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Marine Geology 240 (2007) 65 – 75

MARINE GEOLOGY
INTERNATIONAL JOURNAL OF MARINE GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS

www.elsevier.com/locate/margeo

Erosion and sedimentation in Kalpakkam (N Tamil Nadu, India) from the 26th December 2004 tsunami

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Received 26 August 2006; received in revised form 18 January 2007; accepted 1 February 2007

Abstract

Laterally extensive sand sheets deposited by the 26th December 2004 Asian tsunami provide a valuable modern analogue for comparison with wash over deposits of unknown origin. In many places on the east coast of India, distinct deposits of marine sand drape the landscape and overlie the muddy soils of the coastal plain. This paper discusses detailed measurements of coastal topography, tsunami flow height, and deposit thickness made at Kalpakkam, India. Five transects were examined in detail to assess the sedimentology and spatial distribution of the tsunami deposit. Near the mean water line, the tsunami eroded approximately 10–25 cm of sand from the beach and berm. At Kalpakkam the sand sheet deposited by the tsunami begins 25 m from the shore extending 420 m inland where it becomes thin and patchy approximately 30 m from the limit of inundation. In some cases, the deposit consists of 2 to 4 normally graded units, with coarse sand near the base and fine sand at the top, a characteristic observed in many tsunami deposits worldwide. In many places, the deposits also contain numerous thin laminated units, a characteristic usually associated with storm over wash. The presence of the laminated beds is indicative of the complexity of tsunami sedimentation on the coast. Such observations are essential to the formation of definitive facies models for palaeo-overwash studies that are capable of distinguishing between sediments deposited by storms or tsunami.

Keywords: Tsunami deposit; Kalpakkam; coastal sedimentation; erosion; sedimentology

1. Introduction

The term tsunami is a collective noun, meaning that it may be used as singular or plural, that is derived from the Japanese word meaning harbour wave (Dawson, 1994; Bryant, 2001). Often originally called tidal waves, the phenomenon has little to do with tides and the term refers to waves which have a characteristically long wavelength. They can now be generally defined for the scientific literature as long period waves generated by a sudden displacement of the water surface (De Lange and Fraser, 1999). Such waves have sufficiently high velocities and bed shear stresses to suspend and transport large quantities of sediment (Gelfenbaum and Jaffe, 2003). Within the geological timescale, tsunami can be

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0025-3227/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.margeo.2007.02.003

considered low-frequency, high-magnitude events. Several studies of sedimentation associated with contemporary tsunami inundation have been undertaken, for example by Dawson (1994), Nishimura and Miyaji (1995), Sato et al. (1995), Shi et al. (1995), Yeh et al. (1993). These studies reveal the complex patterns of erosion and sedimentation associated with large-scale movement of sediment both in onshore and seaward direction.

Since 1992 there have been 10 major tsunami worldwide, including Nicaragua (1992), Flores (1992), Okushiri (1993), East Java (1994), Shikotan (1994), Mindoro (1994), Irian Jaya (1996), Peru (1996), Papua New Guinea (1998), Peru (2001) and most recently South Asia in 2004. Studies of these events have led to an improved understanding of tsunami generation, propagation, and inundation. In particular, studies of the sedimentary deposits from the Okushiri, Japan tsunami (Nishimura and Miyaji, 1995; Sato et al., 1995), the Flores Island, Indonesia tsunami (Dawson, 1994; Shi et al., 1995), and the Papua New Guinea (Gelfenbaum and Jaffe, 2003) describe the pattern of sedimentation associated with a tsunami. For example, both Shi et al. (1995) and Gelfenbaum and Jaffe (2003) find that the grain-size fines landward in the deposit on Flores Island. The purpose of this manuscript is to describe the erosion and sedimentation associated with the 26th December 2004 south Asian tsunami. Sedimentation on this siliclastic coast yields some interesting contrasts with other tsunami deposits such as those found in Papua New Guinea and Japan thus adding to the observations of modern tsunami sedimentation that will ultimately improve the identification and interpretation of palaeotsunami in the geologic record.

1.1. The description of 2004 Asian tsunami

On Sunday 26 December 2004, a large earthquake occurred off the west coast of the Indonesian island of Sumatra (Fig. 1A) generating a tsunami that caused over 200,000 fatalities in 12 countries across the Indian Ocean basin (Ghobaraha et al., 2006). Tens of thousands were also reported missing and over a million left homeless (Kawata et al., 2005; Yalciner et al., 2005). The tsunami was a truly global event, with significant wave activity recorded around the world (Titov et al., 2005).

The tsunami was generated by the third largest earthquake ever recorded, with a moment magnitude of approximately 9.0 (Ammon et al., 2005; Lay et al., 2005; Park et al., 2005; Stein and Okal, 2005). The main shock occurred at 0 h 58′53″ GMT, with hypocenter, located, i.e., 160 km west of Sumatra (3.32N and 95.85E), at a depth of approximately 25–30 km (Grilli et al., in press). The main shock epicenter is marked on Fig. 1A.

The amount of uplift (seafloor displacement) is debated (Bilham, 2005; Lay et al., 2005; Stein and Okal, 2005) but is thought to be average 7–10 m (Bilham, 2005) and is centered at northwest margin of Sumatra, around 5N. Sea level changes in Andaman and Nicobar Islands, in the north, indicate that the coseismic crustal deformation extended that far north (Kayanne et al., 2005), further confirming the source length. The sea floor motion displaced an estimated ~ 30 km^3 of water on the ocean surface, causing the tsunami in the process.

On the Indian coast, the tsunami involved of three large waves, the first making landfall approximately 9.25am (Indian local time) some 3 h after the initial earthquake. The tsunami comprised three waves that arrived at 5-minute intervals. According to eyewitnesses, the second and third waves flowed over the low-lying coast before the first wave completely receded. In many places, waves ripped large trees out of the ground by the roots and moved both traditional wooden and modern brick and mortar structures off of their pilings or foundations tens to hundreds of meters away from the coast.

1.2. The past tsunami in Indian Ocean

Unlike the Pacific region where many damaging tsunami have occurred tsunami are rare in the Indian Ocean. The occurrence of large tsunami in Bay of Bengal is relatively infrequent. The Bay of Bengal has experienced 5 tsunami during the period from 1881 to 2004, including the 26th December 2004 tsunami. Previous tsunami in the Bay of Bengal were in 1881, 1883, 1907 and 1941 (NOAA compilation). Tsunami were also generated by Sumatran earthquakes of 1833 and 1861 but before the introduction of harbour tide gauges in most parts of the world including India. In most cases no scientific data are available and such events are only recorded in local history.

2. Study area

The study area consists of approximately 60 km of coastal tract from Injambakkam to Kadalore, south of Chennai (Fig. 1B). The study area is one of the most important and sensitive areas in the country and is also the site of the Madras Atomic Power Station (MAPS) which consists of two reactors of 235 MW. The area also contains a coastal township associated with MAPS,