GEOLOGICAL EVIDENCE FOR PALEO-TSUNAMIS IN SRI LANKA

Kapila Dahanayake and Nayomi Kulasena

Department of Geology, University of Peradeniya,
Peradeniya 20400, Sri Lanka.
(e-mail: kapidaha@hotmail.com)

ABSTRACT

After the 2004 Indian Ocean tsunami inundation event, thin sediment films of fining up sequences were located in several topographic depressions of the southern coastal belt of Sri Lanka. The films consisting of silty fine sand with particular microfossil assemblages were located also in closed containers, bottles and kitchen tables. Well preserved microfossils such as foraminifera, radiolarians as well as spicules of sponges were noted in these recent tsunami sediments.

Random augur holes were drilled into some selected depressions in the southern coastal villages of Peraliya and Denuwala situated at locations separated by about 50km. In several such holes, at least two fining up sequences were located below the surface in soil horizons separated from each other by 35cm to 1m. These soil profiles were overlying older coral reefs developed on lateritic formations. The microscopic observations on particular size fractions of the soil horizons showed microfossil assemblages with textures, color and organic C contents strikingly comparable to those observed in the recent tsunami sediments of Sri Lanka. Our findings imply the occurrence of at least two paleo-tsunami events of different ages in Sri Lanka originating apparently from a common source.

1. INTRODUCTION

The undersea tsunamigenic Sumatra-Andaman Indian Ocean earthquake occurred in the morning of 26 December 2004 off the west coast of northern Sumatra registering a magnitude of 9.3 on the Richter Scale (Kruger and Ohrnberger 2005). The tsunami caused enormous destruction to life and property in many countries of the Indian Ocean with over 35,000 deaths recorded in southern, eastern and northern Sri Lanka. Massive tsunami waves with a wave height varying from 3 to 11m moved inland with speeds of about 30 to 40 km per hour through the southern, eastern and northern beaches (Liu et al. 2005; Tanioka et al. 2004 and Wijetunge 2006). These waves brought with them long trains of water carrying dark colored suspensions of fine grained materials from ocean environments. The villagers of Peraliya and Denuwala from the southern coastal belt reported at least three episodes of waves. A few hours later, tsunami waters had receded or were absorbed by the underlying soils leaving behind at least three types of sediments in the highly populated southern coastal zone as follows: (i) A typical sequence of such sediments would show a basal layer of scoured coastal sediments of varying size with debris and artifacts as big as vehicles. (ii) In the middle part of such a sequence, visible mostly in uninhabited beaches, can be observed sandy sediments with signatures of oscillating bidirectional currents developed during final stages of the event due to deposition through gradients in transport (iii) The upper part of a tsunami sedimentary sequence can be interpreted as a calm condition after a tsunamigenic earthquake and it shows fine grained clayey sediments. This unit shows upward fining due to sediment falling out of suspension (Bondevik et al.). These sediments suggest waning flow or pre-backwash deposition.

Preliminary microscopic studies of the sediments showed prolific occurrence of microfossils- that was considered an important signature of tsunami sediments- supported by characteristic cumulative curves. Microfossil assemblages (ostracods, diatoms, foraminiferans and pollen) provide evidence of sediments transported and deposited by tsunamis (Hickman et al., 2001; Prendergast, 2006). Analysis of Dec. 26/04 tsunami sediments collected along Karaikal to Nagapattinam beaches in Tamilnadu, India had revealed a thin cover of silty clay lithology consisting of foraminiferal assemblages. (Satyanarayana et al., 2007). Foraminiferan assemblages reflect the characters of tsunamis such as their direction and coastal topography. The well-preserved benthic assemblages in India are believed to have come from an inner shelf habitat with bathymetry less than 30m (Nagendra et al. 2006). Deep-sea foraminiferal facies indicate the source of particles transported by the tsunami (Uchida et al. 2005). Foraminiferal assemblages can differentiate pre-tsunami sediments from tsunami lain sediments (Hawkes et al. 2006). Historical texts of Sri Lanka refer to at least two past tsunami events that had occurred between 2000 to 3000 B.C (Geiger 1934; Suraweera 2000; Stoddart 2005; Dahanayake 2006). The purpose of the present study is to investigate potential paleo-tsunami horizons located in some soil profiles of the southern coastal region of Sri Lanka.

