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ACKNOWLEDGEMENTS. We thank Dr Chandramohan, Former Deputy Director, HOD, BOD and Dr E. Desa, Ex Director NIO, Goa for providing the opportunity to carry out the work. D.F. also thanks Prof. G. N. Nayak, HOD Marine Sciences, and Goa University for providing the necessary facilities to carry out the dissertation. An anonymous referee helped improve the contents of the text. This is NIO contribution no. 4080.

Received 2 July 2005; revised accepted 5 December 2005

Historic submergence and tsunami destruction of Nancowrie, Kamorta, Katchall and Trinket Islands of Nicobar district: Consequences of 26 December 2004 Sumatra–Andaman earthquake

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The 26 December 2004 Sumatra–Andaman earthquake is one of the largest plate-boundary earthquakes in the recent seismic history of the world. This earthquake has also generated the greatest tsunami run-up and coastal devastation ever recorded. Our field study at four major islands of Nancowrie group of Nicobar District in Andaman and Nicobar archipelago has revealed that the islands are vertically subsided by 1.0–1.75 m with the submergence of coastal land area by thousands of square kilometers. It is also suggested based on our field observations that societal and socio-economic rejuvenation of the islands will need resurvey of entire topography of the islands, coastal bathymetry mapping and identification of newly developed ecological regimes. We have also prepared maps of the coastal submergence for these islands using field observations and remote sensing in this paper. Based on the present field study and geodetic studies by other workers, differential tilting of the Andaman micro-plate is also inferred.

Keywords: Coastal submergence, Nancowire group, Nicobar Islands, tsumani.

THE Sumatra–Andaman earthquake of 26 December 2004 occurred on 6:29 IST (0.58 UTC) at the subduction plate boundary where the Indian and Australian plates converge and plunge below the Sunda plate. The *Mw* 9.3 (revised magnitude) plate boundary earthquake is located at 3.7°N and 95°E off the Sumatra coast near the island of Simuelue with a focal depth[1] of ~15 km. The earthquake is considered as the second largest ever recorded on the globe, and it caused wobbling of the earth's axis[2]. Distribution of aftershocks reveals that the rupture plane is about 1200 km long extending to the north, up to the Andaman and Nicobar Islands[3,4]. Immediate observation by the satellite imageries confirms large-scale subsidence around the epicentral zone and many kilometers north of it, in the Andaman and Nicobar Islands. The present study on preliminary documentation of ground deformation and tsunami effects on the Nancowrie group of islands of Nicobar district, was carried out based on satellite imageries. These imageries provide information on inundation of the islands and site-specific details of subsidence and tsunami run-ups at each location. An attempt is also made to prepare preliminary maps that show the coastal area of subsidence on four islands – Nancowrie, Kamorta, Katchall and Trinket of the Nancowrie group. These inundation maps could be used in future planning of developmental activities in these islands. The coastal villages mentioned later and farm fields on all four islands can be identified as areas likely to be submerged in the future. A similar study on the other islands of Andaman and Nicobar groups could reveal the tectonic behaviour of the Andaman micro-plate.

The Andaman and Nicobar groups of 349 islands, situated in the Bay of Bengal, are separated by the ten-degree channel (Figure 1). The rocks of these islands are believed to have been formed from the sediments scraped off the descending Indian plate interleaved with ophiolites from the ocean floor beneath the Bengal Fan. Detailed geology of the Andamans has been described by Oldham[5] and Tipper[6]. The earliest rocks found in Andamans are Upper Cretaceous clastics with ultramafic and mafic intrusives. A complete succession of Tertiary rocks is found in the Andaman group of islands. Pleistocene sand beds,

