Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 1842

GRAIN-SIZE AND THIN SECTION CHARACTERISTICS OF TSUNAMI SEDIMENTS FROM KHAO LAK, THAILAND

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ABSTRACT

This paper presents the physical properties of a tsunami deposit from Khao Lak, Thailand. The characteristics of tsunami deposit are evaluated from the grain-size distributions and the micro-morphological features analyzed by wet-sieve and thin section methods, respectively. The tsunami deposit is a multiple-layer sediment. It fines upward. The sediments are moderately to poorly sorted fine to very fine sand with shell fragments. They overlay the pre-existing soil. There are three sedimentation sequences in the tsunami deposit which reflect three run-ups or three tsunami waves affecting Khao Lak area. The boundaries of each sedimentation sequence can be located at break points in the plot of grain-size standard deviation with depth. The break points are the changing points of grain-sizes from fine to coarse grains upwards and can be observed in the thin sections as well. Shallow water micro-organisms and micro-shell fragments are also present. Micro-soil rip-up clasts or micro-sand pockets are possibly observed in each sedimentation sequence. Micro-morphological features suggest that the sediments of tsunami deposit are deposited by run-up flows and drawdown (backwash) flows. Mean grain-sizes of the sediments deposited by those flows are not significantly different. The sediments are eroded and transported by tsunamis from coastal and onshore areas to be deposited on the up-land area. The wet-sieve and thin section analyses for the characteristics of tsunami deposit give significantly similar results. However, to reconstruct the geological environment from the characteristics of a tsunami deposit, the characteristics evaluated by the wet-sieve method is more convenient than the thin section method.

Introduction

Tsunami deposits are provisionally distinguished in the field on the basis of anomalous sand horizontals, fining-upward and fining-landward, coupled with organic-rich, fragmented backwash sediment (e.g. Dawson et al., 1991; Shi et al., 1995; Gelfenbaum and Jaffe, 2003; Smith et al., 2004; Srisutam and Wagner, 2009; Srisutam and Wagner, 2010(a)). Grain-size and various parameters derived from the statistical analysis of the grain-size distribution, such as sorting, reflect the energy gradients responsible for transportation and deposition of sand bodies and are therefore important in reconstructing the geological environment (Friedman, 1962).

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Smith et al. (2007), Srisutam and Wagner (2009, 20010(a)) identified the sedimentation sequences with grain-size distribution curves. Hindson and Andrade (1999) proposed that the break points in plot of standard deviation with depth of the tsunami deposit mark a break in turbulence associated with a transition to a lower or higher Reynolds number run-up. Therefore, the characteristics of tsunami deposit at Khao Lak, Thailand are evaluated by such techniques. The thin section for studying the micro-morphological features is also applied for the observation of sedimentation characteristics and the sediment composition in tsunami deposit. The results from those techniques are compared for the accuracy of the field evaluation.

Methods

Sample collection

Undisturbed samples of tsunami deposit were collected in a 3 inches diameter PVC tube in December 2006. The location is Khao Lak (lat. 8°42’30”N, lon. 98°14’22”E), Thailand (Fig. 1). Figure 2(a) and 2(b) show tsunami deposit rests on the pre-existing soil at the collection area and in the sections of sample core, respectively. The sediments located above (the light colored sediments) are the tsunami deposits resulting from the 26 December 2004 tsunami event. The sediments located in the lower part (the dark colored sediments) are the pre-existing soil.

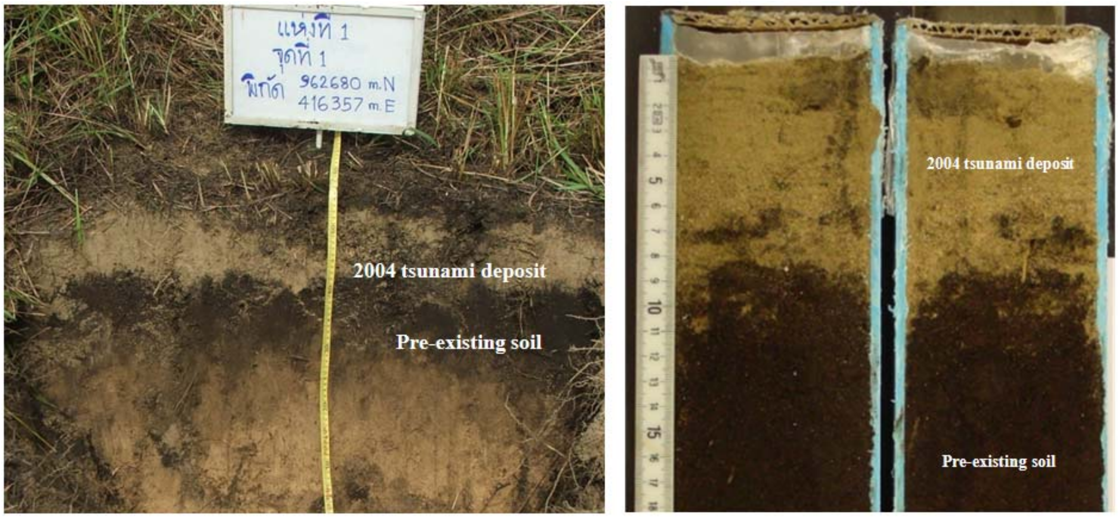
Figure 1. Location of the tsunami deposit sample