2. METHODS OF STUDY

Samples of both recent and paleo-tsunami sediments were collected from the Southern coastal belt of Sri Lanka. Recent samples were collected from selected locations such as closed offices, containers where the recent tsunami waters had found their way via openings. Samples were also collected from kitchen tables and open bottles located/stacked at heights of about 50cm above the ground surface which were preferred sites for deposition of tsunami sediments (Dahanayake 2006). Random drilling of selected depressions was done in the coastal villages of Peraliya and Denuwala (Fig.1) where recent tsunami sediments had preferentially accumulated. This led to the discovery of soil profiles with at least two stratigraphic horizons containing possible paleo-tsunami sediments. These were so identified due to the comparable grain size distribution, microfossil content, Organic C and Calcium Carbonate contents, color and texture as in known recent tsunami sediments. In these older sedimentary deposits the fining upward character was also observed.

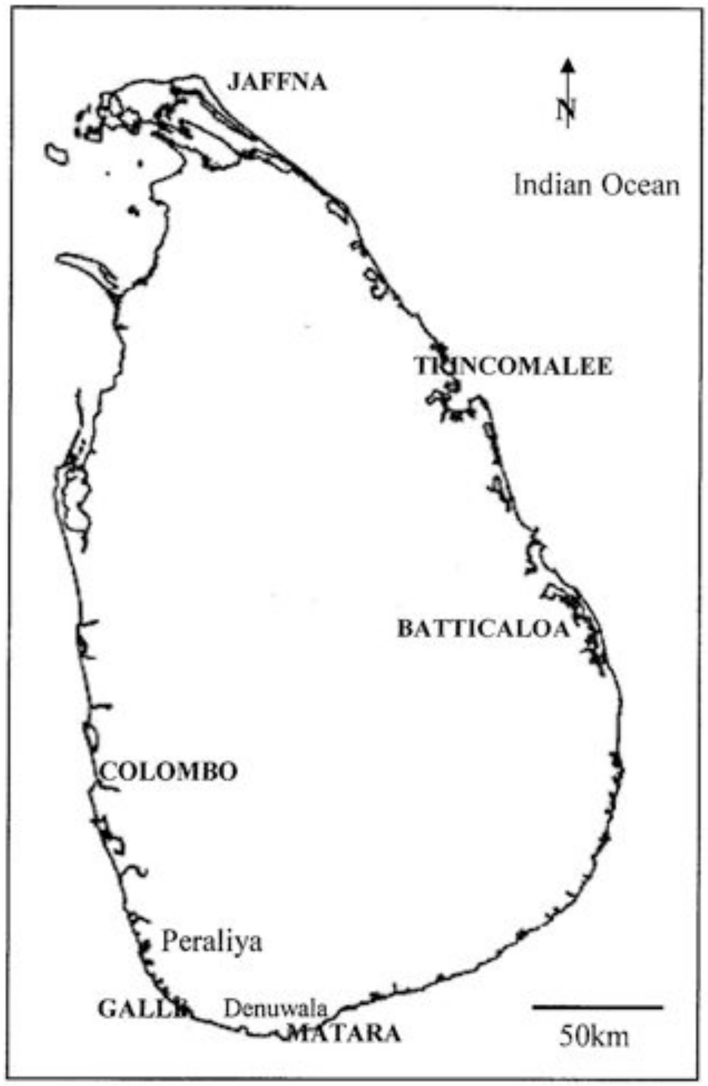


Fig. 1- Map of Sri Lanka showing the locations of the coastal villages of Peraliya and Denuwala

Sediment samples collected from sites described above as well those from storm surge and near shore deposits were air dried and grain size analysis was done using 1mm, 0.5mm, 0.25mm, 0.212mm, 0.125mm, 0.063mm sieves. Cumulative curves (as in Tickell, 1965) were constructed for typical samples from each sampling site from the 2004 tsunami (Fig.2, Fig. 3A) and for the upper and lower brownish layer from each augur hole sample site (Fig.2, Fig. 3B, C). All of the 2004-tsunami samples were scanned for microfossils in each size fraction using a reflected-light microscope. At every site, the 0.125 fraction contained the highest concentration of microfossils. Therefore only that size fraction was used for more detailed identification of microfossils using LEO 1420 VP Scanning Electron Microscope (SEM) on gold-sputtered mounts. This was done with typical selected samples from each 2004 tsunami site and both layers of each augur hole site.

