Polish J. of Environ. Stud. Vol. 18, No. 1 (2009), 103-110

Original Research

Heavy Minerals in 2004 Tsunami Deposits on Kho Khao Island, Thailand

R. Jagodziński*, B. Sternal, W. Szczuciński, S. Lorenc

Institute of Geology, Adam Mickiewicz University, Maków Polnych 16, 61-606 Poznań, Poland

Received: 2 October, 2008
Accepted: 23 November, 2008

Abstract

Heavy mineral assemblages were studied in onshore sandy deposits from the 26 December 2004 tsunami on Kho Khao Island, southern Thailand. The most common minerals included tourmalines, zircon, muscovite, biotite, limonites and opaque minerals. An abundance of micas and depletion in tourmalines allowed us to distinguish the tsunami deposits from modern beach sediments and pre-tsunami soils. Major lateral and vertical changes in the studied profiles were related to an increase in flake-shaped micas upward in the tsunami sequence as well as landward. These variations, although documented for one grain size fraction, corresponded well with changes in the grain size distributions of the whole samples. The observed changes probably reflect wave hydrodynamics and a change in the sedimentation mode from bed-load deposition to settling of the suspended load.

Keywords: tsunami deposits, heavy minerals, micas, Andaman Sea, Thailand

Introduction

Identifying tsunami deposits in the geological record is often very difficult due to the huge variability in tsunami deposits, which are most commonly in the form of sand sheets or boulders. However, it is important to recognize them, particularly on coasts without historical records of tsunamis (e.g., Thailand), because identifying former tsunami deposits may help in assessing tsunami hazard [e.g. 1]. Unfortunately, there is no unique set of features that can help in recognizing tsunami deposits. Several authors [e.g. 2, 3] have tried to present a list of diagnostic features. But, it is clear that several of these must be met in order to identify the sediments as tsunami deposits.

In several studies of modern tsunami deposits left on land, an enrichment in heavy minerals has been reported as one of these characteristics, for example in deposits from the 1992 tsunami in Nicaragua [4], the 2001 tsunami in Peru [5] and the 2004 tsunami in Indonesia, India, Sri Lanka and Thailand [e.g. 6-12]. However, according to the authors, apart from a study by Babu et al. [9] on pre- and post-tsunami mineral assemblages in beach deposits, no detailed mineralogical study has been performed on heavy minerals in modern tsunami deposits.

Studies of heavy minerals have many applications [13], but the most common are those related to sediment provenance and paleo-hydrodynamic and transport reconstruction [e.g. 14-18]. These applications may also be useful in tsunami deposit studies. Heavy minerals may help to determine the region from which the sediments were eroded, and their spatial mineralogical trends in tsunami deposits resulting from hydraulic sorting may reflect sedimentological processes during the tsunami. It is also hypothesized that the latter may leave a particular pattern in the heavy mineral distribution, which may be helpful in identifying and interpreting older tsunami records.

The major objective of the present study is to apply heavy mineral analysis to the 26 December 2004 tsunami deposits, modern beach sands and pre-tsunami soils from Kho Khao Island (Thailand). We addressed three questions:

*e-mail: jagodus@amu.edu.pl

- Can heavy mineral assemblages help distinguish tsunami deposits?
- Can we use them to find the source of the tsunami deposits?
- Do the potential variations in heavy mineral assemblages within the tsunami deposits reflect the hydrodynamics of the wave?

Materials and Methods

Samples were collected shortly after the tsunami (February 2005) and before the rainy season, which could alter the composition of the deposits [8, 19]. The samples were taken from pits along five shore-perpendicular transects (4 to 6 pits for each transect) on Kho Khao Island, Phang Nga Province, Thailand (Fig. 1). Within the transects, besides surface samples, the tsunami deposit layer was also sampled at seven locations in the vertical direction. To determine grain size distribution, sediment samples were dried and sieved into twelve 0.5 phi intervals. A few samples were also analyzed using optical diffractometry on a laser-diffraction-based Mastersizer 2000 Particle Analyzer. The conversion of micrometers into phi values is based on the following relationship:

$$\text{phi } (\Phi) = -\log_2 D$$

...where D is the size in millimeters. The grain size statistics (e.g., mean and sorting) were analyzed using the logarithmic method of moments with the Gradistat software [20]. Two of the most common fractions, 0.063-0.125 and 0.125-0.25mm, were separated by dry sieving and used for heavy mineral separation with a heavy liquid of density 2.84 g cm^{-3}. The studied fraction was treated with HCl to remove calcium carbonate minerals. The remaining heavy minerals were identified and counted in a thin section under a petrographic microscope.

