Erosion and Deposition by the 2004 Indian Ocean Tsunami in Phuket and Phang-nga Provinces, Thailand

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ABSTRACT


The devastating December 26, 2004, tsunami produced abundant geologic effects along the Andaman coast of Thailand. The tsunami inundated the numerous sandy beaches and flowed over the adjacent aeolian dunes. On some of the dunes, the tsunami scoured circular holes 10–30 cm in diameter, and in its waning phases, it coated the holes with mud. The tsunami locally deposited a sand sheet that ranged from 0–30 cm in thickness, with an average thickness of approximately 10 cm. Sedimentary structures within the sand sheet include ripples from inflow and outflow, graded bedding, parallel lamination, and double-layered deposits. Erosion, locally severe, affected sand beaches and tidal inlets. We use these erosional and depositional features to infer the main processes that acted during inundation from the tsunami.

ADDITIONAL INDEX WORDS: Inundation, bedform dune, ripple sand, Phuket, Phang-nga, Ranong.

INTRODUCTION

The December 26, 2004, tsunami that affected the Indian Ocean basin was triggered by a magnitude 9.1–9.3 earthquake along the Indian-Australian subduction zone off the northern coast of Sumatra (LAY et al., 2005). In spite of peninsular Thailand’s location facing the northern part of this subduction zone, the lack of any written historical records, together with the lack of any significant local seismic activity, conspired to conceal this hazard from the scientific community. Hitting without any warning, the tsunami causing thousands of fatalities and huge economic losses in the popular tourist regions of Krabi, Phuket, and Phang-nga provinces (Figure 1). Eyewitness and video accounts demonstrate that the inundation lasted 10–20 minutes before draining. By studying the erosional and depositional features left behind by the tsunami, we hope to better understand the processes involved so that further generations can adequately prepare for future tsunamis.

GENERAL BEHAVIOR OF THE 2004 TSUNAMI IN THAILAND

Tsunamis are ocean waves generated by underwater disturbances of the seafloor or by surface impacts and are triggered by earthquakes and, less commonly, by landslides, volcanic eruptions, and meteorite impacts (CLAGUE, BOBROWSKY, and HUTCHINSON, 2000). These long waves (up to 200 km) travel over the ocean at great velocity. Within the open ocean, the wave height is low, but on reaching shallow water in the vicinity of the coastline, it becomes greatly amplified (BRYANT, 2001). During the process of wave deformation, the height of the wave increases significantly, its velocity decreases, and as the waves strike the coastline, they often cause widespread flooding across low-lying coastal areas (MURTY, 1977). Our field work suggests that decreasing tsunami velocity relies on oceanographic factors such as water depth, shoreface slope, and depth of the tsunami wave base.

The 2004 tsunami hit the Phuket western coast around 0938 local time. However, the records from the nearest tide gauge station on Phuket’s eastern coast indicate a delay of nearly 40 minutes before it hit this part of the island. The present altitude of the high-water mark of ordinary spring tides (HWMOST) at the tide gauging station at Tapaw Noi...
Island, eastern Phuket, is about 1.00 m from the present mean sea level (ROYAL THAI NAVY, 2005). According to this tide gauge (Figure 2A), three main waves struck eastern Phuket between 1020 and 1042. The waves were preceded by a drawdown or withdrawal that began at 1010 and lasted for 10 minutes. The second wave, the most destructive one, arrived at the gauging station at 1029 and was followed by a third tsunami at 1042. Eyewitnesses and video records confirmed that the second wave was strongest, with maximum inundation heights estimated of up to 6.00 m above ground surface and clearly recognized from water marks in the west of Phuket Island. However, tsunami flood level and maximum run-up were different from place to place (Figure 2B).

### OBJECTIVES AND METHODS

Tsunamis leave unique physical evidence of their impact, including, indications of maximum run-up elevation, maximum inundation height aboveground, erosional landforms that affect pretsunami topography, and abundant sedimentary structures on and within a sediment layer. These features must be recorded quickly before they are disturbed or destroyed by natural erosion and deposition or by human reconstruction and development. The main objective of this study was to document the geologic evidence left by the 2004 tsunami and to analyze this data to determine what processes acted during this event. To do this, we focused on the following data.

- We mapped the extent of the tsunami inundation on existing 1:50,000 scale topographic maps.
- We recorded inundation heights (above ground level) according to indicators such as high-water marks or stranded debris.
- To understand the lateral variations in tsunami run-up and inundation heights, we analyzed pertinent geomorphologic features, such as the local shape of the coast, position of headlands, nearshore bathymetry, and onshore topography.
We photographed surficial sedimentary structures and indicators of flow direction on the fresh surfaces of tsunami deposits.

We trenched the tsunami deposits to record the internal stratigraphy and sedimentary structures of the deposit.