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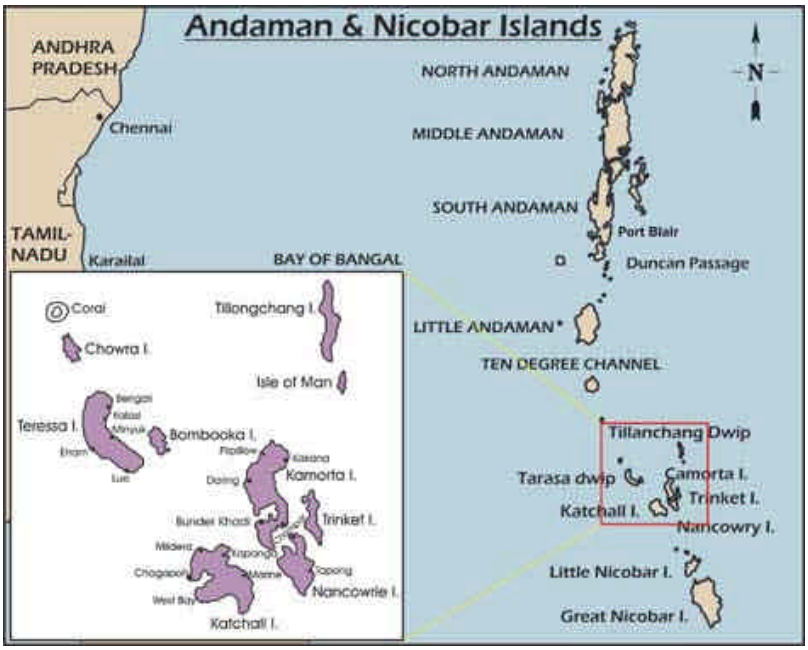

Figure 1. Location map of Nancowrie group of islands of Nicobar district in Andaman and Nicobar Islands that are separated by the ten-degree channel.

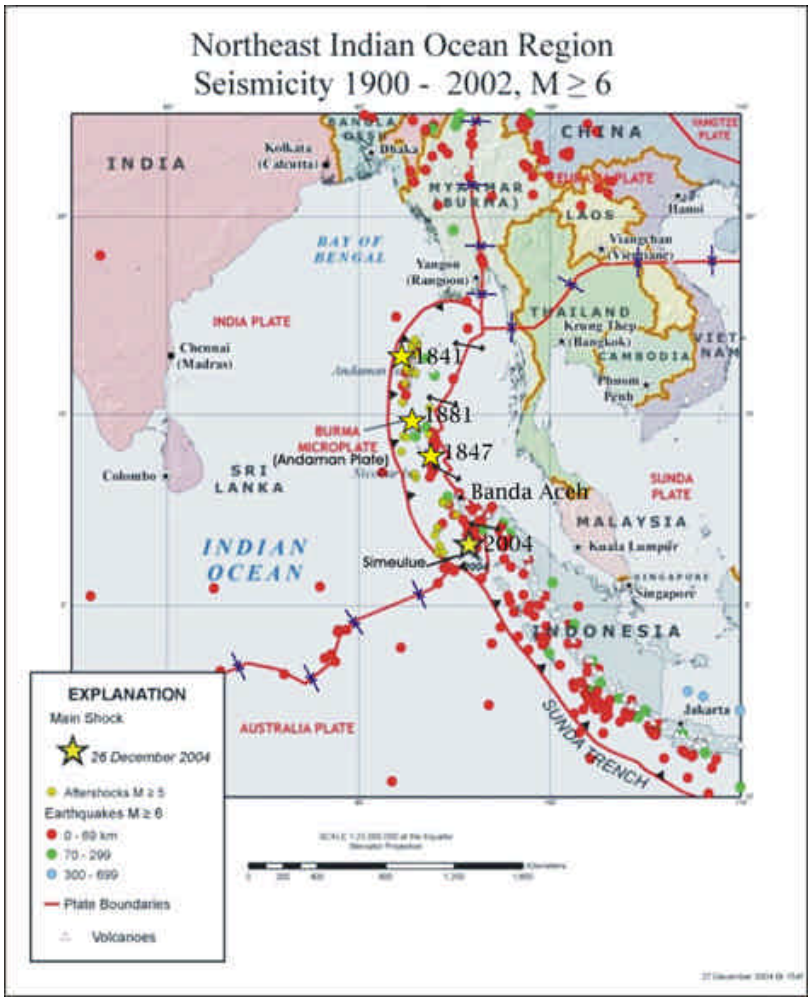

Figure 2. Tectonic map of Southeast Asia showing major plate boundaries and epicentral locations of 24 December 2004 earthquake and also of three historic earthquakes[14].