Study Area

The study was conducted on samples from Kho Khao Island, which was heavily affected by the 2004 tsunami. The investigated western coast of the island is built of several parallel beach ridges, mainly formed during the early to mid Holocene sea level highstand [e.g. 21-23]. The island is separated at its north and south ends by up to 20m deep tidal channels from Phra Tong Island and the mainland, respectively. The tsunami wave run-up was the highest at the southern and northern tips of the island, reaching over

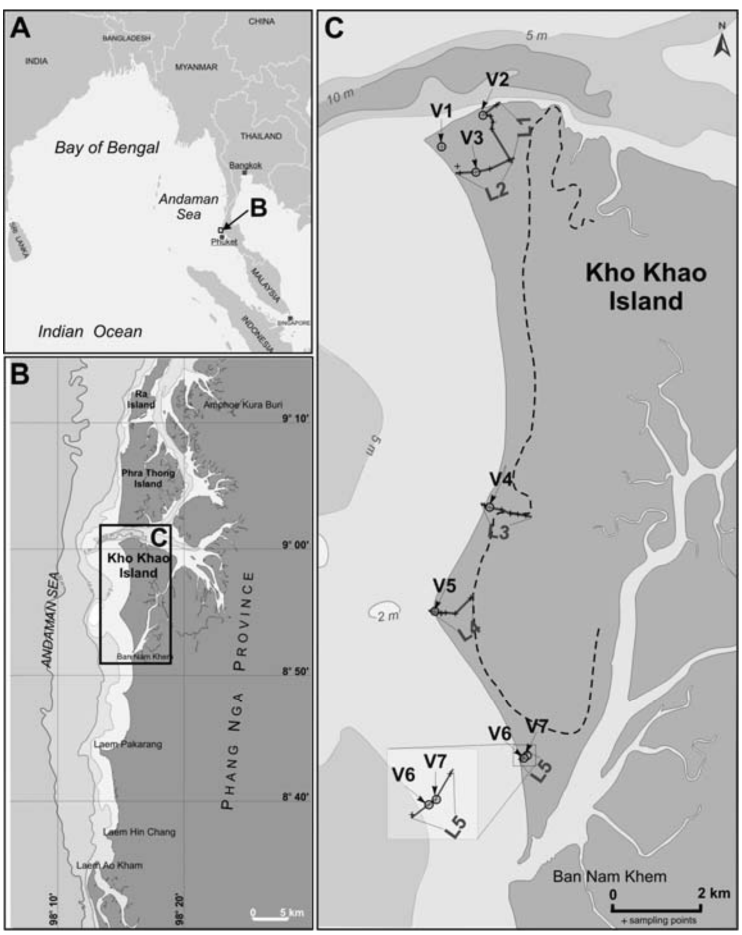

Fig. 1. Location of the study area and sampling points. A) Location of the study area, B) Kho Khao Island in the Andaman Sea, and C) sampling points. The dashed line shows the 2004 tsunami inundation limit. L1-L5 stand for lateral sampling transects, and V1-V7 mark the studied vertical profiles.

6m, whereas in the middle part the run-ups were much smaller, less than 3m [8]. This was partly related to the off-shore coral bank. The inundation zone was more than 1km wide, and the southern, low-lying part of the island was completely flooded.

Results

Sediment Type

The detailed sedimentological properties of tsunami deposits are presented elsewhere [24]; here, we only report the major characteristics. Sedimentary deposits from the tsunami were found in most places where tsunami flooding occurred. The thickness of most of the deposits was mainly from 5 to 20cm. The studied samples belong to a wide textural range, from coarse silt to coarse sand, with very fine to medium sand being the most common. These deposits are usually poorly to moderately sorted and from very fine to very coarsely skewed. The studied pre-tsunami soils are composed mostly of moderately well-sorted fine to medium sand, and the beach sediments from poorly to moderately sorted medium to coarse sand.

The studied lateral profiles are characterized by coarser sediments closest to the shoreline (usually <100m landward), and almost uniform sediments more landward. The finest sediments are found mostly in the middle of the inundation distance. For instance, in profile L1 the finest sediments are found from 50 to 410, and at 1050m from the shoreline, in profile L2 from 430 to 740m, for L3 around 100 and from 800 to 1000m, and in profiles L4 and L5 from 120 to 220m. The mean grain sizes of samples from the vertical profiles are presented in Fig. 2. Profile V1 includes tsunami deposits composed of well-sorted fine sand (25-70cm) with a slight upward-fining trend, and post-tsunami deposits of a new beach. The borders are marked with sharp erosional contacts. Profile V2 is composed of 9cm of moderately-sorted medium sand tsunami deposits lying on pre-tsunami sandy soil. The tsunami deposits are composed of two layers, the lower cross-stratified and the upper with horizontal lamination and an upward-fining trend. In profile V3, tsunami deposits are 17cm thick and composed of moderately to well-sorted fine sand, slightly fining upward. Profile V4 is composed of 11cm of poorly to moderately-sorted fining-upward tsunami deposits covering pre-tsunami soil. The mean grain size of the tsunami deposits decreases upward from medium sand to very coarse silt. Profile V5 is composed of pre-tsunami soil covered with a 7cm-thick blanket of moderately well-sorted to poorly-sorted medium sand tsunami deposits. The deposits are characterized by a fining-upward trend. Profile V6 covers the upper part of a 34cm-thick tsunami deposit layer. It is made up of two fining-upward sequences composed of poorly-sorted sediments. The lower sequence starts with coarse sand and ends with very coarse silt, while the upper one starts with medium sand and fines into very fine sand. Profile V7 is composed of a 15cm-thick tsunami deposit layer with one fining-upward sequence that consists of poorly-sorted medium to very fine sand.

