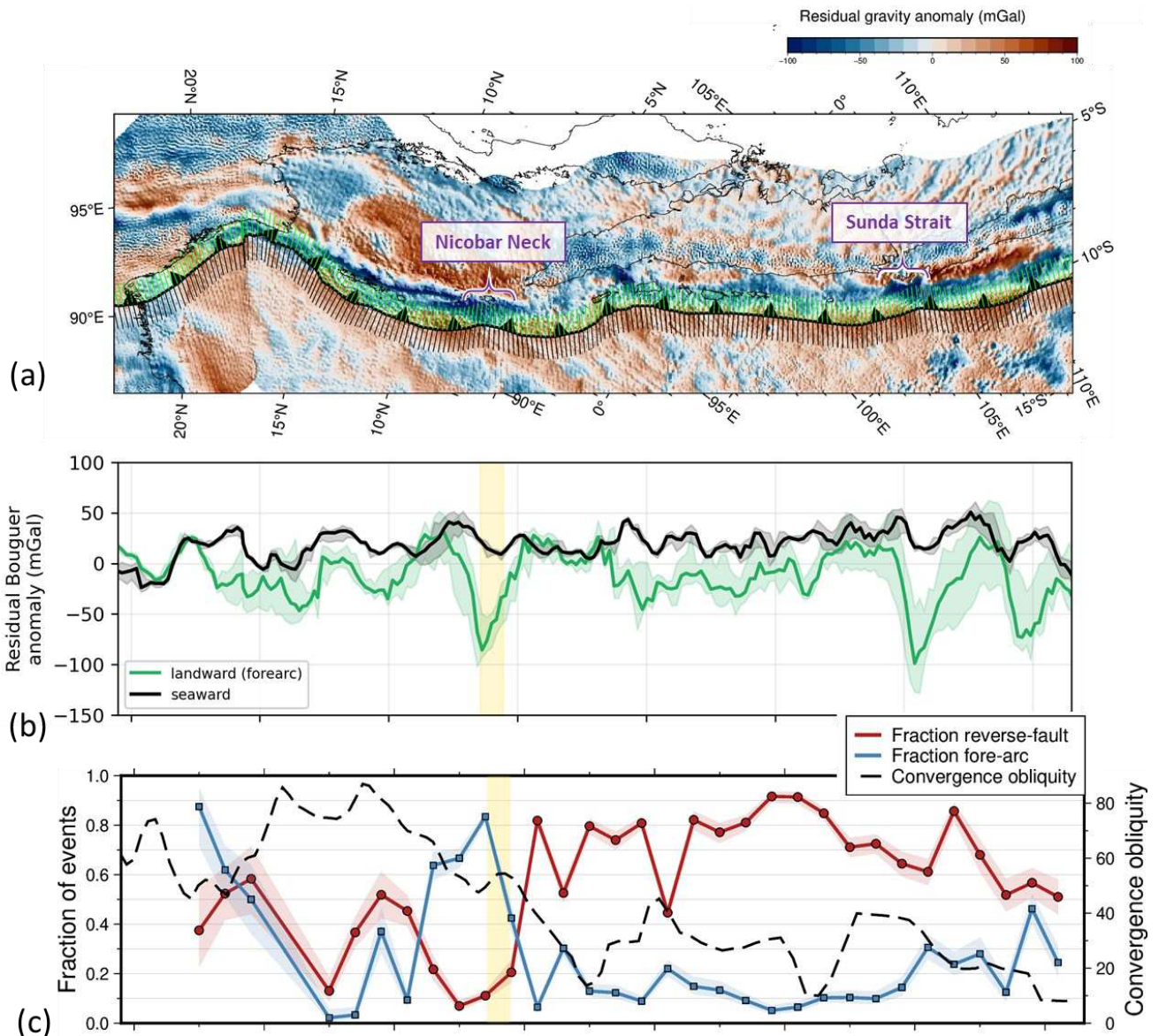


Figure 3. Along-trench variation in residual Bouguer gravity anomaly and seismicity character along the Sunda–Andaman subduction zone. (a) Map of the residual Bouguer gravity field (see Methods). (b) Along-strike profiles of the residual Bouguer gravity field plotted along the horizontal extent of rotated coordinate system of (a). Profiles are perpendicular to the trench, plotted for 120 km landward (green) and seaward (black) sides each. Two prominent negative anomalies in the forearc (green,