Grain-size analysis

Grain-size distributions for geomorphic and stratigraphic units are obtained by the wet-sieve method. The 0.50-phi sieve intervals are used. Furthermore, the parameters of texture grain-size are calculated on the basis of the Folk and Ward (1957) statistics. The phi scale is based on the following relationship:

$$\phi = -\log_2 d$$

where ϕ is phi size and d is the grain diameter in millimeters



(a) (b)

Figure 2. The tsunami deposits; (a) Tsunami deposit rests on the pre-existing soil; (b) The sections of sample core.

Sample preparation for thin section analysis

The thin sections are cut from samples hardened with epoxy resin. Samples for thin-sectioning are collected at the core depth of 0-16 cm. Since, the samples are sands (cohesionless soil), the pushing of thing-walled aluminum boxes into the core of soft sediment similar to that made by Francus (1998) could not be made. Therefore, the whole section of sample core is left to dry by air. Then, it is impregnated by a low-viscosity epoxy resin, and hardened (Fig. 3). The sections for the preparation of thin section are cut from the depth 0-16 cm, providing an undisturbed vertical slice of the sediments.

Figure 3. The preparation of core soft sediment for the hardened samples

Examination and evaluation of the characteristics of tsunami deposit

The grain-size statistical parameters (graphic mean, inclusive graphic standard deviation (sorting), inclusive graphic skewness and graphic kurtosis) are calculated from the grain-size distributions analyzed by the wet-sieve method. The thin sections are examined and photographed with the scanner and the optical microscope for micro-morphological features and composition.

Results

Grain-size distributions

The vertical variations of tsunami deposit textures are shown in figure 4. The mean grain-sizes are 2.62ϕ to 3.27ϕ (fine to very fine sand). Entirely, the tsunami deposit fines upward. The standard deviations (sorting) are 0.73ϕ to 1.37ϕ (moderately to poorly sorted). There are two break points (the points of slope changing, + to – and – to +) in the plot of standard deviation with depth. Therefore, there are three major sediment layers in the tsunami deposit as that discussed by Hindson and Andrade (1999) and Srisutam and Wagner (2009, 20010(a)). There are three sets of the decreasing upward skewness. The skewness values are -0.32 to 0.02. These suggest that the grain-size distributions are mostly coarse skewed where the fine sediments are abundant. The bases of the decreasing upward skewness sets are located at the same depths of the break points in the plot of standard deviation with depth. The kurtosis values are 0.78 to 2.17 which suggest that the grain-size distributions of tsunami deposit are flat (multi-modal) and sharp (uni-modal) at the lower and upper part of the tsunami deposit, respectively.