Heavy Minerals Assemblage

The analyzed heavy minerals (HM) in the selected grain size fractions constitute 0.17 to 5.67%, with 1.69% on average. The suite of HM is very poor. They are divided on the basis of their abundance into major and accessory minerals. The first group includes tourmalines, muscovite, biotite, limonites, nontransparent heavy minerals (opaque) and zircon. Major minerals compose a total of 99% of all HM. The accessory minerals are chlorites, amphiboles, epidotes, garnets and rutile. Major minerals are common throughout the study region, but the contents of particular minerals vary widely. The minimum content of each is around 0%. The tourmalines content in the HM is 37.8% on average, but the maximum reaches as high as 77.8%. Limonites, opaque

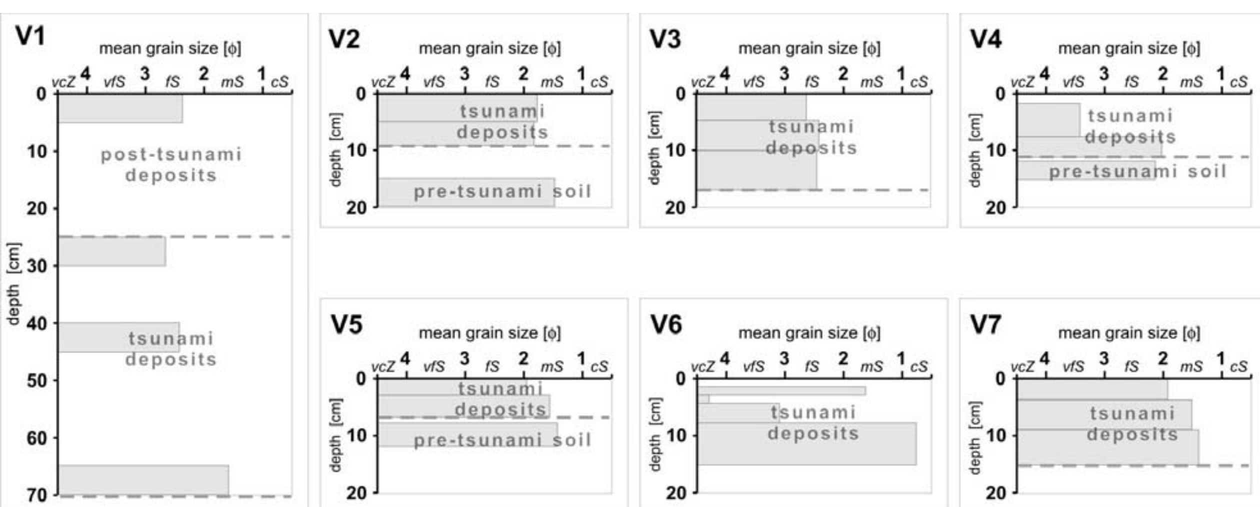

Fig. 2. Mean grain size (in Φ scale) of samples analyzed in vertical profiles. Sediment type abbreviations: vcZ - very coarse silt, vfS – very fine sand, fS – fine sand, mS – medium sand, cS – coarse sand.

minerals and muscovite have similar maximum contents of about 69%, with average values of 20.7, 17.7 and 16.3%, respectively. Biotite and zircon, although present in most of the samples, have smaller concentrations, respectively 4.8 and 1.3% on average.

Because similar variations were found among some of the major minerals, they were grouped into three pairs. The first is composed of tourmalines and zircon (Tu+Zi), as both minerals are transparent and usually found to be prismatic in shape (close to spherical). The second pair consists of micas: muscovite and biotite (Ms+Bi), which are characterized by a platy flake shape and almost the same density. These are the lightest among the studied minerals. The third is a group of nontransparent HM composed of limonites and other opaque HM (Opq+Li).

Heavy Minerals in the Tsunami Deposits, Beach Sediment and Paleosoils

The participations of these three HM groups, namely Tu+Zi, Ms+Bi and Opq+Li, were compared in the tsunami deposits, modern beach sediments and pre-tsunami soils. The tsunami deposits are the most dissimilar (Table 1). Their minor component is the Tu+Zi group, with an average content of 33.1%. The Ms+Bi group, although with an average content of only 25.6%, dominates particularly in samples from the middle and southern parts of the island, and in the uppermost part of the tsunami layer, where its content commonly exceeds even 50%. The average content of Opq+Li is the highest, at 40%. However, similarly to the previous groups, its content varies across a wide range.

