# Probable role of sediments in blinding the rupture – lessons from the 2004 Sumatra–Andaman earthquake and implication for the Himalayan earthquakes

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**Several evidences show that during the 2004 Sumatra–Andaman earthquake, the rupture in the Andaman region did not extend up to the trench. Consistent with the earthquake processes at several subduction zones of the world, we propose that subducted unconsolidated sediments of Ganga and Brahmaputra rivers on the Indian plate make the shallow portion of the plate boundary interface behave aseismically and hence the rupture remained blind in the Andaman region. We propose that a similar situation exists in the Himalayan region where the subducted sediments of the Indo-Ganga plains under the Outer Himalaya limit the up-dip rupture propagation during great and major earthquakes. In such a case, rupture during great and major earthquakes may not extend up to the surface. Lack of evidence of surface faulting during the past major and great Himalayan earthquakes is consistent with this idea.**

**Keywords:** Great earthquakes, Himalaya, Indo-Ganga plains, 2004 Sumatra–Andaman earthquake.

THE 2004 Sumatra–Andaman earthquake nucleated near northern Sumatra and its rupture propagated northward for about 1400 km along the frontal arc[1,2]. One of the interesting features of this earthquake was that in the Andaman region, the rupture did not extend up to the trench unlike the Sumatra and Nicobar region, where it reached right up to the trench (Figure 1). Henstock *et al.*[3] and Singh *et al.*[4] presented convincing morphological and seismic evidence of rupture breaking the trench and reaching the surface in the Sumatra region. In the Andaman region, though there is no such direct evidence, it is evident from the modelling of the tide gauge, seismic waveform and global positioning system (GPS) derived coseismic offsets[5,6] that the rupture did not extend till the trench. It is also evident from the aftershocks of the earthquake[6]. Along its entire rupture length, aftershock clusters mark the up-dip edge of the rupture. In the Andaman region, the aftershock clusters systematically shift towards east, away from the trench leaving the Andaman frontal arc region near the trench almost devoid of the aftershocks. The Andaman segment did not generate tsunami, and one of the many reasons is that the rupture did not extend up to the trench in the Andaman region. It may be noted here that the recent strong aftershocks in the Andaman region that occurred near the trench, namely the 27 June 2008 Little Andaman ($M_w$ 6.6); 10 August 2009 Coco ($M_w$ 7.6) and 30 March 2010 Diglipur ($M_w$ 6.6) earthquakes, are typically intra-plate earthquakes, as their hypocentres lie in the subducting Indian plate. They probably occurred through reactivation in predominantly normal motion on the preexisting steep planes of the subducting 90°E ridge under the favourable influence of the coseismic deformation due to the 2004 Sumatra–Andaman earthquake and its ongoing postseismic deformation[6,7]. Thus these aftershocks did not occur on the plate boundary interface. In short, all these analyses and observations suggest that in the Andaman region, shallow portion of the subduction interface remained unruptured during the 2004 Sumatra–Andaman earthquake (Figure 1). It is possible that this shallow portion of the subduction interface is aseismic, as has been observed in many subduction