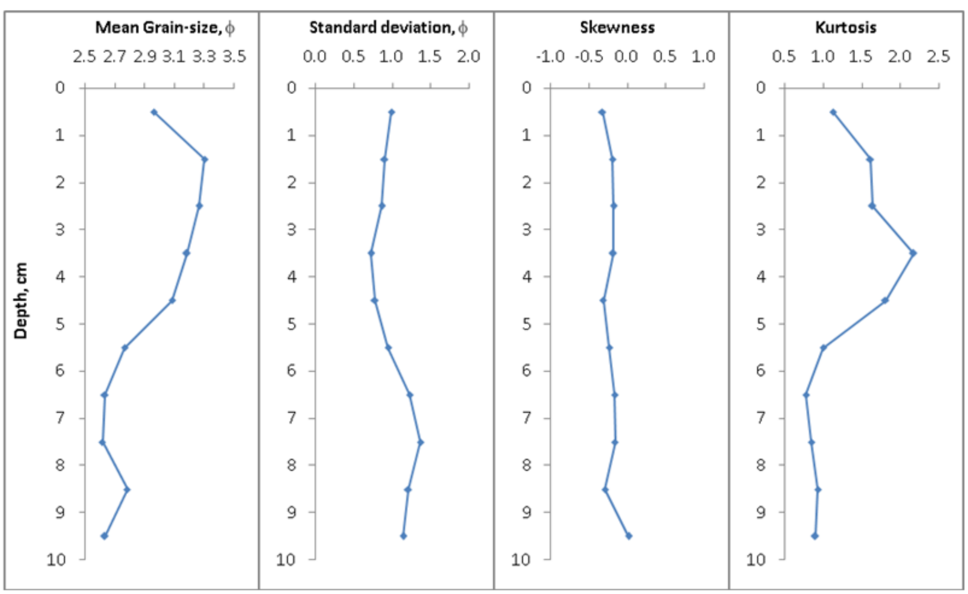


Figure 4. The vertical variation in grain-size parameters of the tsunami deposit at Khao Lak, Thailand.

According to Srisutam and Wagner (2009, 2010(a)), plots of standard deviation with depth and the grain-size distribution curve for the sediment layer in 1 cm intervals are used (Fig. 5) for the identification of the major sediment layers. The boundaries of the major sediment layers are identified at the break points in the plot of standard deviation with depth which relate to the increasing percent content of the coarse particles in grain-size distribution curve (fine grains to coarse grains upwards). Therefore, there are three major sediment layers which reflect three sedimentation sequences in the tsunami deposit.