Beach sediments and pre-tsunami soils are similar as regards the HM suite, but the contents of particular HM differ from tsunami deposits (Table 1). These are dominated by very high contents of Tu+Zi, and much lower ones of Ms+Bi. The content of the Opq+Li group is very similar or slightly smaller than in the tsunami deposits. The only major difference between beach and soil sediments is the ratio of Opq to Li. Opaque minerals are twice as common in the beach sediments; in the soils the ratio was opposite.

Table 1. Mean, minimum and maximum concentrations of the three major heavy mineral groups in tsunami deposits, beach sediments and pre-tsunami soils.

sediment type		Tu+Zi	Ms+Bi	Opq+Li
tsunami deposits	mean	33.1	25.6	40.0
	st. dev.	25.0	27.9	17.7
	max	75.9	95.9	73.4
	min	0.8	0.2	0.9
beach sediments	mean	57.0	8.5	33.2
	st. dev.	21.7	14.7	17.7
	max	78.1	43.6	71.6
	min	26.9	0.0	20.0
pre-tsunami soils	mean	52.7	8.0	32.8
	st. dev.	26.8	15.9	21.3
	max	78.1	43.6	71.6
	min	8.0	0.0	8.0

Lateral Changes in Heavy Mineral Contents within the Tsunami Deposits

The spatial changes in HM composition of the tsunami deposits (Fig. 3) were investigated along 5 lateral transects. The greatest difference was observed between northern Kho Khao (transects L1 and L2) and the middle and southern parts of the island. In the north, samples are dominated by the Tu+Zi group, and Ms+Bi is in most cases <10%. In the remaining transects, the contents of all three groups are on average similar, but vary a lot along the transects.

Transects L1 and L2 reveal the domination of the Tu+Zi group, which reaches maximum concentrations in samples taken from the shoreline or closest to the shoreline and at the maximum tsunami inundation distance. In the middle part of the transects, the content of this group decreases to about 60%, associated with an increase in opaque minerals (transect L1) or muscovite (transect L2). Changes in the lateral transects L3-L5 (Fig. 3) are characterized by very high contents of minerals from the Tu+Zi group very close to the shoreline and a rapid decrease more than 100m inland. The Ms+Bi group is almost absent in the zone close to the shoreline, but its content increases more inland, reaching maximum values at 100, 300 and 700m from the coastline for transects L5, L4 and L3, respectively. The variations in the Opq+Li group are large, from 1 to 73%, but no clear trend is observed.

Vertical Changes in Heavy Minerals in the Tsunami Deposits

The vertical changes in the HM composition were studied along 7 profiles (Fig. 4) located mainly in the zone 50 – 100 m from the shoreline. In the northern part of Kho Khao Island three profiles were analyzed (V1-V3). The most common group, Tu+Zi, dominates the HM assemblage, but reveals a slight decrease in the upper portion of the tsunami deposits. As in the surface samples, the Ms+Bi group is poorly represented. It is found in concentrations greater than 10% only in the uppermost parts of the tsunami deposits in profiles V1 and V3. The Opq+Li group has small irregular variations, and its content varies from 20 to 34%. Profile V4 reveals the dominance of the Tu+Zi group and the absence of the Ms+Bi group in pre-tsunami soils. The tsunami deposits are composed mainly of the Opq+Li group, with similar participation of the remaining groups, except in the uppermost sample, where the Ms+Bi content increases significantly. In profile V5, practically no vertical changes are observed, in contrast to profile V6, which shows a variable pattern. This profile is characterized by two maxima in the Ms+Bi content, in the surface sample (0-1.5cm) and in the middle part of the profile (3-8cm).

Both maxima are associated with minima in the abundance of the remaining HM groups. In profile V7, like in profile V4, the change in composition is found only in the surface sample, in which a significant increase in Ms+Bi is observed.

Discussion

The results presented here reveal that in addition to the variation in heavy mineral composition within the tsunami deposits, there are also differences between tsunami deposits, beach sediments and pre-tsunami soils. These differences may be significant for studies of paleotsunami deposits. In the present study, beach sediments and pre-tsunami soils have almost identical heavy mineral compositions. This is mainly because pre-tsunami soils developed on old beach ridges formed mainly during the Holocene sea level high-stand, so they are actually fossil beach sediments. The only major difference is in the proportion of limonites to opaques; this may be due to the authogenic formation of limonites due to soil-forming processes. The difference between tsunami deposits and beach sediments or soils is more distinct and related to bigger contents of micas in tsunami deposits rather than tourmalines. This difference may be related to the mode of sediment transport and deposition. Beach sediments are transported mainly as a bed load along the bottom. On the other hand, a tsunami can transport sediments in bed load and suspension. The micas, due to their flaky shape, may be more easily suspended in water and successively settled from suspension. Another characteristic feature is the vertical change in mica distribution