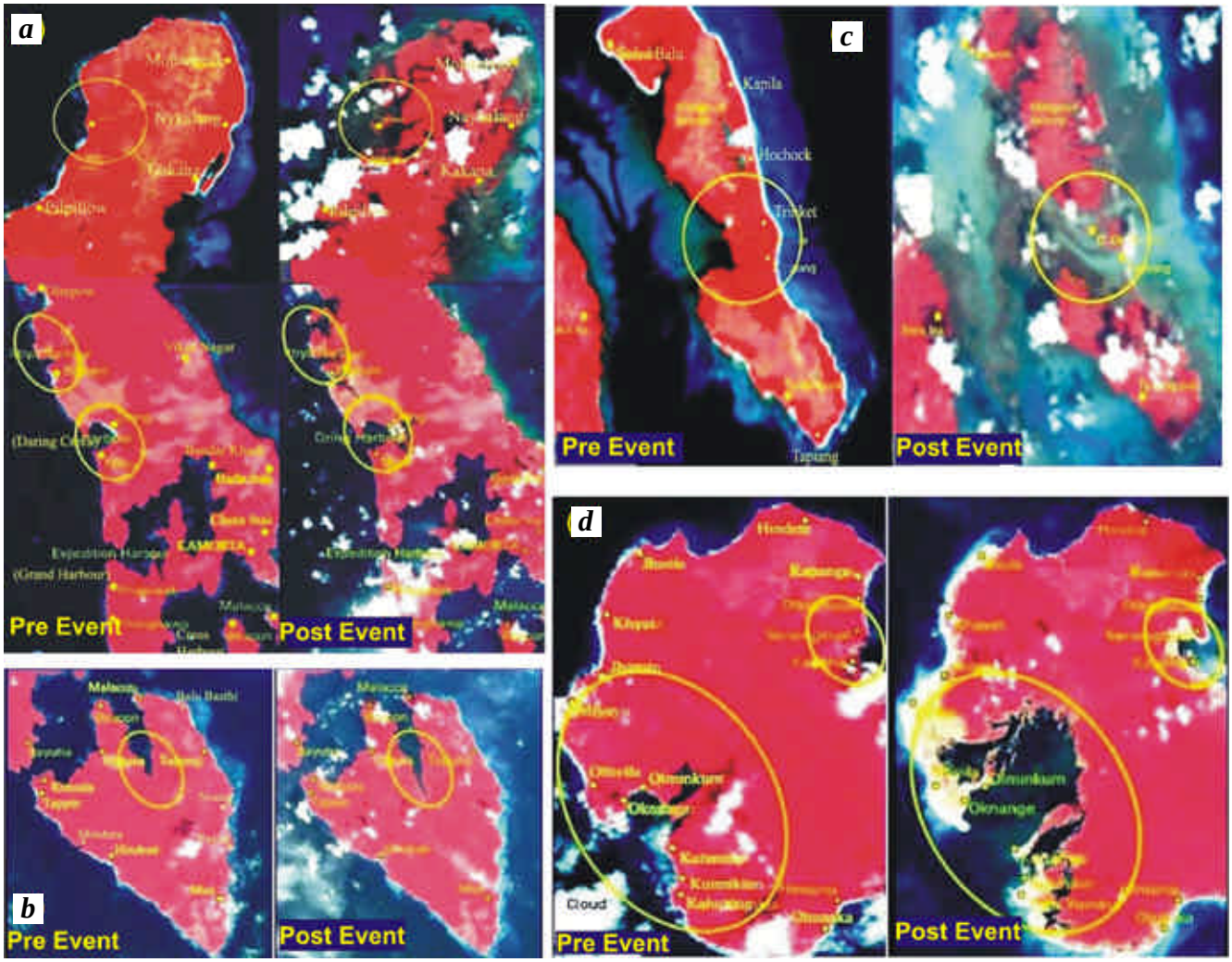

Figure 3. Pre- and post-earthquake satellite imageries of Kamorta (***a***), Nancowrie (***b***), Trinket (***c***) and Katchall (***d***) islands showing submergence of coastal regions and changes in topographic conditions of each island[17].

coral banks and raised carbonate platforms are the youngest formations[7]. The rocks are highly folded and faulted with regional strike of N–S and NNE–SSW, in response to N to NE convergence[8].