~100 mGal) are evident: one at the Nicobar Neck (~6–7°N), shaded yellow, and one at the Sunda Strait (~6°S). (c) Along-strike variation in earthquake mechanism (fraction of events; left axis) and convergence obliquity (degrees; right axis). The fraction of thrust/interface events (red) and off-slab fore-arc events (blue) and convergence obliquity (dashed-black) are plotted.

Discussion

Evidence of the kinematic boundary at the Nicobar Neck

The geodetic and slip-vector data require a kinematic break near Nicobar Islands in the forearc sliver plate, and the gravity data reveal a co-located, ~100 mGal low that can be attributed to low-density, fluid-rich upper-plate material. We therefore interpret the Nicobar Neck as a structurally distinct, mechanically weakened forearc domain (Fig. 4), in which serpentinisation of the mantle wedge and/or a long-lived fault zone lowers the bulk density and reduces the strength of the upper plate^{32,33}. The same interpretation applies to the ~100 mGal low at the Sunda Strait, which coincides with the trans-tensional boundary between the Sumatran and Javan forearc slivers and likely marks a comparably weakened, low-density forearc domain.

An important question for our interpretation is whether the boundary we resolve is an upper-plate feature, or the surface expression of a lower-plate process. S wave receiver functions infer a ~20 km offset in the base of the subducted lithosphere near ~8°N, interpreted as slab tearing and segmentation, although the imaging resolution is low²⁰. Sub-slab anisotropy potentially differs across the margin (with trench-parallel beneath the Andaman and trench-perpendicular beneath Sumatra), and has been interpreted as toroidal mantle flow around a slab edge or tear^{35,36}. Geodynamic modelling indicates that megathrust frictional strength peaks beneath northern Sumatra and decreases northward into the Andaman (both stronger than Java)³⁷. We take no position on whether these lower-plate processes operate beneath the Nicobar Neck; the evidence is itself equivocal, and resolving it will require further work. Our argument is that the Nicobar Neck transition is expressed independently in the upper plate, as a kinematic and gravimetric boundary that does not require, but is potentially complementary with, lower-plate disruption.

The 2004 Sumatra–Andaman earthquake as a compound rupture across the Nicobar Neck boundary

The 2004 Mw 9.1–9.3 rupture had peak coseismic slip (~15–20 m) concentrated offshore Aceh and diminishing into the Nicobar–Andaman sector, where slip was smaller, more oblique, and slower^{11,13,14}. At the Nicobar region specifically, the rupture transitioned from near-pure dip-slip to increasingly oblique motion (Fig. 1b,c). High-frequency radiation also weakened northward of the Nicobar Neck, and postseismic deformation (dominated by frictional afterslip) was disproportionately large, locally rivaling or exceeding the coseismic signal¹⁷. Sustained clustered aftershock swarms further distinguish the Nicobar segment as a zone of protracted post-rupture activity^{4,6,22}. These along-strike heterogeneities have been variously attributed to smooth variations in slab interface properties and thermal structure, to slab geometry and possible slab tearing^{20,21}, or to subducting topography^{38,39}. In our framework, the 2004 rupture is best understood not as a single rupture of a uniform plate interface, but as a compound event that propagated across two kinematically distinct forearc plate boundaries: the Sumatran segment in the south and the Andaman segment in the north, separated by the Nicobar Neck.