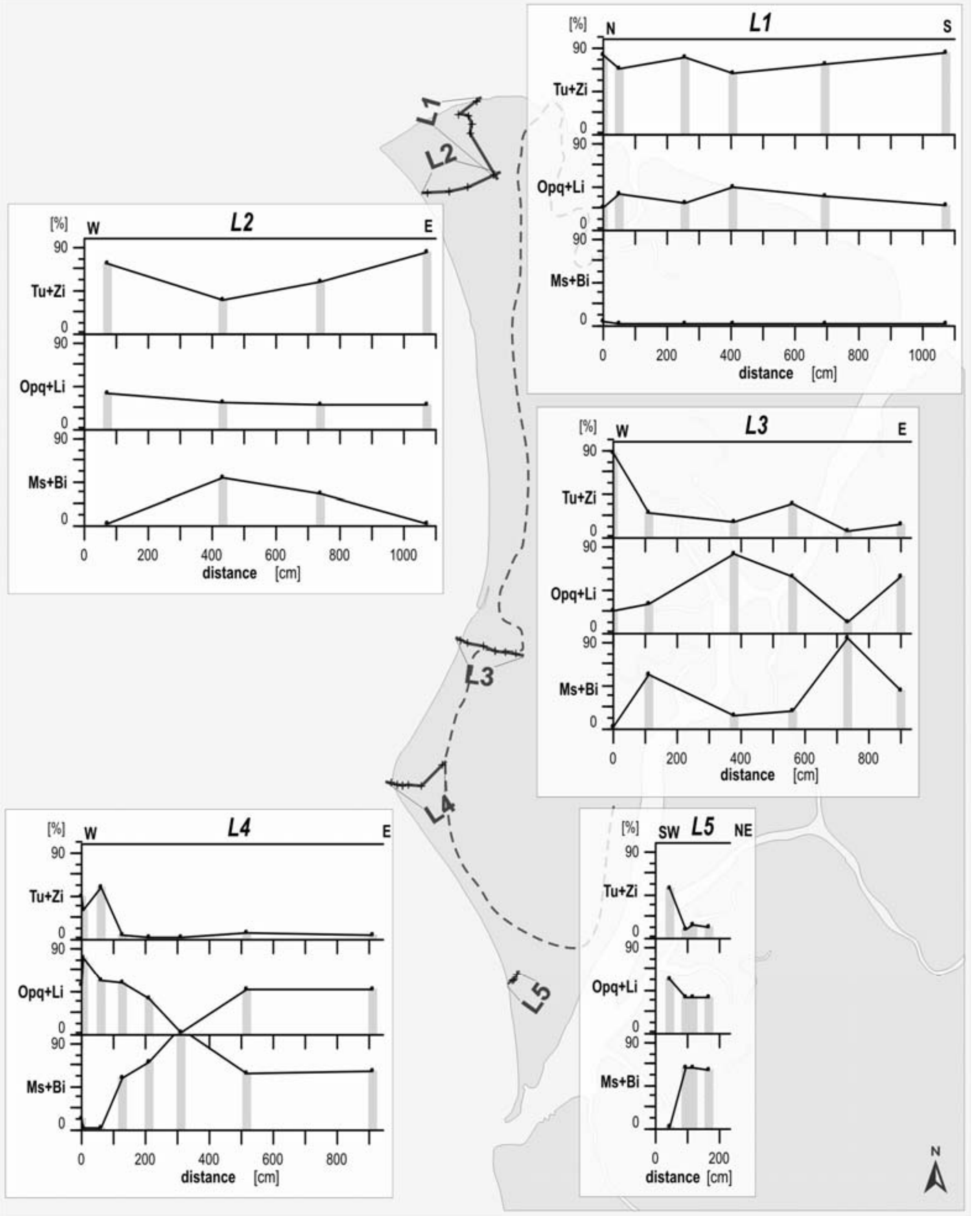

Fig. 3. Lateral changes in the contents of the major HM groups in the tsunami deposits.

within the tsunami deposits. These are usually most common in the uppermost part of the tsunami sequence. This feature may help in identifying the upper boundaries of tsunami deposits in the sedimentary record. One good example of this potential application is represented by profile V1 (Fig. 4), in which tsunami deposits are already covered by prograding beach sediments.

In general, the similar heavy mineral assemblages of the three studied sediment types suggest that beach or pre-tsunami coastal soils may be source areas for tsunami deposits, but the common presence of micas suggests that these sources are not unique, and that some inner shelf sediments were probably also eroded and transferred on land by the tsunami wave. This conclusion agrees with the results of previous studies on the potential source areas of the tsunami deposits, based on textural parameters, microfossils, offshore erosional features and numerical models [e.g. 6, 24-29]. However, it is not possible to specify the exact provenance of the tsunami deposits due to small differences in the heavy mineral assemblages, as well as limited reference data [e.g. 30]. The observed low abundances of micas in the tsunami deposits on northern Kho Khao Island are probably related to the characteristics of nearshore sediments, which are modified by very strong tidal currents. North of Kho Khao Island, there is a deep tidal channel (Fig. 1), which serves as a bypass zone for large amounts of water pumped

