Bilham, R. (2006). Dangerous Tectonics, Fragile Buildings, and Tough Decisions, Science 31 March 2006: (311)5769, 1873 - 1875 DOI: 10.1126/science.1125176

When the going gets tough, it is merely a matter of time before rupture on a plate boundary gets going - again [1]. Stresses took 92 days from Indonesia's December 2004 Mw=9.2 earthquake to communicate across the island of Simeulue before they propelled a second great earthquake, this time to the south. Deformation in this 28 March Mw=8.7 Nias earthquake was captured in unprecedented detail by Briggs and his colleagues [1]who were documenting at that time the effects of its December predecessor,

Had the March Nias quake with its rupture length of 400 km occurred simultaneously with the earlier 1600-km-long neighbour, the total energy release would have been equivalent to a Mw=9.3 earthquake. But it didn't, and the causes for its hesitation now pose interesting questions, the answers to which have important consequences for nations in the path of plate collisions in SE Asia. Each end of this vast 2000-km long rip along the NE edge of the Indo-Australian plate now points suggestively at adjoining segments of the plate boundary that are themselves considered overdue for rupture [2,3]. Why did the rupture stop where it did, and could the plate boundary conceivably rip further?

Simeulue, an island similar in size and shape to Long-Island NY, lies above a wrinkle in the plate boundary, ground-zero to both the December and March earthquakes, and, apparently, a barrier tough enough to prevent throughgoing slip. Such barriers pin the ends of earthquake ruptures, yet no one is certain how they do it [3,4,5]. Slip often nucleates from them and/or to them, and occasionally straight through them, as was the case in contiguous great Japanese earthquakes, that sometimes rupture individually an at other times simultaneously [6]. Dual behaviour is vexing because it implies that barriers cannot always be relied on to arrest rupture, adding a chaotic element to forecasting the locations of likely future events. Barriers prevent small earthquakes from becoming big earthquakes at all scales, and many problems in seismology would benefit from a better understanding of their physics [7]. Serendipitously,the Simeulue barrier offered a veiled view of some of its secrets during the flurry of post-seismic deformation studies that followed December's earthquake .

The time history of vertical deformation there is recorded in the growth and kill fields of a million tiny corals [8]. In December the northern end of the island rose 1.4m. Near-shore corals responded to the twisting and bending of their island, dying where exposed to the tropical sun, and establishing new thriving colonies safely below the lowest tides. On 28 March 1.6 m uplift of the southern end of the island again checked their growth establishing yet lower, optimum growth levels from which Briggs and coworkers have pieced together an elegant 4-d time history of distortion of the island's shorelines. The complex deformation of Simeulue and its neighbouring islands were confirmed by data from GPS receivers placed throughout the islands and mainland monitoring the aftermath of the December event.

The measurements indicated clearly why the March earthquake, unlike the December catastrophe, produced no substantial tsunami - energy release was one fifth, rupture length one quarter, maximum uplift one half, and most of the uplift occurred on land rather than beneath the sea.

But the measurements also captured Simeulue in the act of impeding, or seeding, rupture. The corals tell of a 20 cm uplift of the foundations to their watery homes in 2003 during a Mw=7.3 earthquake. This modest ancestor to the two great earthquakes separated their slip areas but failed to trigger either event. Briggs and coauthors speculate that most probably the barrier corresponds to a scissors-like tear in the descending plate. Certainly elucidation of its structure and rheological properties are now of of great importance to understanding how it permitted earthquakes to nucleate to north and south, and may provide important clues applicable to earthquakes elsewhere.

Cornered?

These clues are more than of esoteric interest because numerous segments of SE Asia's plate boundaries are today sufficiently mature to slip in massive earthquakes. They include not only segments of the Sunda arc east of the March earthquake that are clearly ripe for failure [2, 3], but the region of the Indo-Burman ranges north of the December rupture, which has no recent history of significant slip, and where such slip must now be considered quite possible. They also include parts of the Himalaya and India's western plate boundary.