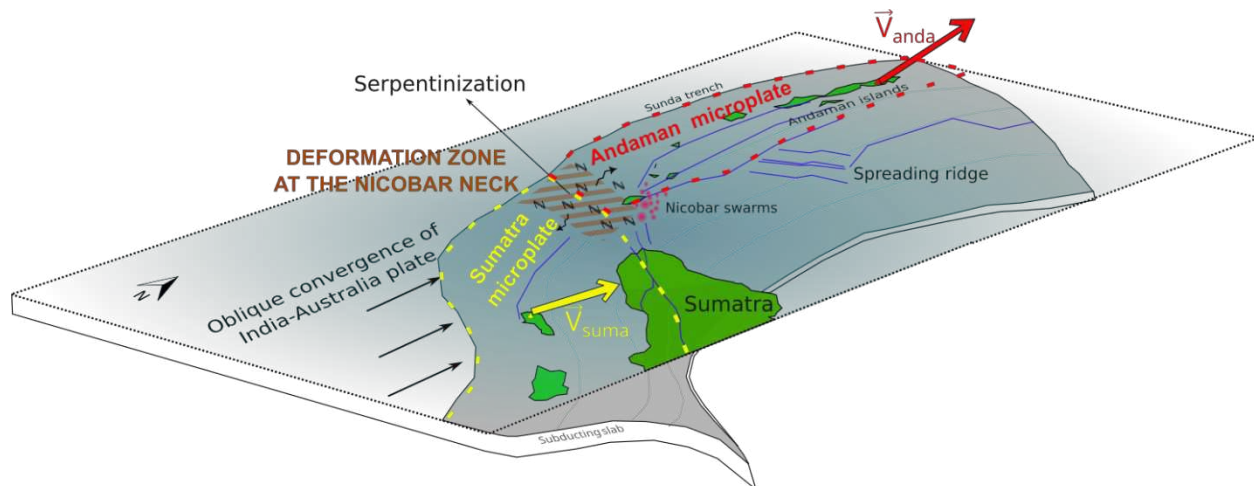


Figure 4. Schematic of two kinematically distinct forearc micro-plates. Red and yellow boundaries represent the Andaman and Sumatra microplates, respectively. $\vec{V}_{anda}$ (Andaman) and $\vec{V}_{suma}$ (Sumatra) are representative velocity vectors for two microplate locations, separated by deformation zone at the Nicobar Neck.

Whether a rupture can propagate across a major structural or kinematic boundary reflects a balance between the dynamic stress carried by the rupture front and the change in failure conditions across that boundary⁴⁰. Transitions are more likely to be crossed where the megathrust remains geometrically continuous and stress orientations are compatible, whereas sharp changes in interface geometry or obliquity can inhibit propagation. Globally, the small number of well-documented earthquakes that propagate across major tectonic boundaries, for example, the 2007 Solomon Islands event across the Australia–Woodlark–Pacific triple junction⁴¹ demonstrated that such behaviour, while not the norm, is part of the megathrust rupture repertoire. Boundary-crossing ruptures may be more common than presently appreciated, with consequences for the long upper-bound rupture lengths that should be considered in tsunami-hazard scenarios along long, segmented margins.

The Andaman–Nicobar Fault as an under-recognised seismic and tsunami source

Our block model requires the offshore Andaman–Nicobar Fault to carry 39 mm/yr of trench-parallel slip, roughly twice the rate of the onshore Sumatran Fault to the south. Despite this surprisingly large slip budget, no large earthquakes have been documented on this structure in the instrumental or historical record. The historical catalogue is sparse and dominated by megathrust events, so this absence may partly reflect incomplete documentation. The implication is that either the fault accommodates most of its slip aseismically, the slip is distributed across multiple subparallel structures within the Andaman forearc, or, the fault is locked over a substantial portion of its area and accumulates strain that will eventually be released seismically. We cannot at present discriminate between these possibilities, but each carries distinct implications.

If the slip is largely aseismic, the structure is consistent with a creeping continuation of the Sumatran Fault system into a mechanically weaker, more fluid-rich forearc. If slip is distributed, the Andaman forearc must contain a network of strike-slip structures collectively absorbing ~39 mm/yr. The principal mapped candidates are the West Andaman Fault and the Seulimeum strand of the Sumatran Fault system, but no single structure has been credited with rates of this magnitude. However, much of this area is not mapped with high-resolution bathymetry or seismic reflection surveys, and so the possibility of unmapped strike-slip structure remains. If, however, the Andaman–Nicobar Fault is largely locked,

the implied moment-accumulation rate is among the highest of any incompletely characterised fault globally. Its rupture potential would be a significant addition to regional tsunami hazard, a strike-slip event of comparable kinematics to the 2012 Wharton Basin earthquake but located within the shallow Andaman Sea, where any vertical component of slip (or lateral displacement of steep seafloor surfaces) could generate locally damaging tsunamis. Distinguishing between these end-members should be a priority for future regional geodetic densification, ocean-bottom seismometer deployment and marine geophysical imaging.