Complex tectonic setting of the islands is due to the presence of subducting Indian plate to the west, spreading centres and strike-slip faults to the east of the islands (Figure 2). In addition, the Andaman–Nicobar ridge acts as a small tectonic plate that has been referred to as the Burma plate by Curray *et al.*[8,9] and as the Andaman plate by Dasgupta[10] (Figure 2). In recent and historic times, only three high-magnitude earthquakes are known to have occurred in this region[11–13]. These were in 1847, 1881 and 1941. The main shock of 26 December 2004 was followed by several aftershocks[3,4,14]. The 2004 earthquake may be regarded as a mega-thrust, plate-boundary type, that triggered a tsunami which travelled across the world's oceans, affecting also the Indian coast. Primary surface deformation features are not traceable because of the submarine plate-boundary earthquake; however secondary ruptures on the ground can be traceable at many places. An immediate and apparent effect of this earthquake is a significant subsidence and uplift of the coast and large-scale reduction of the land area. Here we discuss some of these effects at Kamorta, Katchall, Nancowrie and Trinket Islands of Nicobar district.

Nancowrie group of islands comprises of Nancowrie, Kamorta, Trinket, Katchall, Taressa, Chowra, Bombooka, Isle of Man and Tillang Chong Islands (Figure 1). This group has limited number of beaches, but most of the coasts resemble drowned river valleys or rias. Creeks at Champin, Daring and Itthiya in Kamorta truly reflect successive subsidence since a long time in geological history, as strong coastal erosion has created sea caves. Also seen are miniature cliffs of alluvial and colluvial fans that have undergone erosion after submergence. The present earthquake is a vital evidence of subsidence of this archipelago.

The pre- and post-earthquake satellite imageries and aerial photographs of Kamorta, Nancowrie, Katchall and Trinket Islands show coastal inundation and drying-up of

coastal mangroves and tropical forests (Figures 3 and 4 *a*–*c*). Places like Kamorta, Daring Creek, Bada and Chhota Inak, Olinpow, Ohia, Manjula, Neecha-Tapu, Pilpillow, Upper-Tapu, Kuikya, Kakana, Munak, Ramjoo, Payuha and Changuha are amongst the most affected coastal villages in Kamorta Island, while Champin, Hitui, Malacca, Hinnunga, Balubasti, Altheak, Tapong, Niyak, Payak, Mus and Hindra in Nancowrie Island are strongly affected by the subsidence phenomena and tsunami run-up (Figures 3 and 4 *a*). Katchall has two major bays respectively, in the east and west, while there are wide bays each at the north and south too. The western bay, facing the open sea of the Bay of Bengal has been hit severely. Further the coastal land is almost flat with low relief, while the bay on this side is swampy, covered by dense mangrove forests. All these conditions could be responsible for large-scale devastation. The western section of a 25 km long road from the east bay jetty to the west bay via Kapanga, Mildera, Beachdera, Jhoola, Jhansin, Hitlat and Oltivila has almost vanished or submerged. Pre- and post-earthquake satellite imageries of a small, elongated and almost featureless Trinket Island shows its blatant trisection in the post-earthquake topography (Figure 3 *c*). The three distinct islets are now connected by low-lying sandbar deposits 20–30 m wide, which used to be a strip of fertile land of 3–4 km width, entirely covered by coconut and other tropical vegetation (Figure 4 *b*). Places which are severely affected by the tsunami and submergence on this island are Trinket, Kapilla, Safed Balu, Tapiang and Hochock.