RESULTS

During the period of tsunami standstill inland, a lot of effects were accompanied (e.g., contamination of soil, surface water, and groundwater; shoreface sediments moved up onto the land; changes in morphology of inlet/outlet tidal channel; erosion of beach sediment). We measured maximum run-up, maximum flood level, distance of inundation, and the time the tsunami hit the land in detail and came up with a brief conclusion that the power of the tsunami differed from place to place, dependent mostly on the coastal morphology of the shoreline. One other additional factor is the direction of the tsunami in term of refraction and reflection.

Inundation and Tsunami Height

As a result of our investigation, we found dramatic variations in tsunami run-up extent and height, even in a single location. The tsunami locally ran up to 3 km from the coast and much farther inland via tidal channel. Ban Nam Khem, Phang-nga province, is one good example of this style of tsunami behavior (Figure 3). From video camera record and eyewitnesses, tsunami waves refracted around headlands in parallel with the curve of a sheltered bay or beach. We suggest that the sinuosity of the bay is one of the geomorphologic factors that controlled the behavior of the run-up of tsunami waves onto the land. The greater the curvature of the shoreline, the more the waves were focused on bays. However, tsunami height might also depend on nearshore bathymetry as much as it depends on curvature of the shoreline. Tsunami height where the hills and mountains block the narrow beach were higher than at other places—Khao Lak beach, Phang-nga province, for example (Figure 4).

Tsunami Deposits

Characteristics of sand sheets from ancient and recent tsunamis have been reported from many parts of the world (e.g., Atwater, 1987, 1992; Atwater et al., 1995; Dawson, Long, and Smith, 1988; Minoura and Nakaya, 1991; Nanayama...
Figure 4. Inundation map (displayed as shaded area on topographic map) along Khao Lak beach; (A) the opening of new inlet/outlet, (B) the collapsed building near Ban Bang Niang, and (C) erosion along a channel bank. (D) The narrow beach morphology indicated that the vast damage occurred in the southern part of Khao Lak beach. For color version of this figure, see page 1206.
et al., 2000). Particular sedimentologic evidence observed in the Andaman tsunami field includes bedform dunes and ripple sands. The tsunami deposit were preserved as bedform dunes and small ripple sands in seaward and landward current directions. Small seaward ripple sands were also recognized on top of these bedform dunes. The best locality to observe these patterns of tsunami deposits occurred at Bang Tao beach, north of Phuket Island (Figure 5). Detail observations of internal sedimentary structures and grain properties of tsunami sediments from this area indicated that tsunami sediments here were deposited by at least two upflows, which eroded the majority of beach sediments and moved them to deposit as double-layered sand sheets as far as 200 m inland. Similar double layers of landward tsunami sediments were observed from Ban Khuek Khak, Phang-nga province (Figure 6). They also indicate that tsunami upflow deposited sediment twice in this area. However, a very thin mud layer 2–3 mm in thickness coating the tsunami sand sediments was also recognized throughout, and it cracked a week after the tsunami (Figure 7). Signs of a depositional layer indicative of short-term stagnant seawater or slowly draining seawater to the shore is also likely.

Erosional Features on Pre tsunami Surface

The evidence of vortices responsible for pre-tsunami surface sculpturing, especially instant circular holes that eroded into dunes, were found from Ban Nam Khem, Phang-nga province (Figure 8). Circular holes induced by tsunami here displayed as groove holes with small granules inside, and in its waning
phases, the tsunami coated the holes with a thin 2–3 mm layer of mud. On some of the dunes, the tsunami scoured circular holes 10–30 cm in diameter that extended as far as 300 m inland. Such circular holes could be indicative of rapid turbulence and rotation of tsunami upflow. A thin layer of mud then coated the holes from slowly draining stagnant water. This unique circular hole pattern was found only on the surface of pretsunami dune sediments.

Tsunami waves eroded the modern foreshore sands (Figure 9). This erosional feature shows a pattern similar to those of common storm processes and was seen extensively in most foreshore deposits a few days after the tsunami. These kidney-shaped erosional surfaces are seen in pretsunami foreshore sediments, probably filled up by either reworked foreshore sands or offshore sediments induced by the tsunami waves.

### DISCUSSION

The 2004 tsunami produced a vast area of erosion on the coastline and, in turn, deposition of tsunami sediments occurred inland. On the basis of sedimentologic clues from Phuket and Phang-nga provinces, the 2004 tsunami cut into the modern sand beaches and aeolian dunes and partly brought those sediments to deposit farther inland by upflows. However, it is still unknown whether any farther offshore sediment sources were brought up onto land by this 2004 tsunami.

It is no surprise that the catastrophic nature of the 2004 tsunami caused the sedimentation rate in 2004 to vastly exceed the average rate of earlier millennia. Erosion and deposition along the Andaman coast of Phuket and Phang-nga provinces have been interpreted with the use of sedimentologic clues in this paper. Characteristics of a sheet of tsunami deposits, in terms of its sedimentologic features, are a very important key to the better understanding of the nature of the 2004 tsunami upflow and return flow depositions. In the future, we can infer these sedimentologic features to help understand the paleotsunami deposits in this region.

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LITERATURE CITED