Implications for regional hazard

Existing earthquake and tsunami-hazard scenarios for the Andaman–Sumatra margin generally treat it as a single kinematic domain. Our results indicate that this picture is incomplete. The presence of a forearc plate boundary at the Nicobar Neck, the distinct loading directions and rates of the Sumatran and Andaman segments, and the substantial fraction of the regional slip budget carried on the under-characterised Andaman–Nicobar Fault, all imply that the seismic and tsunamigenic potential of the system is partitioned differently from what current models assume. Boundary-crossing ruptures of the kind we propose for 2004 are a feature of the system, not an exception.

The block-model framework we present is the missing kinematic baseline from which the dynamics, segmentation and hazard of the Andaman–Sumatra margin can be quantitatively reassessed. Within this framework many of the long-standing questions of the region, including the divergent responses of neighbouring fault systems to the 2004 stress pulse, the persistent Nicobar swarm activity, the location and behaviour of the offshore Andaman–Nicobar Fault, and the relationship between the Sumatran and Rakhine systems, can be approached more quantitatively than has previously been possible.

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Data and Methods

Geodetic data

We compile a regional GNSS velocity field for the Sunda–Andaman margin by combining published interseismic velocities from Sumatra²⁴, the Andaman and Nicobar Islands⁴², Myanmar²⁵, and Java^{43,44}. Velocities are expressed in ITRF2008 Sunda-fixed reference frame to facilitate direct comparison of forearc motion against the incoming Indian plate. Where reported uncertainties differ between studies, we adopt published 1-sigma values; where stations from different networks overlap, we adopt the velocity with the longer time series and the smaller formal uncertainty.

Earthquake slip-vector azimuths

Earthquake slip-vector azimuths (SVAs) provide a complementary, kinematically critical constraint on relative block motions. We compile SVAs from the Global Centroid Moment Tensor (GCMT) catalogue for the period 1976–2024. The SVAs are obtained for thrust as well as shallow crustal fore-arc and back-arc events. For thrust events, we selected the ones that satisfy two criteria: (i) thrust-mechanism events located on the plate interface, determined by comparing the centroid depth and nodal-plane orientation to the Slab2 geometry, with events lying within a ± 10 km of the slab surface and whose shallowly dipping nodal plane is consistent with the local slab dip; and (ii) magnitude $M_w > 5.5$, sufficient to produce a stable centroid solution. For each selected event the SVA is computed from the shallowly dipping nodal plane.

SVAs constrain the direction of relative block motion across the megathrust interface and are particularly useful in regions of sparse or uncertain GNSS coverage. We assign uncertainties of $\pm 10^\circ$ to individual SVAs, larger than the formal CMT precision, to absorb the contribution of moment-tensor scatter and slab-geometry uncertainty.

Fault geometry and block definitions

Block boundaries are defined from a combination of mapped surface fault traces, relocated seismicity, marine geophysical imaging and slab geometry. The major blocks included in the regional model are: the Indian plate, the Australian plate, the Sunda plate, the Burma plate, the Sumatra forearc sliver, the