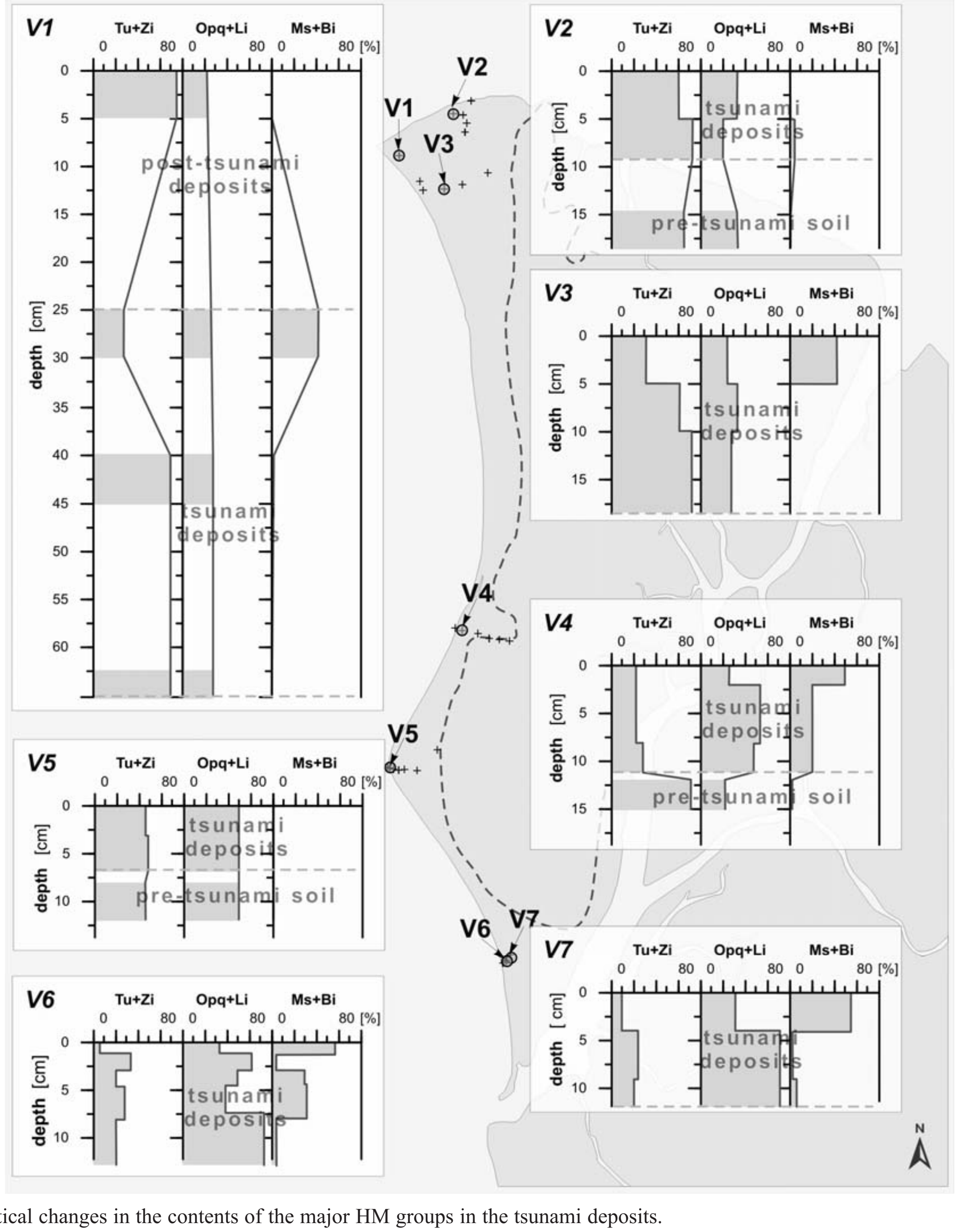

Fig. 4. Vertical changes in the contents of the major HM groups in the tsunami deposits.

in and out during each flood and ebb tide. These conditions prevent the deposition of flaky minerals like micas, which are probably transported further offshore or onto tidal flats east of Kho Khao. This causes the nearshore sediments near the northern part of Kho Khao, which probably served as a source area for tsunami deposits, to be depleted in micas.

The hydrodynamic properties of heavy minerals are distinct from the most common mineral grains (e.g., quartz), but they also differ within the suite of heavy minerals due to variable densities, shapes and diameters. The impact of the latter was excluded in the present study by using the same grain size fraction. Because of this, it may be surprising that the maximum content of micas was found in the finest-grained sediment samples. This relation was observed in both lateral transects and vertical profiles, where fining upward of the bulk grain size is often associated with an upward increase in mica content in the heavy minerals suite of the studied fraction. This good correlation is particularly well expressed by profile V6, where two fining-upward sequences were documented in grain size analysis (Fig. 4). Similarly, two micas concentration maximas were found at relevant levels in the profile. This coincidence suggests common driving mechanisms. Tsunamis may transport and deposit sandy sediments on land in several modes, with sediment transport as bed load and suspension load being the most common [e.g. 31, 32]. The presence of a fining upward sequence is usually treated as proof of sedimentation from suspension. However, we can imagine a case in which bed load transport of diminishing energy produces a similar sequence. The abundance of mica flakes in the uppermost part of the sequence supports the idea of sedimentation from suspension. On the other hand, depletion in micas or their absence in the lowermost parts of the tsunami deposit layer suggests bed load transport and deposition.