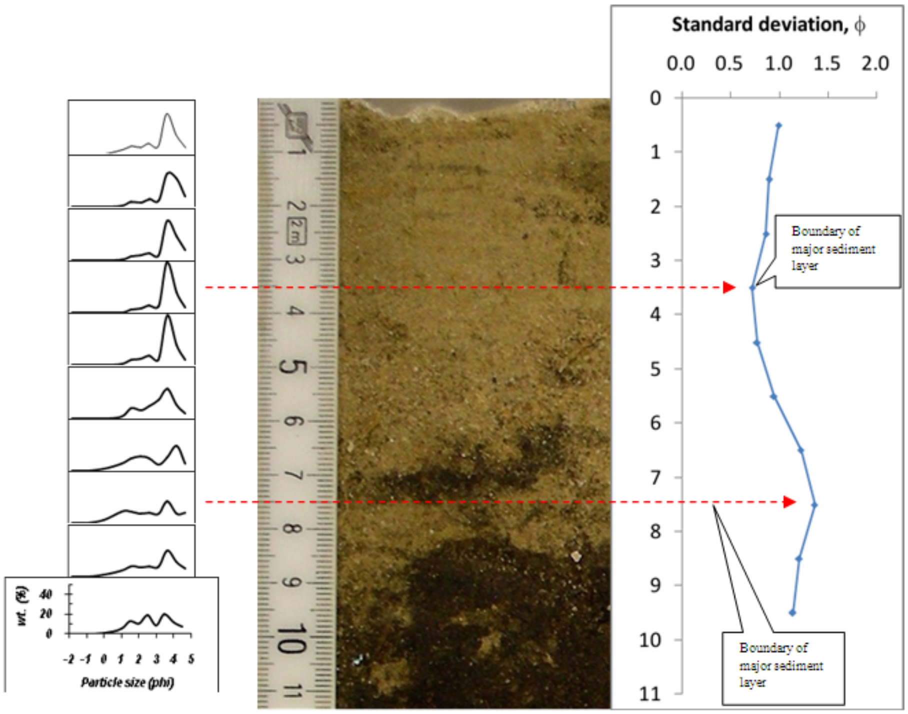
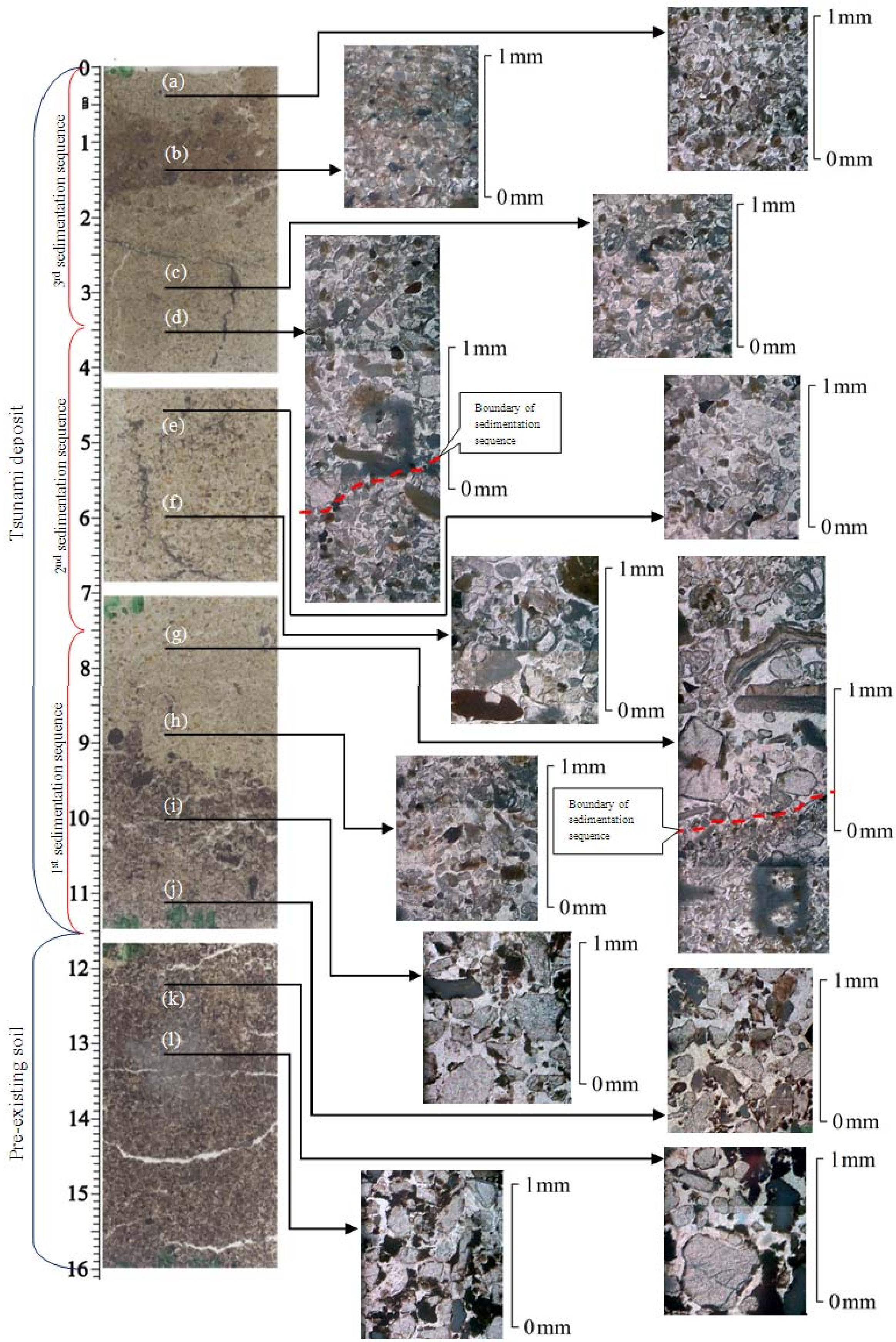


Figure 5. Plots of the standard deviation with depth and the grain-size distribution curves for the tsunami deposit in 1 cm intervals show the boundaries of the major sediment layers.

Thin section

The tsunami sediments (light colored sediments) are medium to very fine grained. Sub-angular to sub-rounded grains are widely dispersed. There is an evidence of grass roots which are the brown materials at the top of the tsunami deposit (0-2 cm). Organic materials (dark colored materials) are dispersed in the sediment at the bottom of the tsunami deposit (9-12 cm). The tsunami deposit fines upward with multiple sedimentation layers (Fig. 6). The base of each major sediment layer is identified by the changing of grain-size from fine grain to coarse grain upwards. The bases of the major sediment layers are observed at the depths of 3-4 cm (the base of the 3rd major sediment layer, Fig. 6(d)) and 7-8 cm (the base of the 2nd major sediment layer, Fig. 6(g)). The base of tsunami deposit (the base of the 1st major sediment layer) is not identified by a changing of grain-size. It is identified by the roundness of the grains and the content of organic materials in the sediments. The pre-existing soil is composed of rounded grains and the percentage of organic material in the sediment is higher. Therefore, the depth which separates the tsunami deposit from the pre-existing soil is at a depth of 11-12 cm (the base of the 1st major sediment layer, see Fig. 6(j) and Fig. 6(k)). There are three major sediment layers or three sedimentation sequences in the tsunami deposit in total. The 1st, 2nd and 3rd sedimentation sequences are at the depth of 7.5-11.5 cm, 3.5-7.5 cm and 0-3.5 cm, respectively.