Fig. 2- Dug pit profile at Peraliya showing the Recent (TS3) and Paleo-tsunami (PTS 1, 2) horizons. Note the characteristic yellowish brown coloration of tsunami sediments

3. RESULTS

Several randomly selected soil profiles located at about 100m inland from the southern coast were studied. The locations of the profiles were at the coastal villages of Peraliya and Denuwala situated 50 km apart (Figs. 1 & 2). The profiles show comparable horizons as follows: (Top to Bottom) A-

Relatively thin yellowish brown horizon of Recent tsunami sediments; B- Black clayey calcareous humic soil; C-thin yellowish brown Paleo-tsunami (?) horizon; D- Black clayey calcareous humic soil; E- Yellowish brown clayey fine sand paleo-tsunami (?) horizon; F- Mollusc-rich Coral Reef; G- Lateritic bedrock.

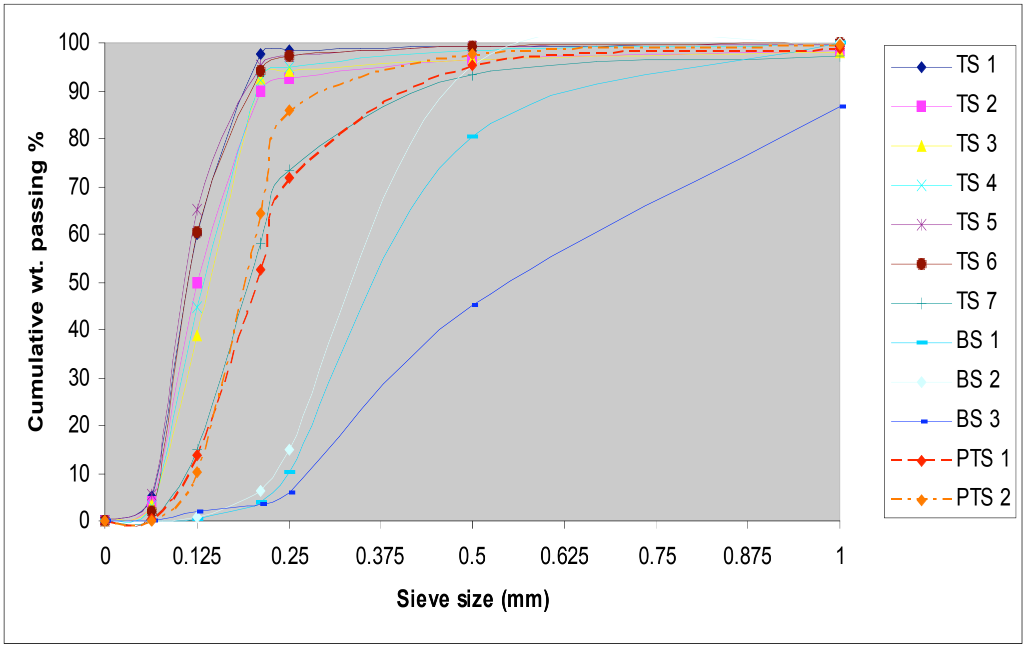
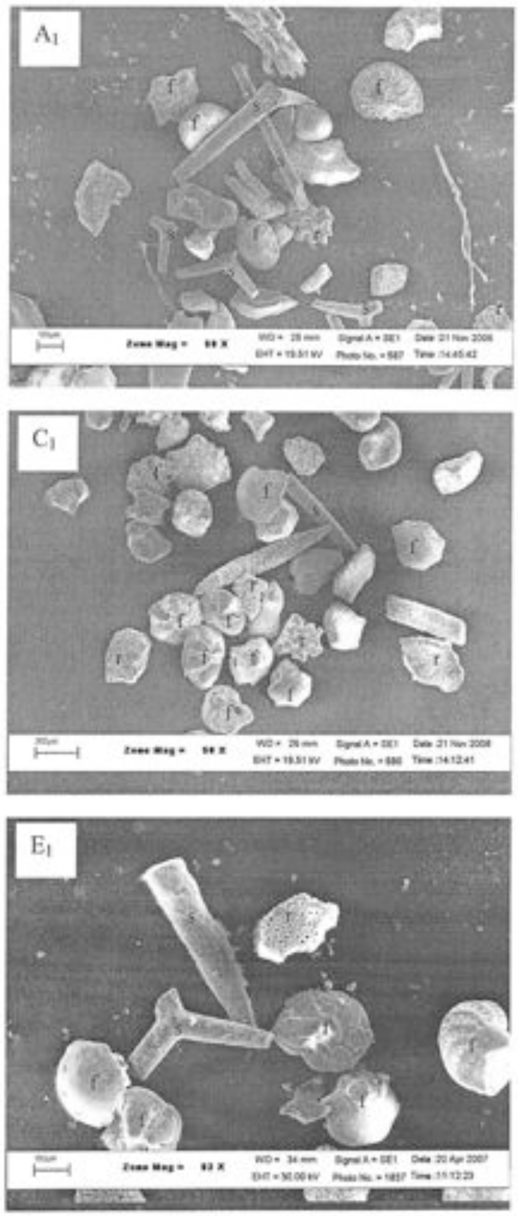