The Indian plate has been cornered by three killer quakes in the past 5 years: the Mw=7.6 Bhuj (≈18,500 dead), the Mw=9.2 Sumatra-Andaman rupture (≈300,000), and most recently the Mw=7.6 Kashmir earthquake (73338 dead as of January 2006). This fatal sequence has no precise historical precedent in the Indo-Asian collision zone, and because of this, no easy answer can be offered to the most obvious of questions - is this the end, or are more catastrophic earthquakes poised to occur?

The conservative answer to this question is that we are witnessing a coincidence, a random fluctuation in the timing of earthquakes that occur at intervals of hundreds of years. History reveals numerous of these coincidences, however, which suggests that there may be more these clusters than random chance: in Mongolia [9], in the northern US [10], and in the Pacific [11] Even in India a cluster of seven fatal earthquakes bracketed World War II leaving 50,000 dead in their wake (Figure 1). The comparative lull following this sequence has led to complacency in the rigorous application of earthquake resistant building code in India, despite the definition of a code in 1931 following the Mw=7.3 Mach earthquake that started the sequence.

The non-conservative answer is that several mature seismic gaps are known [12], and that the past five years have nudged these and neighbouring regions towards failure (Figure 1). The 1819 Allah Bund, and 2001 Bhuj earthquakes have stressed regions within striking distance of populations exceeding 20 million (Karachi and Ahmedabad). The 8 October Kashmir earthquake has stressed adjoining Himalayan regions where no great earthquake has occurred since the 16th century[13]. A 600 km long region of the central Himalaya has apparently not slipped since 1505 [14]. The more ancient the predessor the larger will be the future earthquake, and the recurrence of these Himalayan M>8 earthquakes would now threaten a dozen megacities in Pakistan and India. No M>8 earthquakes are known on the Chaman fault system that separates the western edge of the Indian plate from the Asian plate, and although it is possible that earthquakes here cannot exceed Mw=7.7, similar that suffered by Quetta in 1935, this earthquake is imfamous for holding the previous record (35,000) number of fatalities for an Indian subcontinent earthquake prior to last October's Kashmir earthquake.

The question of why these recent earthquakes stopped where they did, and whether the increased stresses that now lay seige to their rupture termination points will succumb to failure sooner than later, is one that regrettably cannot be answered. Why do contiguous ruptures tarry? Coulomb failure models can tell us clearly where to expect failure [3, 15] , but we remain clueless about the settings on the delayed-action fuses that have now been lit.

Tough decisions now face the politicians and urban planners of Sumatra, India, Pakistan, Nepal and Bangladesh. The simple solution, to toss money at monitoring technologies, is laudable but may be less effective in saving lives than community education. The proposed Indian Ocean tsunami warning system will cost many orders of magnitude more than telling schoolchildren and their parents about the causes and effects of tsunamis. The half million dwellings and 7600 schools that collapsed in Kashmir last October were almost entirely constructed in the past 20 years. They collapsed more from ignorance in assembly than from severity in shaking. Correctly assembled buildings survived intact as beacons to education. The 26 January Bhuj 2001 earthquake occurred in a region long designated at high risk from future shocks, yet earthquake resistant code here was so unevenly applied that the same percentage of the population was killed by building collapse as occurred in 1819 when earthquake resistant construction was unknown [16].

Most troubling of all is that although these three recent Indian plate earthquakes have raised public awareness of the precarious state of dwellings in their region, these earthquakes could have occurred in any of a dozen other locations surrounding the Indian plate with similar or worse effects. None of the earthquakes were direct hits on any of the numerous megacities that populate the plate. A >30% deathtoll is typical of a direct hit from a quite modest earthquake beneath a city like Tangshan, Mussaferabad or Balakot. Such an event beneath Karachi, Lahore, Lucknow, Benares, Dacca or Bombay would result in a disaster of unprecendented magnitude were it to occur, and it seems only a matter of time before it does [17]. The well-intentioned frenzy of earthquake resistant reconstruction that is now essential in the epicentral regions in response to the past 5 years of earthquake-collapse, is not attended by any similar frenzy of attention to reconstruction and retrofitting in the next dozen earthquake targets. That is not to say that urban planners are being complacent. New Delhi and other cities have started a retrofit campaign [18], but the costs are daunting and almost unimaginably expensive.