Tsunami deposit
Pre-existing soil
3rd sedimentation sequence
2nd sedimentation sequence
1st sedimentation sequence
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
1mm
0mm
Boundary of sedimentation sequence

Figure 6. The pictures of thin sections show details of the sediments in the tsunami deposit. The upper parts (light colored sediments, at the depth of 0-11.5 cm) are the tsunami deposit. The lower part(dark colored sediments) is the pre-existing soil. The sediments fine upward with three major sediment layers.

Shell fragments and shallow water micro-organisms are commonly found in the tsunami deposit as shown in figure 7(a). It is possible to observe the micro-soil rip-up clasts or the micro-sand pockets (a cluster of sediments which are coarser or finer than the surrounding sediment) in each sedimentation sequence (Fig. 7(b)). The most abundant sediment grains are quartz, some muscovite mica and some organic material (Fig. 8).

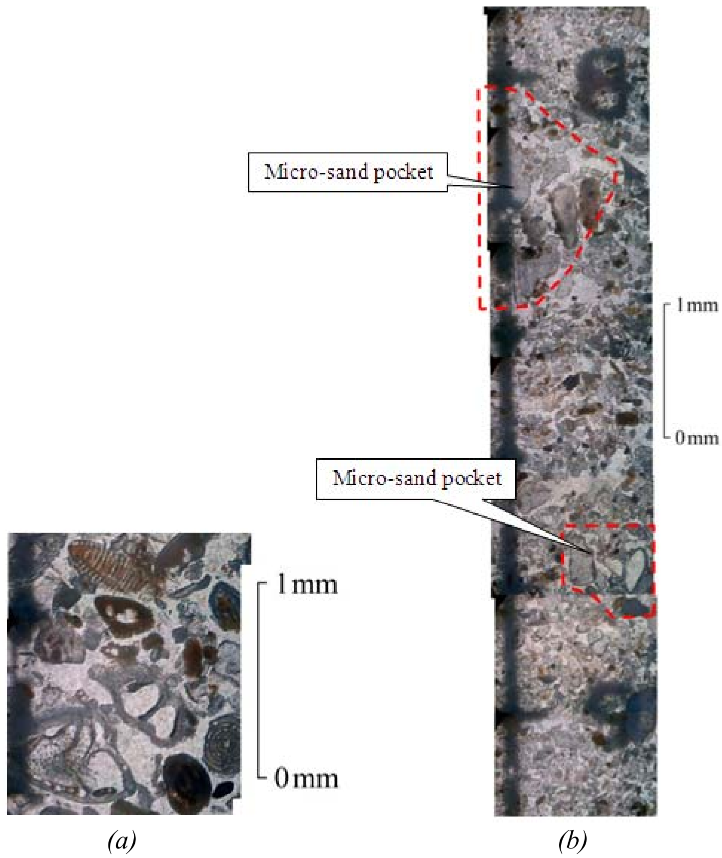
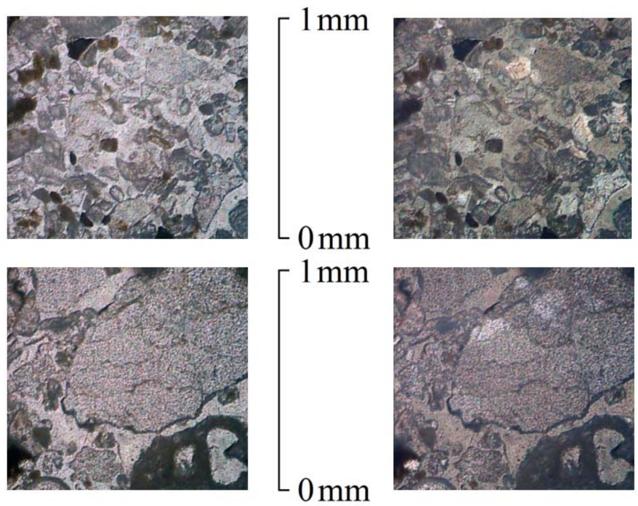


Figure 7. (a) Shell fragment and shallow water micro-organisms in the tsunami deposit (an example from the depth of 6.3-6.4 cm) and (b) example of the micro- sand pockets from the depth 8.5-9.0 cm.