Conclusions

The presented analysis shows that studying the heavy mineral assemblages can be helpful in identifying tsunami deposits. Due to the common presence of micas in tsunami deposits, their heavy mineral suites differ from modern and fossil beach sediments. Elevated concentrations of micas in the uppermost parts of tsunami deposits may help in deciphering their upper boundaries when they are covered by other similar sediments (e.g., beach sands). The assemblage of heavy minerals suggests that most of the tsunami deposits were derived from beaches and soils in the coastal zone, but probably also from seafloor sediments. The very good correlation of variations in mica concentrations in one studied grain size fraction with sediment bulk grain size suggests a common driving mechanism, probably related to changes in the deposition mode from bed load transport (absence of micas) to suspension settling (abundant micas) in tsunami sedimentation. This study reveals that heavy mineral analysis is a potentially useful supplementary tool in studies of tsunami sedimentation and tsunami deposits.

Acknowledgements

This study was supported by the Polish Ministry of Science and Higher Education through research grant No. N N523 376833. Witold Szczuciński was supported by a fellowship from the Foundation for Polish Science (FNP). The authors thank Grzegorz Rachlewicz, Darunee Saisuttichai and Thawatchai Tepsuwan for their help during fieldwork, and Radosław Jagodziński for his assistance in laboratory work.

References

1. NANAYAMA F., SATAKE K., FURUKAWA R., SHIMOKAWA K., ATWATER B.F., SHIGENO K., YAMAKI S. Unusually large earthquakes inferred from tsunami deposits along the Kuril trench. Nature **424**, 660, **2003**.
2. GOFF J., CHAGUÉ-GOFF C., NICHOL S. Palaeotsunami deposits: A New Zealand perspective. Sed. Geol. **143**, 1, **2001**.
3. SHIKI T., TACHIBANA T., FUJIWARA O., GOTO K., NANAYAMA F., YAMAZAKI T. Characteristic features of tsunamiites. In: Tsunamiites – Features and Implications. Shiki et al. (eds.) Elsevier, pp. 319-340, **2008**.
4. HIGMAN B., BOURGEOIS J. Deposits of the 1992 Nicaragua tsunami. In: Tsunamiites – Features and Implications. Shiki et al. (eds.) Elsevier, pp. 81-103, **2008**.
5. MORTON R.A., GELFENBAUM G., JAFFE B.E. Physical criteria for distinguishing sandy tsunami and storm deposits using modern examples. Sed. Geol. **200**, 184, **2007**.
6. RAZZHIGAEVA N.G., GANZEI L.A., GREBENNIKOVA T.A., IVANOVA E.D., KAISTRENKO V.M. Sedimentation particularities during the tsunami of December 26, 2004, in northern Indonesia: Simelue Island and the Medan coast of Sumatra Island. Oceanology **46**, 875, **2006**.
7. SINGARASUBRAMANIAN S.R., MUKESH M.V., MANOHARAN K., MURUGAN S., BAKKIARAJ D., JOHN PETER A. Sediment characteristics of the M-9 tsunami event between Rameswaram and Thoothukudi, Gulf of Mannar, southeast coast of India. Sci. Tsunami Hazards **25**, 160, **2006**.
8. SZCZUCIŃSKI W., CHAIMANEE N., NIEDZIELSKI P., RACHLEWICZ G., SAISUTTICHAI D., TEPSUWAN T., LORENC S., SIEPAK J. Environmental and geological impacts of the 26 December 2004 tsunami in coastal zone of Thailand - overview of short and long-term effects. Polish J. Environ. Stud. **15**, 793, **2006**.
9. BABU N., SURESH BABU D.S., MOHAN DAS P.N. Impact of tsunami on texture and mineralogy of a major placer deposit in southwest coast of India. Environ. Geol. **52**, 71, **2007**.
10. BAHLBURG H., WEISS R. Sedimentology of the December 26, 2004, Sumatra tsunami deposits in eastern India (Tamil Nadu) and Kenya. International J. Earth Sci. **96**, 1195, **2007**.
11. NARAYANA A.C., TATAVARTI R., SHINU N., SUBEER A. Tsunami of December 26, 2004 on the southwest coast of India: Post-tsunami geomorphic and sediment characteristics. Mar. Geol. **242**, 155, **2007**.
12. MORTON R.A., GOFF J.R., NICHOL S.L. Hydrodynamic implications of textural trends 2004 tsunami in Sri Lanka. Sed. Geol. **207**, 56, **2008**.