Andaman forearc, and a newly introduced forearc block separated from the Sumatran sliver across the Nicobar Neck boundary at ~6–7°N. The Sunda megathrust geometry follows Slab2²⁷. The onshore Sumatran Fault follows mapped traces from previous studies^{24,45}. The offshore Sumatran Fault, the Andaman–Nicobar Fault, is mapped from marine seismic reflection imaging^{3,26}, bathymetry and from along-arc continuity arguments. The Sagaing Fault follows mapped traces from ref.⁴⁶. Boundaries within the Andaman back-arc spreading system follow refs.^{1,4}. Block boundaries that are not associated with mapped active structures are conservatively dashed in Figure 1 and are not assumed to be seismogenic. The Nicobar Neck boundary is a structural feature implied by the kinematic inversion. We test its placement and necessity directly by comparing the data fit of our preferred model geometry against four alternative models: (I) a boundary at Simeulue Saddle (the inherited placement from the global plate model¹⁸) instead of the Nicobar Neck; (II) Two forearc boundaries, one at the Nicobar Neck and the other at the Simeulue Saddle; (III) a forearc boundary at the Simeulue Saddle and a boundary in the subducting plate (in line with the Nicobar Neck), reflecting a slab tear–style geometry, (IV) a single continuous Andaman forearc sliver that extends unbroken northward into western Myanmar, rather than terminating where the Andaman–Nicobar Fault curves into the trench.

Kinematic block inversion

Block rotation rates and fault slip rates are estimated using the kinematic block-inversion code TDEFNODE⁴⁷, which simultaneously fits GNSS velocities and earthquake SVAs in a non-linear inversion. The model parameterises rigid-block rotation rates about Euler poles, with fault slip rates derived from the block-motion vectors and local fault strike. Coupling on the megathrust is parameterised as a depth-dependent locking fraction; coupling on upper-plate faults is parameterised to be constrained within 20 km depth.

Data weighting balances the relative information content of GNSS velocities and SVAs by scaling such that each dataset contributes a comparable fraction to the total $\chi^2/\text{d.o.f.}$ Our preferred model achieves a $\chi^2/\text{d.o.f.}$ of 2.35 (Fig. 2). The results from alternative models (I–IV) are provided in the supplementary material (Figs. S1–S4).

Model I ($\chi^2/\text{d.o.f.} = 2.64$) fits the SVAs poorly along the Andaman–Nicobar section, because relative motion across that segment is governed by the northern Sumatra block rather than by the along-arc partitioning resolved in our preferred model.

Model II ($\chi^2/\text{d.o.f.} = 3.4$) introduces an additional, independently rotating block bounded by the Simeulue Saddle and the Nicobar Neck. Adding this block spends further degrees of freedom, so the reduced chi-square carries a parsimony penalty. More importantly, the continuity of SVAs from Sumatra well past Simeulue argues against a significant kinematic break at that location.

Model III ($\chi^2/\text{d.o.f.} = 2.8$) produces a poor fit to the GPS data. Placing the boundary at Simeulue improves the SVA fit, but only at the cost of requiring effectively unphysical convergence velocities on the downgoing plate south of Nicobar in order to match the observed high GPS velocities in the Andaman.

Model IV ($\chi^2/\text{d.o.f.} = 2.44$) omits the northward termination of the Andaman segment and the western Myanmar section. Although its global misfit is only marginally higher than the preferred model, the fit to the GNSS velocities is systematically poor at the western Myanmar stations. This indicates the western Myanmar GPS velocities and Andaman GPS velocities cannot be explained by a single sliver plate. Notably, the northward termination of 2004 rupture roughly coincides with the termination of Andaman sliver plate boundary in our preferred model, although offshore data (currently unavailable) is needed to place it with more confidence.

Residual Bouguer gravity analysis

The Bouguer gravity field is taken from the WGM2012 global model⁴⁸ (computed using the standard crustal density assumption of 2670 kg m^{-3}). Following the approach of previous studies^{29,49}, we isolate short-wavelength forearc anomalies by removing a locally varying regional background. We construct 600 km long trench-normal profiles at 25 km spacing along the Sunda megathrust, sample the Bouguer anomaly along each by bilinear interpolation, and form the background field by applying a two-dimensional Gaussian filter to the stacked profiles, with smoothing lengths of $\sim 250 \text{ km}$ along strike and $\sim 60 \text{ km}$ in the trench-normal direction. Subtracting this background yields a residual Bouguer anomaly that preserves short-wavelength along-strike variations in forearc density while removing the long-wavelength signatures of the subducting slab, of crustal-thickness variation across the margin, and of regional flexure. Further, 120 km long landward and seaward side across-arc profiles are extracted to analyse the near-trench variation in Bouguer anomalies.

-----End of manuscript-----

Supplementary Files

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