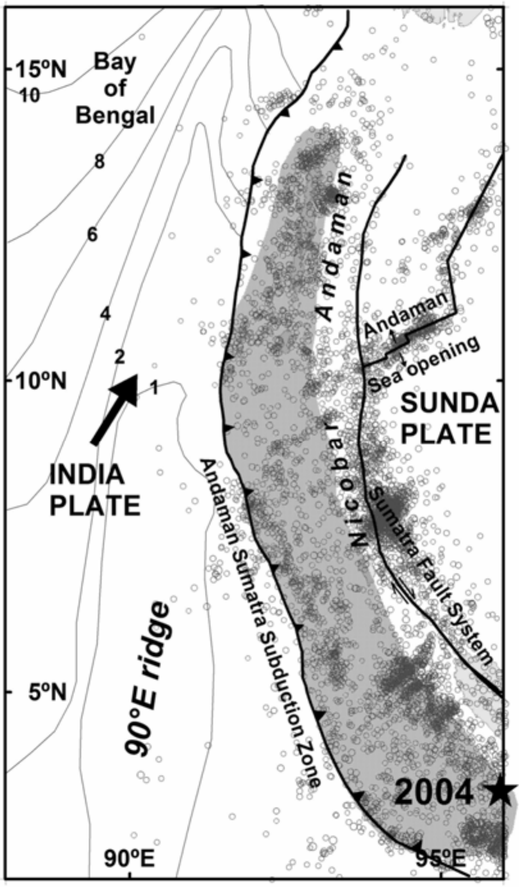

**Figure 1.** Rupture of the 2004 Sumatra–Andaman earthquake and its aftershocks. Approximate thickness of the Bay of Bengal sediments (in km) on the India plate is also shown[22]. In the Andaman region, note the absence of aftershocks near the trench and a systematic shift in the up-dip edge of the rupture towards east, away from the trench, implying that the rupture did not extend up to the trench in the up-dip direction.

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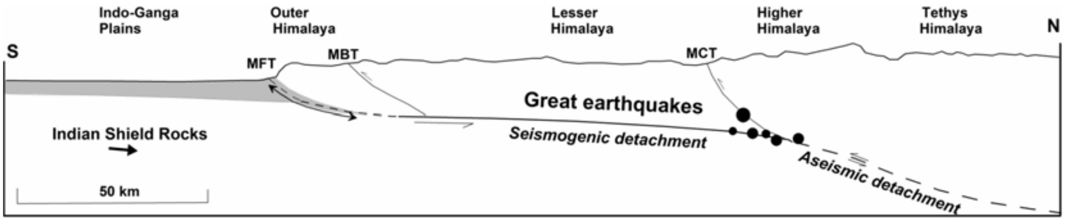

**Figure 2.** A schematic vertical cross-section across the Himalaya[13]. In this model ruptures of the great earthquakes occur on the seismogenic detachment under the Outer and Lesser Himalaya. Part of the detachment under the southern Outer Himalaya (marked with double verging arrow) may be aseismic due to subduction of unconsolidated sediments of the Indo-Ganga plains. Hence rupture of the great earthquakes may not extend in the up-dip direction up to the surface. Filled circles denote hypocentres of moderate magnitude earthquakes of the Himalayan seismic belt.

zones of the world[9], particularly the subduction zones where the sediment supply is abundant. It has been suggested that subduction of such unconsolidated sediments on the subducting plate may cause very weak coupling between the two plates[8–10] and may lead to aseismic motion at the shallow part of the subduction interface. The extent of aseismic motion may depend upon sediment thickness, and their physical and chemical properties. Deeper part of the subduction interface may be locked as the subducted sediments become compact at that depth and alter their mineral composition due to high temperature and pressure. During the earthquake, the unconsolidated sediments at shallow depth may slow down the speed of the incoming rupture front and may eventually terminate it before it reaches the surface[10]. In the Andaman region, sediment thickness deposited by Ganga and Brahmaputra rivers is of the order of about 6 km which decreases towards the south[11,12]. We propose that the subduction of these sediments on the Indian plate might have caused the shallow portion of the Andaman frontal arc to remain aseismic, and hence in the Andaman region, where there are thick sediments, rupture of the 2004 Sumatra–Andaman earthquake did not extend up to the trench.