Fig. 3- The diagram showing the grain size distribution curves of Recent Tsunami sediments (TS 1-7), Paleo-tsunami sediments (PTS 1-2) and Beach sand (BS 1-3). Note the comparable grain size distributions of Recent and Paleo-tsunami sediments.

Detailed observations on horizons given in Figures 2 and 4 reveal there is a high concentration of well-preserved microfossils in the thin yellowish brown horizons. The microfossils found in the recent known tsunami sediments show striking similarities to those of the Paleo-tsunami sediments reported here. The types of microfossils are comparable and organic C of all the thin horizons lies between 1.9 to 2.7 %. Their texture and color are comparable to those deposited during Dec 26/04 tsunami inundation event. Microfossils are rarely observed in the humic horizons which have relatively high organic C contents (6 to 8 %). The soil profiles in the study areas overlie coral limestone formations.

a) Both sediment types studied were brownish yellow in color and of fine sand size generally showing a fining upward trend in the field. Cumulative curves of both types of sediments showed comparable grain size distributions. Similar trends were noted for all the paleo-sediment samples studied. It is interesting to note that the cumulative curve for the 2004 tsunami sediment (TS 7 in Fig. 3) from the **arrack** bottle (Dahanayake, 2006) and those for the paleo-tsunami sediments studied (PTS 1 to PTS 2 in Fig. 3 showed strikingly similar trends.



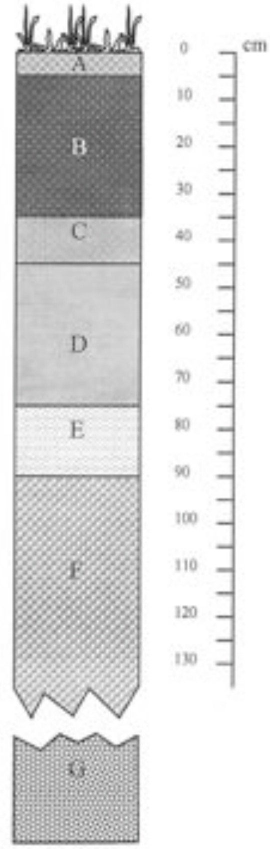


Fig. 4- Soil Profile at Peraliya

Description of Horizons in the Soil Profile

A- Yellowish brown Recent tsunami sediment with clayey fine sand with small mollusk tests –fining upward character observed

B- Black clayey calcareous humic soil with coarse weathered rock fragments

C- Paleo-tsunami horizon with clayey fine sand underlain by coarser layer rich in small mollusk tests- fining upward character observed

D- Black clayey calcareous soil with soil coated small mollusks.

E- Paleo-tsunami horizon with yellowish brown clayey fine sand underlain by coarser layer rich in mollusk tests

F- Mollusk rich reef G- Lateritic Bedrock

A$_1$, C$_1$ & E$_1$ are photomicrographs showing microfossil assemblages found in soil horizons A, C & E respectively ***- s-spicules of sponges; f-foraminifera and r-radiolaria***.

b) In both types of sediments, assemblages of microfossils as well as sub rounded quartz grains were found more or less exclusively on the fraction retained on the 0.125 mm sieve (Fig. 3).

c) The above observations highlight the similarities of both 2004 tsunami and paleo-tsunami sediments collected from the Southern coastal region of Sri Lanka in grain size distribution as well as microfossil contents.

4. DISCUSSION AND CONCLUSIONS

The microfossil content, textural and compositional attributes of Recent tsunami sediment samples collected from various locations were strikingly similar to those sediment horizons lying at depths ranging from 35cm to 1m in the soil profiles studied. These observations suggest (a) at least two past tsunami events and (b) the arrival of tsunami waters across a common source area which had been agitated due to breaking of tsunami waves in a relatively shallow ocean environment. The similarity of texture, color and composition with comparable microfossil assemblages of radiolarians, foraminiferans, and diatoms in both recent and older sediment layers suggest a paleo -tsunami origin for the older stratigraphic horizons. At least two such events are represented in the soil profiles studied. There are references in ancient texts such as Jataka Stories and others to paleo-tsunamis in the Indian Ocean and the present observations confirm such historical observations. Currently efforts are under way to determine radiocarbon dates for stratigraphically older horizons represented in the soil profiles studied.