Discussion

The results indicate that the wet-sieve and thin section analyses can be used to illustrate the characteristics of a tsunami deposit. Both techniques show best the unique characteristics which are similar. The tsunami deposit is composed of multiple fining upward sediment layers. The vertical variations of grain-size parameters from the wet-sieve suggest that there are three major sediment layers in the tsunami deposit which is the same observation as from the thin sections. The bases of the major sediment layers are at the depth of 3-4 cm, 7-8 cm and 11-12 cm. They are at the break points in the plot of standard deviation with depth and at the locations



(a) Plane-polarized photomicrograph (b) Cross-polarized photomicrograph

Figure 8. Polarizing microscope pictures of the tsunami deposit thin sections. The cross-polarized picture better displays the mineralogy of the sediment. The quartz grains are the large grey grains, which are displaying corroded margins. The brightly colored mineral is muscovite mica, in typical lath shaped appearance. The dark colored material are organic components in the tsunami deposit.

of grain-size changing from fine grain to coarse grain upwards from the wet-sieve and thin section analyses, respectively. The similar characteristics from both methods can be explained by the previous works of Friedman (1958, 1962) and Johnson (1994). They presented that a linear relationship exists for grain-size analysis between the quartile measures of sieving and thin section data. There is very little scatter on either side of the regression line for this relationship and the coefficient of correlation is close to 1.0. The number of major sediment layers suggests that three run-ups or three tsunami waves affected the study area which is in accordance with eyewitnesses presented by Szczuciński et al. (2006) and Hori et al. (2007).

In this study, minor details which could not be observed in wet-sieve analysis such as the contact between tsunami deposit and pre-existing soil (the base of the tsunami deposit), the micro-soil rip-up clasts or micro-sand pockets in the major sediment layer and the mineral content, were identified in thin sections. Generally, the contact between tsunami deposit and pre-existing soil (the base of the tsunami deposit) is identified at the boundary where the color of sediments is changing (dark color to light color sediments). The thin section shows that the contact of tsunami deposit and pre-existing soil is located lower than the boundary where the color of the sediment changes from dark to light. The sediment lying immediately over the contact of the tsunami deposit and the pre-existing soil has a darker color than the sediments in the upper part. Sediments at the base of a tsunami deposit are composed of coastal sand (light color), onshore sediments and organic materials (dark color) (see Fig. 6(j), Fig. 6(k)). These suggest that tsunamis erode and transport pre-existing sediments from the coastal and onshore areas to be deposited on the up-land area. This phenomenon occurs not only in the 1st major sediment layer (the base of tsunami deposit), but also occurs in the 2nd and the 3rd major sediment layer. However, it is more easy to be observed in the 1st major sediment layer more than in the others. The micro-soil rip-up clasts or micro-sand pockets observed in the major sediment layer might be the result of turbulence associated with a transition to a lower or higher

Reynolds number flow. The turbulence must be a transition of run-up flow to drawdown flow (backwash). It could be said that in each major sediment layer, there are sediments deposited by run-up flow and drawdown flow and the mean grain-size of the sediments deposited by those flows is not significantly different. The mineral content of tsunami deposit can be evaluated under the polarizing microscope. The results show that the tsunami sediment grains are mostly quartz and some muscovite mica. These minerals are major minerals found in sand and silt deposits at the coastal area (e.g. Smith et al., 1976; Harris et al., 1989).

Conclusions

1.) The tsunami deposit is a multiple fining upward sediment layer with coarser shell fragments overlying the pre-existing soil. The sediments are deposited by run-up flow and drawdown flow and the mean grain-size of the sediments deposited by those flows is not significantly different.

2.) The tsunami sediments are mixed sediments of coastal sand, pre-existing onshore sediments and organic materials. The sediments are eroded and transported by tsunamis from the coastal and onshore areas to be deposited on the up-land area.

3.) There are three major sediment layers in the tsunami deposit at Khao Lak, Thailand which reflect three run-ups or three tsunami waves affecting this area.

4.) The boundaries of the major sediment layers are located at the break points in the plot of grain-size standard deviation with depth and at the locations of grain-size changing from fine grain to coarse grain upwards.

5.) Wet-sieve and thin section analyses show the unique characteristics of tsunami deposit which are similar. The thin section results illustrate minor additional characteristics of tsunami deposit. However, the evaluation of the characteristics of a tsunami deposit for reconstructing the geological environment by the wet-sieve method is more convenient than the thin section method (e.g. Srisutam and Wagner, 2009, 2010(a), 2010(b)).

Acknowledgement

We thank Dr. Raimund Schneider for the introduction and collaboration in the thin section preparation.

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