2007 年度　第 17 回
地質学セミナー
日時：12月12日（水）　17時より　場所：総合研究棟B棟 110 教室
EARTH EVOLUTION SCIENCES UNIVERSITY OF TSUKUBA
筑波大学 地球進化科学

RECONSTRUCTION AND RECOGNITION OF FLOW CONDITIONS FROM TSUNAMI DEPOSITS: IN CASE OF THE 2004 INDIAN OCEAN TSUNAMI

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Surface and internal sedimentary structures of the 2004 tsunami deposits at Bangtao beach, Phuket provide an opportunity to understand flow conditions. In this area, the 2004 Indian Ocean tsunami produced a repeated sequence in which rapid inflow of turbulent water was followed by ponding and then by gradual outflow. Photographs and eyewitness accounts show an initial withdrawal followed by series of inflows. The tsunami left behind a sand sheet as much as 25 cm thick. Hypothesis was made that tsunami deposits were derived from shoreface, beach and small channel deposits, particularly during the 3rd inflow. Supporting evidence, collected along five transect lines, includes internal sedimentary structures and surface bedforms. By relating these deposits to the photographs and eyewitness data, an attempt was made to reconstruct the hydraulic conditions of the tsunami flows and flow velocitiy.

The post-tsunami sedimentary surface patterns include current dunes and ripples that lack mud coating. Most of the current dunes and ripples exhibit landward-oriented morphology; their lee sides face landward. The measurement of bedforms in terms of their wavelength, amplitude, bedform symmetry and asymmetry, lee and stoss angles, thickness of entire deposits from each pit and measured distance of inland distribution was carefully recorded.

The size of inflow current dune and ripple surface structures decreased landward. Surficial evidence for outflow was limited to small ripples superimposed on inflow dunes. These ripple marks have a seaward orientation. These sedimentary surface patterns may provide information about current dune-ripple transition velocity during inflow and imply minimal outflow deposition.

Internal sedimentary structures within sand sheets consist of parallel lamination, landward and seaward inclined lamination, rip-up clasts of mud and sand, and graded bedding. The structures especially sharp contact help define two stratigraphic units (Units 1 and 2). Units 1 and 2 superimposed with clear sharp contact on former surface of buried soil. On all transects both units thin landward and terminate within 160 m of the shoreline.

By relating surface bedforms and internal stratigraphy, the tsunami deposit preserves evidence for two times of vigorous inflow (Fig.1). Each of these is marked by mud rip-ups, medium to coarse sand that grades upward to fine, landward-inclined laminae, and a sharp basal contact. The top of the sand sheet, when observed in the first days after the tsunami, abounded in current dunes and ripples of mostly landward orientation.

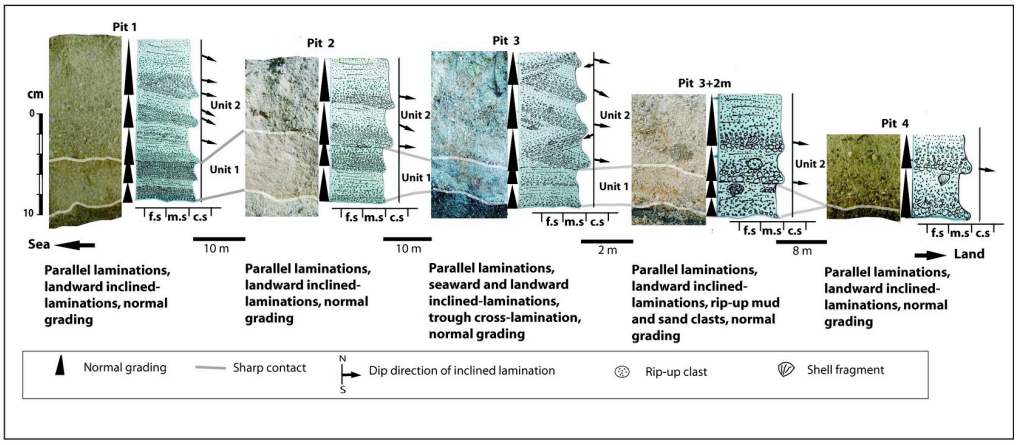

Fig. 1. Stratigraphic columns near the coast along a 30-m-long part of transect 1. Stratigraphic columns of pits no. 1, 2 and 3 were drawn from peelings. Scale bar beneath pictures represent distance between pits.

The estimation of depth-averaged flow velocity and near bottom threshold velocity was done based on grain size, thickness and surface structural patterns. The maximum depth-averaged flow velocity of tsunami wave train (that is the 3rd inflow) was about 21 m/sec at 30 m inland to approximately 7 m/sec at 160 m inland. Near bottom threshold velocity calculated from the biggest dune morphology shows a range of flow velocity of 1.74 to 1.03 m/sec. At flow depth about 3 m, depth-averaged flow velocity was about 12 times greater than near bottom velocity and, in general, flow speed decreased landward as flow depth decreased (Fig.2).

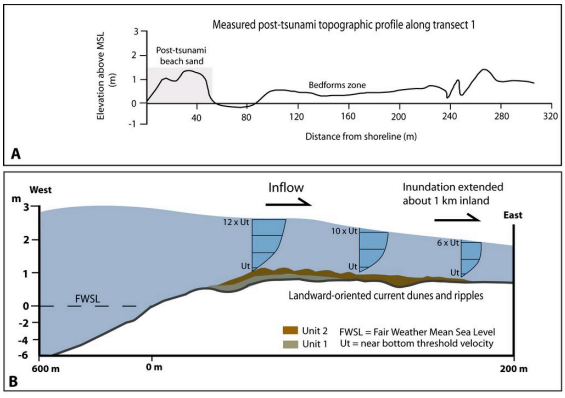

Fig. 7

Fig.2. Reconstructed schematic diagram showing vertical profiles of computed depth-averaged tsunami flow and the near-bottom threshold velocities.

The tsunami's first positive wave left no onshore sedimentary record in this pitting area. The second wave deposited sand that is much less extensive and slightly finer than that of the third wave. The deposit of both these waves contains multiple fining-upward sequences possibly due to multiple surges in one wave train. The combination of eyewitness accounts, post-tsunami photographs, and tsunami geology suggest the following hydraulic condition:

- The first tsunami uprush wave did not cross beach ridge. Accordingly it did not register as a unit in the onshore tsunami-laid sand sheet.
- Inflow during the second wave deposited Unit 1.
- Stronger, more extensive inflow from the third wave with flow depth upto 3 m deposited the coarser, more extensive Unit 2. This inflow eroded the surface of Unit 1 and suspended a large amount of beach sediments, transported them inland, and produced current dunes and ripples.
- Outflow had no lasting stratigraphic record at the sites we examined. Its effects were instead limited to the small seaward-oriented ripple marks superimposed on landward-oriented dune surfaces.

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