The diversion of funds to something as simple and fundamental as safe dwellings for citizens of the Indian plate, surely poses tough decisions for leaders of the several nations in the collision zone. It's tough luck for these citizens if these leaders decide, through indifference, to ignore this early-millenium triple wake-up call. Steady-state common sense appears to be the only solution to the world's earthquake vulnerable populations. Instead of a knee-jerk reaction to earthquakes, where interest and political brownie-points stale with a 6 month half-life, it is essential that the replacement of the ancient building stock of cities, be it a 20-year or 50-year turnover, be undertaken with mandatory earthquake resistant code. This won't stop the carnage immediately, but it will significantly reduce it, and it will make politicians and urban planners look less culpable than they do right now.

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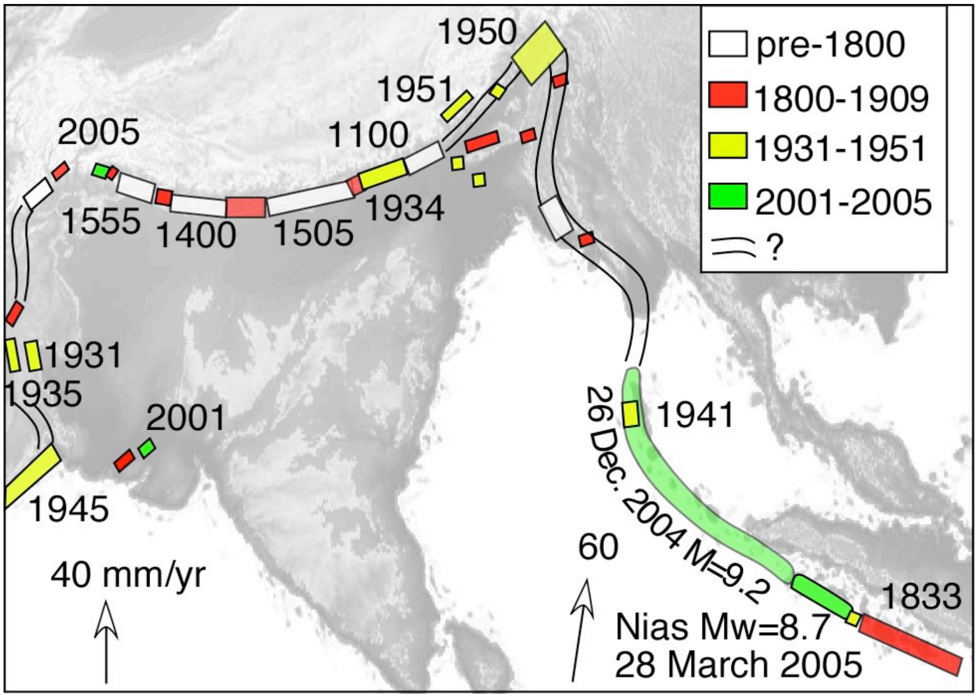

Fig. 1. Earthquakes on or near the boundary of the Indo/Australian plate. Data are incomplete where no dates are shown, and only the most recent known major earthquake is indicated elsewhere. Recent events (green) have loaded adjoining regions, and although previous earthquakes are not known to have triggered contiguous regions, clusters of events may have occurred in the 15th/16th centuries, and near the time of World War II. Was the 20th century cluster of fatal earthquakes (7.3<Mw<8.5) a freak coincidence, or a coherent response of the plate boundary to Indo-Asian collision? Could the 2001/5 earthquakes be part of a similar adjustment?