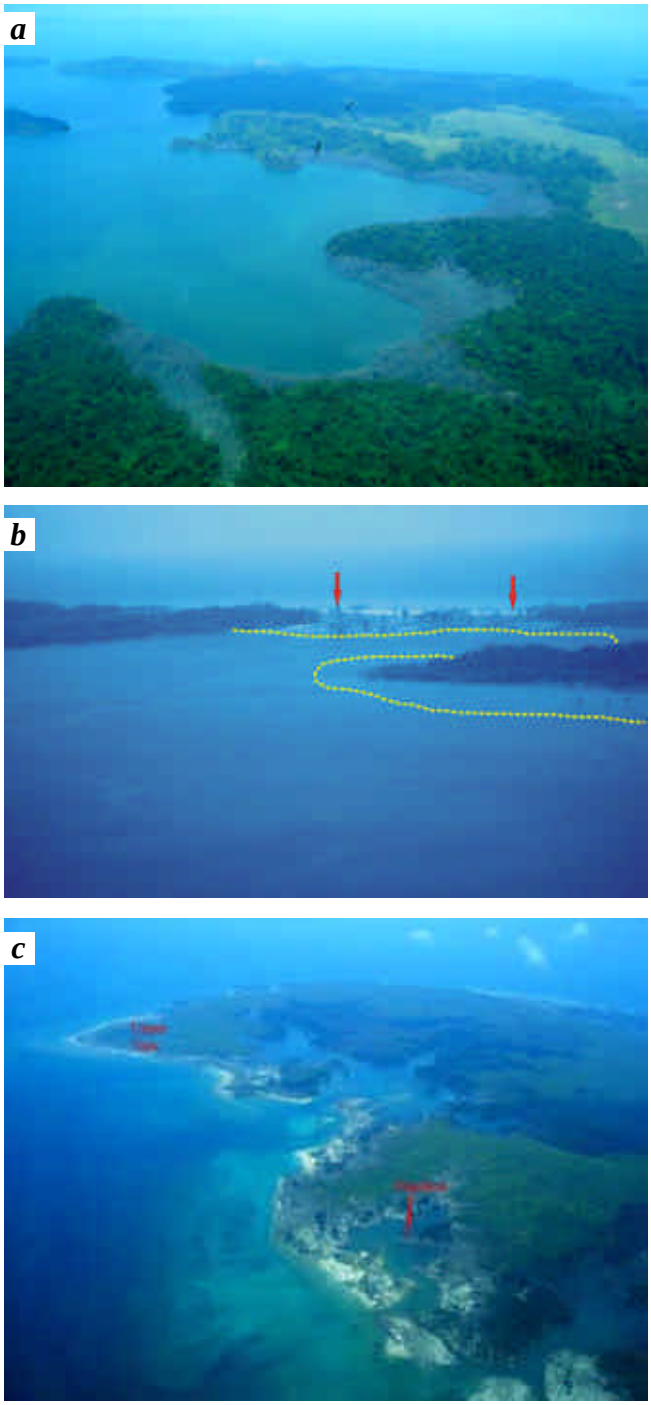

Figure 4. ***a***, Aerial view of Kamorta Island. Dried coastal forests are seen in discernible grey colour along the shores of the Grand Harbour. ***b***, Aerial view of Trinket Island. Arrows mark the sandbar bridge that connects southern and middle part of the island. The narrow strip of sand bar is 20–30 m in width shown closely in Figure 5 *e*, *f*. Yellow lines indicate previous coast line. ***c***, Aerial view of northern part of Kamorta Island distinctly showing coastal inundation in the creeks and submergence of sandy beaches in the western part. The flat land at Pillpillow is under the water, with most of the vegetation having been destroyed.

Field and aerial studies of each island provide vital support to the fact that the present group of islands has been sunk by varied degrees on both the east and west coasts. The water level at Daring creek and Itthiya harbour is increased by 2.0 m. This is responsible for the transgression of 2.5–3.0 km of northern and northeastern coastal flat land that once used to be a fertile land, while at Pilpillow and Upper Tapu, new creeks have come into existence (Figures 3 *a* and 4 *c*). The coastal and creek mangrove ecosystem is entirely lost due to subsidence of low-lying and flat land in the north and northeastern part of the Daring creek (Figure 5 *a*). The Kamorta jetty acts as a reference point for the assessment of coastal subsidence, because the way connecting the jetty and the port has been innundated by 0.75–1.0 m (Figure 5 *b*) during high tide. This suggests 1.5–1.75 m subsidence of the path collectively by overall subsidence of the island and gravity slumping and lateral spread at the site. The total subsidence found during the present field study also matches with the results of GPS measurements by Jade *et al.*[15,16] at Car Nicobar that gives 1.1 m vertical and 6.49 ± 0.009 m horizontal displacement.

Field observations at Champin, Hitui and Balubasti villages in Nancowrie Island suggest that most of the coastal coconut and betel-nut plantations and clusters of tribal settlements have been affected. Champin jetty has been submerged by 1.5 m and has developed irreparable cracks, which have made it entirely unusable. Taking a traverse from the east bay to the west bay in Katchall, it is

Figure 5. ***a***, North and northeast facing view near the mouth of Daring Creek. From the foreground to the distant background the entire fertile flat land is submerged, but a narrow strip of land has remained. ***b***, Photograph of a way to Kamorta jetty. Note the knee to waist-deep water during high tide, which indicates submergence of the coast by 1.5–1.75 m. ***c***, A damaged school building built near the eastern bay shore in Kapanga village, Katchall. ***d***, Photograph showing destructive effect of tsunami in the western coast of Katchall, Jhoola village, where dense coastal forests are changed to coastal deserts. ***e***, Close view of sand bar bridge indicated by arrows in Figure 4 *b*. The flat and featureless Trinket land under subsidence is seen in the foreground, while Andaman Sea is seen in the background. Note uprooted trees and their stumps in the foreground which were large coconut farms and coastal forests. ***f***, Close view of a narrow sandbar bridge connecting south and middle segments of Trinket Island. Note the devastated ground in the right and Andaman Sea in the left.