Acknowledgements

The authors wish to thank Prof. Atula Senaratne, Dr H.M.T.G.A.Pitawala, Dr Ms. Sudharma Yatigammana - colleagues of one of us (K.D) at the Departments of Geology and Zoology of the Faculty of Science, University of Peradeniya for their assistance in analyzing the samples and identification of microfossils. Ms Sepa Nanayakkara, Research Officer at the Industrial Training Institute (ITI), Colombo kindly assisted with SEM studies. Ms Menaka Hindagolla, Senior Assistant Librarian at the University Library of Peradeniya helped in bibliographic searches. Finally the kindness of the villagers of tsunami-stricken southern coastal region of Sri Lanka is remembered with gratitude. A generous research grant (RG/2005/DMM/05) for one of us (K.D) from National Science Foundation (NSF) of Sri Lanka is gratefully acknowledged.

5. REFERENCES

Dahanayake, K. (2006) Science at the Solstice: A day in the life of a scientific planet, Abstract on Tsunami sediments. Nature, v.441, pp.1040-1045.

Geiger, W. (Translator), (1934) *The Mahawamsa* (The Great Chronicle of Ceylon-Sri Lanka) Oxford University Press London, (in Sinhala).

Hickman, C. P., Roberts, L. S., Larson, A. (*2001*) Integrated Principles of Zoology. McGraw-Hill New York

Kruger, F., Ohrnberger, M. (2005) Tracking the rupture of the $M_w = 9.3$ Sumatra earthquake over 1150km at teleseismic distance, Nature, v.435, pp.937-939.

Liu, P.L.F., Lynett, P., Fernando, H., Jaffe, B.E., Fritz, H., Higman, B., Morton, R., Goff, J., Synolakis, C. (2005) Observations by the International Tsunami survey Team in Sri Lanka. Science, v.308, p.1595.

Nagendra, R., Kamalak Kannan, B.V., Sajith, C., Sen, G., Reddy, A.N., Srinivasalu, S. (2005) A record of foraminiferal assemblage in tsunami sediments along Nagappattinam coast, Tamil Nadu. Curr. Sci., v.89, pp.1947-1952.

Prendergast, A. (2006) Echoes of ancient tsunamis. AusGeo News #83.

Satyanarayana, K., Nallapa Reddy, A., Jaiprakash, B.C., Chidambaram, L., 2007. A note on foraminifera, grain size and clay mineralogy of tsunami sediments from Karaikal-Nagore-Nagapattinam beaches, Southeast Coast of India. Journal Geological Society of India, v.69, pp.70-74

Stoddart, J. (2005) Tidal waves in Ceylon resulting from the Eruptions in the Straits of Sunda, August 1883. Surveyor General's Report, Ceylon (Sri Lanka). Island Newspaper, Sri Lanka Feb. 15.

Suraweera, A. V. (2000) Rajavaliya- A Comprehensive account of the kings of Sri Lanka. Vishvalekha Publication, Sri Lanka.

Tanioka, Y., Nishimura, Y., Hirakawa, K., Imamura, F., Abe, I., Abe, Y., Shindou, K., Matsutomi, H., Takahashi, T., Imai, K., Harada, K., Namegawa, Y., Hasegawa, Y., Hayashi, Y., Nanayama, F., Kamataki, T., Kawata, Y., Fukasawa, Y., Koshimura, S., hada, Y., Azumai, Y., Hirata, K., Kamikawa, A., Yoshikawa, A., Shiga, T., Kobayashi, M., Masaka, S. (2004) Tsunami run-up heights of the 2003 Tokachi-oki earthquake. Earth Planet Space, v.56, pp.359-365.

Uchida, J., Abe, K., Hasegawa, S., Fujiwara, O., Kamataki, T., Irizuki, T., Hirakawa, K. (2005) Characteristics of Faunal Succession of Foraminifera in Tsunami-deposits and Recognition of Sauce Area of Particles- A Case Study of the Holocene Tsunami Deposits at Tateyama, Southern Part of the Boso Peninsula, Central Japan. Abstract American Geophysical union-#T11A-0361.

Wijetunge, J.J. (2006) Tsunami on 26 December 2004: Spatial distribution of tsunami height and the extent o inundation in Sri Lanka. Science of tsunami hazards, v.24, pp.225-239.