13. MANGE M.A., WRIGHT D.T. (eds.) Heavy minerals in use. Developments in Sedimentology 58, Elsevier, pp. 1-1283, **2007**.
14. STATTEGGER K. Heavy minerals and provenance of sands; modeling of lithological and members from river sands of northern Austria and from sandstones of the Austroalpine Gosau Formation (Late Cretaceous). J. Sed. Res. **57**, 301, **1987**.
15. JAGODZIŃSKI R. Petrography and geochemistry of surface sediments from Sunda and Vietnamese shelves (South China Sea). Wydawnictwo Naukowe UAM, pp. 1-144, **2005**.
16. CASCALHO J., FRADIQUE C. The sources and hydraulic sorting of heavy minerals on the northern Portuguese continental margin. In: Heavy minerals in use. Mange and Wright (eds.), Developments in Sedimentology 58, Elsevier, pp.75-110, **2007**.
17. GARZANTI E., ANDÒ S. Heavy mineral concentration in modern sands: implications for provenance interpretation. In: Heavy minerals in use. Mange and Wright (eds.), Developments in Sedimentology 58, Elsevier, pp.75-110, **2007**.
18. KOMAR P.D. The entrainment, transport and sorting of heavy minerals by waves and currents. In: Heavy minerals in use. Mange and Wright (eds.), Developments in Sedimentology 58, Elsevier, pp. 3-48, **2007**.
19. SZCZUCIŃSKI W., NIEDZIELSKI P., KOZAK L., FRANKOWSKI M., ZIOŁA A., LORENC S. Effect of rainy season on mobilization of contaminants from tsunami deposits left in a coastal zone of Thailand by the 26 December 2004 tsunami. Environ. Geol. **53**, 253, **2007**.
20. BLOTT S.J., PYE K. Gradistat: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms **26**, 1237, **2001**.
21. GEYH M.A., STREIF H., KUDRASS H.R. Sea-level changes during the late Pleistocene and Holocene in the Strait of Malacca. Nature **278**, 441, **1979**.
22. SINSAKUL S. Evidence of quarternary sea level changes in the coastal areas of Thailand: a review. J. Southeast Asian Earth Sci. **7**, 23, **1992**.
23. HORTON B.P., GIBBARD P.L., MILNE G.M., MORLEY R.J., PURIN TAVARAGUL C., STARGARDT J.M. Holocene sea levels and palaeoenvironments, Malay-Thai Peninsula, southeast Asia. The Holocene **15**, 1199, **2005**.
24. SZCZUCIŃSKI W., RACHLEWICZ G., CHAIMANEE N., SAISUTTICHAI D., TEPSUWAN T., LORENC S. Tsunami deposits left by the 26 December 2004 tsunami in coastal zone of Thailand (Phang Nga and Phuket) – their properties and sources. submitted.
25. NANAYAMA F., SHIGENO K. Inflow and outflow facies from the 1993 tsunami in southwest Hokkaido. Sed. Geol. **187**, 139, **2006**.
26. HAWKES A.D., BIRD M., COWIE S., GRUNDY-WARR C., HORTON B.J., TAN SHAU HWAI A., LAW L., MACGREGOR C., NOTT J., ONG J.E., RIGG J., ROBINSON R., TAN-MULLINS M., TIONG SA T., YASIN Z., AIK L.W. Sediments deposited by 2004 Indian Ocean Tsunami along the Malaysia-Thailand Peninsula. Mar. Geol. **242**, 169, **2007**.
27. WEISS R. Sediment grains moved by passing tsunami waves: Tsunami deposits in deep water. Mar. Geol. **250**, 251, **2008**.
28. FELDENS P., SCHWARZER K., SZCZUCIŃSKI W., STATTEGGER K., SAKUNA D., SOMGPONGCHAIYKUL P. Impact of the 2004 Indian Ocean Tsunami on seafloor morphology and sediments offshore Pakarang Cape, Thailand. Polish J. Environ. Stud., **18**, 63, **2009**.
29. KOKOCIŃSKI M., SZCZUCIŃSKI W., ZGRUNDO A., IBRAGIMOW A. Diatom assemblages in 26 December 2004 tsunami deposits from coastal zone of Thailand as sediment provenance indicators. Polish J. Environ. Stud., **18**, 93, **2009**.
30. USIRIPRISAN C., CHIEMCHINDARATANA S., SHOOSUWAN S., CHATRAPAKPONG Y. Offshore exploration for tin and heavy minerals in the Andaman Sea. Department of Mineral Resources, Bangkok and UNDP, New York, pp. 224, **1987**.
31. DAWSON A.G., SHI S. Tsunami deposits. Pure Applied Geoph. **157**, 875, **2000**.
32. SUGAWARA D., MINOURA K., IMAMURA F. Tsunamis and tsunami sedimentology. In: Tsunamiites – Features and Implications. Shiki et al. (eds.) Elsevier, pp. 9-49, **2008**.