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Sheltered coastal environments as archives of paleo-tsunami deposits: Observations from the 2004 Indian Ocean tsunami

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ABSTRACT

The 2004 earthquake left several traces of coseismic land deformation and tsunami deposits, both on the islands along the plate boundary and distant shores of the Indian Ocean rim countries. Researchers are now exploring these sites to develop a chronology of past events. Where the coastal regions are also inundated by storm surges, there is an additional challenge to discriminate between the deposits formed by these two processes. Paleo-tsunami research relies largely on finding deposits where preservation potential is high and storm surge origin can be excluded. During the past decade of our work along the Andaman and Nicobar Islands and the east coast of India, we have observed that the 2004 tsunami deposits are best preserved in lagoons, inland streams and also on elevated terraces. Chronological evidence for older events obtained from such sites is better correlated with those from Thailand, Sri Lanka and Indonesia, reiterating their usefulness in tsunami geology studies.

1. Introduction

The devastating Indian Ocean transoceanic tsunami had no known historical precedence. Prior to 2004, little or no paleo-tsunami research had been done in the region. Although storms and cyclones have been frequently documented in the Bay of Bengal, their deposits were not researched on until after the 2004 Indian Ocean tsunami. The variety of deposits formed by the 2004 tsunami in various coastal environments help to understand environments of deposition and assess their preservation potential. A decade of research has generated evidence for two paleo-tsunamis in the Indian Ocean during the last millennium (Jankaew et al., 2008; Monecke et al., 2008; Ranasinghe et al., 2010; Prendergast et al., 2012; Brill et al., 2012; Rajendran et al., 2013). Search for more evidence is continuing.

Reconstruction of tsunami history is based on evidence preserved from coseismic subsidence (Atwater, 1987); tsunami deposits (e.g. Peters and Jaffe, 2010); and historical documents (Atwater et al., 2005). Coseismic evidence is limited to regions within the rupture zone but tsunami deposits are formed also at distant and transoceanic locations, all of which are used for reconstruction of regional tsunami history (see Goto et al., 2012 for a review). Paleo-tsunami deposits close to the subduction zone are often associated with coseismic features such as subsided coastal marshes (Atwater, 1987). Tsunami deposits at distant transoceanic locations are not associated with any land deformation and in the storm-prone regions storm deposits are also likely to be preserved in the coastal stratigraphy. The variety of coastal environments close to and far from the rupture zone of the 2004 earthquake provided a template and the previous events have now been dated as ~500 and ~1000 years old (Rajendran et al., 2013 and references therein).

Some morphological settings are particularly favorable for the deposition and preservation of tsunami deposits and here we cite a few examples, based on our observations from the 2004 earthquake. An inland stream for example carries tsunami debris far inland and they get preserved within the stratigraphy because the region is away from the influence of usual coastal surges. We refer to such sites as "sheltered" or "protected" and as illustrated from some examples, the ages of the pre-2004 Indian Ocean tsunamis obtained from these sites are in the same bracket with those from Thailand, Indonesia and Sri Lanka. Due to their inland locations, storm origin can be excluded with more confidence for these inland sites. For storm-prone regions, a comparative study of tsunami and storm deposits make their characterization easier.

Field reports on the storm deposits from the east coast of India prior to 2004 are sparse and the importance of studying the storm deposits was recognized only after this event. The available historic

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data provided by the India Meteorological Department (IMD, 2008) records show that the Tamil Nadu coast of India has a history of storms, but they usually affect only a few tens of kilometers along specific parts of the coast. Wave heights are usually within 3 m, although heights up to 6 m have been recorded at locations close to 10°N (Fig. 1; Dube et al., 1994, 1997; IMD, 2008). A cyclonic storm that made a landfall on the southeastern coast of India during 2011 (Thane) offered a unique opportunity to study how deposits from both these coastal processes are formed at some locations on the east coast (Srinivasalu et al., 2012). Storm records of the India Meteorological Department (IMD, 2008) suggest that since 1891 the Andaman and Nicobar Islands (A&N) have been barely affected by any storm surges. In the absence of any systematically documented evidence on inundation limits and details on the nature of storm deposits along the Indian coast, we use observations elsewhere (e.g. Morton et al., 2007).

1.1. Sheltered sites as repositories of paleo-tsunami deposits

Importance of sheltered sites such as coastal lakes; marshes, lagoons and streams have been widely recognized in tsunami geology (e.g. Minoura et al., 1987; Minoura and Nakaya, 1991; Minoura et al., 1994; Kelsey et al., 2005; Matsumoto et al., 2010). These depositional environments are isolated from regular beach processes and some, by virtue of their elevation or distance from the coast are also beyond the reach of storm surges, but accessible by tsunami. The surface of deposition is also an important factor for preserving distinct and recognizable contacts with the pre-existing surface. For example, tsunami sands deposited over sandy beaches may show poor contrast with the underlying strata where as those deposits within lagoons or swales may develop on mud or fine silt. Sands deposited over vegetated tidal marshes are often preserved as sand-peat couplets making their identification and age determination relatively easier (Nelson et al., 1996).