We propose that a similar situation exists in the Himalayan region where evidences of surface faulting during the previous great and major earthquakes are largely absent and where thick sediments of Indo-Ganga plains lie over the subducting Indian plate. Great and major earthquakes in the Himalaya occur due to the underthrusting of the Indian plate beneath the Eurasian plate. According to the plate tectonics hypothesis and the concepts of subduction zone earthquakes, as applied to the Himalaya to explain the earthquake occurrence, the convergence in the Himalaya is accommodated through slip on the detachment[13]. The detachment is the surface between the underthrusting Indian shield rocks and the overlying Himalayan rocks. The part of the detachment that lies under the Outer and Lesser Himalaya is seismogenic and slips episodically during great and major earthquakes. It accumulates strain during the interseismic period when it is locked, which is released during the infrequent earthquakes through sudden slip. The detachment that lies under the Higher and Tethys Himalaya slips aseismically and does not contribute to strain accumulation (Figure 2). The great and major thrust earthquakes in the Himalaya are considered to have occurred on the seismognic detachment under the Outer and Lesser Himalaya[13–18]. In about past hundred years or so, three great or major earthquakes have occurred in the Himalaya, viz., the 1905 Kangra, 1934 Nepal–Bihar and 1950 Assam earthquake. In all cases it is assumed that the rupture of these earthquakes nucleated near the down-dip edge of the seismogenic detachment under the southern Higher Himalaya which propagated southward in up-dip direction along the detachment under the Lesser and Outer Himalaya. Although some recent palaeoseismological studies[19] suggest evidence of surface faulting near the up-dip termination of the rupture of previous great Himalayan earthquakes, there are no evidences of surface faulting during the well-documented great and major earthquakes of the past 100 years[13–15]. The seismogenic detachment under the Himalaya might be extending up to the deformation front marked with the Main Frontal Thrust. However, akin to the subduction zones with high sediment influx, we propose that the shallow up-dip portion of the detachment could be aseismic because of subduction of the 4–6 km thick sediments of the Indo-Ganga plains lying on the underthrusting Indian plate. Subduction of these unconsolidated sediments may cause weak coupling between the overlying Himalayan wedge and the underthrusting Indian shield rocks at shallow depths, which may not allow the great earthquake rupture to propagate up to the surface and hence in most cases the rupture of great earthquakes will remain blind under the Outer Himalaya. However, in the sediments starved regions, or the regions where thickness of the sediments is very less, rupture may propagate up to the surface. A good example which can be cited in this context is the 2005 Kashmir earthquake which occurred in the Indo-Kohistan Seismic Zone, near the northeastern Himalayan syntaxis[20]. The rupture of this earthquake extended right up to the surface[21]. Apart from many other possible reasons, we propose that the absence of sediments in that region could also be one of the reasons for surface faulting. Although there may be several other factors governing the absence of surface rupture during great and major earthquakes in the Himalaya, we propose that the subduction of sediments play an important role in not allowing the rupture to outcrop near their up-dip termination. Deep drilling in the Andaman and Himalayan regions through the plate boundary interface/detachment and geochemical analyses of the recovered sediment core and modelling of the effects of sediments in controlling the rupture characteristics may possibly provide further evidence in support of this hypothesis.

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ACKNOWLEDGEMENTS. Discussions with Kusala Rajendran, B. R. Arora, C. Subrahmanyam, U. Raval, S. Sinharoy and Bhaskar Kundu helped in building up the argument. Our work in the Andaman Nicobar region is financially supported by MoES.

Received 8 January 2010; revised accepted 23 April 2010

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# Linear sex ratio change in the clutch sequence of *Melopsittacus undulatus*

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**Sex ratio, though a significant trait in natural selection, was left open in Darwin's explanations of natural selection. The first explanation for sex ratio being equal was that of Fisher. Since then, several instances of deviation from equal sex ratio have been described both in invertebrates and vertebrates. *Melopsittacus undulatus* is an exotic monogamous pet bird. Male and female on becoming sexually mature form a lifelong pair bond. During the breeding phase of their life (3–4 years) the female lays several egg clutches. Since 2005, 120 pair bonded sets in a sequence of five successive generations were reared. Data on male/female ratio of the 120 pairs showed a definite linear pattern of sex ratio shift among the offsprings across the clutch sequence of the pair bonds. This sex ratio shift is found to be directly correlated to the physiological status and reproductive behavioural courtship display**

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