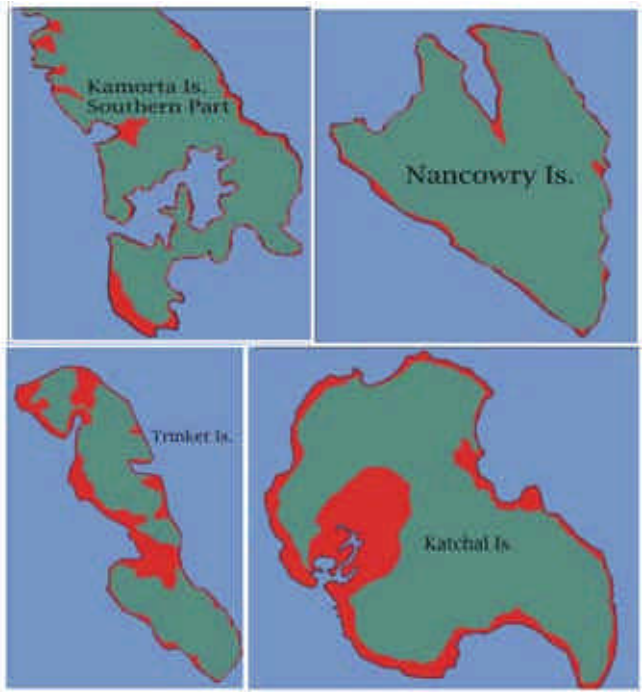

Figure 6. Revised map of Nancowrie group of islands (the study is confined to Kamorta, Nancowrie, Katchall and Trinket Islands), showing coastal area under submergence in red colour (not to actual scale).

observed that the village Kapanga is entirely ruined leaving some walls of cement and concrete buildings made for hospital and school (Figure 5 *c*). The east bay area has expanded twofold, where the old jetty has also been submerged. Jhoola, Jansin, Hitlat, Kalupong, Kamriak, Katahua, Miyayu and Chongipon villages located 0.5 to 1.0 km from the coast in the west and southwest have entirely vanished from the map. Jhoola in the eastern coast has been wiped out leaving a dreary ground of dilapidated, uprooted and dried trees (Figure 5 *d*). The west bay swamp is engulfed and transgressed by nearly 4 km. Calculating the ground slope and aerial subsidence (transgression), the land of Katchall is found to be submerged by 2.0–2.5 m.

Trinket is one of the worst affected islands, where the land is reduced manifold, leaving only slender sandbars that are constantly being washed away and reconstructed by wave actions (Figures 3 *c* and 5 *e*). Taking the drowned houses and coconut trees as markers, it is inferred that land submergence in Trinket Island is found to be between 1.5 and 1.75 m. A natural sand bridge that connects the south and middle island is >3.2 km long and was 2.0 to 3.0 km wide before the earthquake (Figures 3 *c* and 5 *f*), which has been slandered by 20–30 m only.

The field study at Nancowrie group of islands reveals that the islands are vertically submerged by 1.0–1.75 m, while the coastal area is reduced by thousands of square kilometers which need to be surveyed. The infrastructural and developmental planning of the islands will also need detailed mapping and surveying of each island, while development and restoration of coastal ecosystem will also require a detailed understanding of the ecological conditions on this group of islands. As an outcome of the present study, tentative and most preliminary inundation maps have been prepared that indicate subsidence and major changes in the coastal profiles of each island (Figure 6). It can be inferred from the present field study and supportive GPS study[15,16] that during this megathrust earthquake, the Andaman micro-plate has been tilted towards the Andaman back-arc area in the east, while it uplifted exactly above the subduction plate boundary in the west.

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ACKNOWLEDGEMENTS. Financial support from the Department of Science and Technology, New Delhi is acknowledged. M.G.T. thanks the islanders of Andaman and Nicobar Islands who guided and supported him in the field. I also thank the anonymous reviewer for suggesting improvements.

Received 5 July 2005; revised accepted 3 January 2006