There are several examples of geomorphologic settings that make sheltered environments and here we illustrate two cases. Retreated beaches forming ridge-swale topography is an ideal setting for the deposition and preservation of tsunami deposits (Fig. 1a). If their locations are beyond the reach of storms, there is a higher chance of attributing tsunami origin to the high-energy deposits found at such locations. The vegetation within the depressions destroyed by the tsunami develops as a layer of peat or peat-rich horizon within the swale. This would be a good indicator for tsunami deposition and the peat layer may be treated as part of the event horizon (e.g. Jankaew et al., 2008; Rajendran et al., 2013). Elevated beach terraces that are not reached by storms are also open to tsunamis, where tsunami may deposit large size debris. Streams also transport rolled up debris to inland locations, where they would remain preserved (Fig. 2b). Along coastal regions that are not storm-prone, inland transportation of boulders is possible only through tsunami and such sites are also treated as protected. In this paper we revisit some sites in the Andaman group of islands (Hut Bay, Port Blair, Interview Island and East Island) and Kaveripattinam (on the east coast) to highlight how

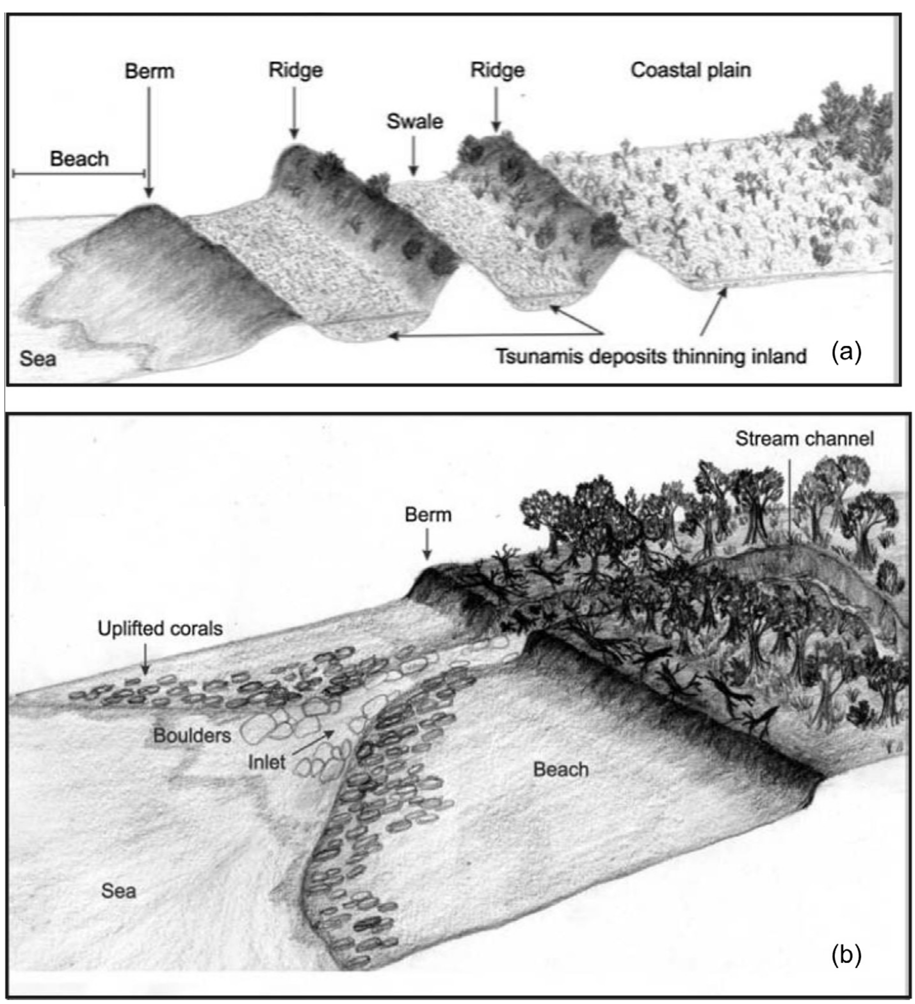

Fig. 1. Sketches showing examples of typical sheltered environments discussed in this paper; (a) A swale-ridge topography and (b) elevated beaches and inland streams.