PRESERVATION POTENTIAL OF 2004 INDIAN OCEAN TSUNAMI SEDIMENT IN LOW-LYING AREAS, CHANGWAT PHUKET

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(Kruawun Jankaew, Ph.D.)

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PRESERVATION POTENTIAL OF 2004 INDIAN OCEAN TSUNAMI SEDIMENT IN LOW-LYING AREAS, CHANGWAT PHUKET

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ABSTRACT - After the 2004 Indian Ocean tsunami event, studies on tsunami deposit has increased. Preservation potential of tsunami sediment, which is evaluated from their sedimentary structures and thickness (Szczucinski, 2012), is of the utmost importance for estimation of recurrence intervals of tsunamigenic earthquakes. A low preservation of tsunami deposits in the geological record may lead to an underestimation of tsunami hazard (Spiske, 2013). Phuket was one of the areas most affected by the 2004 tsunami event. Although tourism is developed in the coastal areas and may disturb the tsunami deposit and its preservation, we found a 3 to 20 cm layer of sand which was interpreted as 2004 tsunami deposit in Layan Lagoon and Laguna area. These sand layers consist of fine to coarse sand, normal grading, mud rip-up clasts, sharp basal contact and few shell fragments. The 2004 tsunami deposit is underlain and overlain by fine-grained sediments commonly deposited by suspension in the lagoon which lead to high preservation potential of tsunami sand layer. In contrast, the low potential area is represented by the Bangtao area. The preservation potential depends on depositional environment (e.g. lagoon or plain), climate (e.g. arid or tropical) and anthropogenic modification such as land development for tourism or tin-mining. It is found that the sedimentation rate in Layan Lagoon and Laguna area are 2.2 cm/yr and 2.5 cm/yr, respectively.

KEY WORDS: preservation potential, Indian Ocean Tsunami 2004, tsunami deposits, low-lying areas, Phuket

ศักยภาพในการคงสภาพของตะกอนสึนามิ พ.ศ.2547 ในพื้นที่ลุ่มจังหวัดภูเก็ต

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บดคัดย่อ – หลังเหตุการณ์สึนามิปี พ.ศ.2547 ทำให้มีการศึกษาวิจัยเกี่ยวกับตะกอนสึนามิเพิ่มมากขึ้น ศักยภาพในการคงสภาพของตะกอนสึนามิซึ่งประเมินจากความสมบูรณ์ของชั้นตะกอนได้แก่ ความหนาและโครงสร้างทางตะกอนวิทยา (Szczucinski, 2012) สามารถช่วยในการประเมินคาบอุบัติซ้ำของการเกิดแผ่นดินไหวที่ทำให้เกิดสึนามิได้ และศักยภาพการคงสภาพที่มีค่าต่ำนำไปสู่การประเมินความรุนแรงที่ต่ำกว่าความเป็นจริง (Spiske, 2013) จังหวัดภูเก็ตเป็นพื้นที่ที่ได้รับผลกระทบจากเหตุการณ์ปี พ.ศ.2547 แห่งหนึ่ง โดยแม้ว่าจังหวัดภูเก็ตมีการประกอบธุรกิจการท่องเที่ยวในบริเวณชายหาดซึ่งเป็นปัจจัยที่รบกวนการสะสมตัวและการคงสภาพของตะกอนสึนามิ แต่ก็ยังสามารถพบตะกอนสึนามิ พ.ศ.2547 ได้ในบริเวณทะเลสาบลายันและบริเวณลากูนารีสอร์ท โดยแสดงในลักษณะชั้นตะกอนทรายหนาประมาณ 3-20 เซนติเมตร ที่ประกอบด้วย ทรายขนาดละเอียดถึงหยาบ มีการเรียงขนาดแบบปกติ พบก้อนดินเหนียวและรอยสัมผัสคมชัดปรากฏอยู่บริเวณด้านล่างของชั้นตะกอนทราย และยังพบเศษเปลือกหอยที่แตกหัก โดยชั้นทรายมีการวางตัวอยู่ระหว่างชั้นตะกอนละเอียดที่สะสมตัวในทะเลสาบและมีศักยภาพสูงในการคงสภาพแตกต่างจากบริเวณหาดบางเทาซึ่งมีศักยภาพต่ำ โดยศักยภาพในการคงสภาพของตะกอนสึนามินี้ขึ้นอยู่กับ สภาพแวดล้อมการสะสมตัว (เช่น ทะเลสาบ, ที่ราบลุ่ม) สภาพภูมิอากาศ (เช่น สภาพอากาศแบบแห้งแล้งหรือร้อนชื้น) และการกระทำของมนุษย์ (เช่น การพัฒนาที่ดินเพื่อธุรกิจการท่องเที่ยว การทำเหมืองแร่ดีบุก) พบว่าในทะเลสาบลายันและบริเวณลากูนารีสอร์ทมีอัตราในการสะสมตัวของตะกอนหลังเหตุการณ์สึนามิ พ.ศ.2547 ในทะเลสาบเท่ากับ 2.2 เซนติเมตรต่อปีและ 2.5 เซนติเมตรต่อปีตามลำดับ

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CHAPTER 1: INTRODUCTION

1.1 Rationale

1.2 Objectives

1.3 Scope of work

1.4 Expected results

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1.5.1 Geographic features

1.5.2 Climate

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Chapter 1: Introduction

1.1 Rationale

On the 26th December 2004, an earthquake (Mw 9.1-9.3) caused the catastrophic tsunami which struck the western coast of 6 provinces in southern Thailand and other countries located along the Indian Ocean's shoreline. More than 230,000 people in 14 countries died and a lot of infrastructure and properties were destroyed.

Tsunami sediment is crucial geological evidence of tsunami events. Such deposits are being used to identify past tsunami events and thereby better constrain estimates of both the earthquake and tsunami hazard. The existence of deposits following recent tsunami implies that the geological record in both marine and coastal sedimentary environments should be rich in tsunami sediments even if decades or centuries have passed. However, although tsunami sediments are found in several areas, some are disturbed by either anthropogenic activities or naturally.

The evaluation of the preservation potential of event deposits is very important for the estimation of recurrence intervals of tsunamigenic earthquakes that are then used to assess the tsunami risk of a certain coastline. A low preservation of tsunami deposits in the geological record may lead to an underestimation of tsunami hazard (Spiske, 2013).

Phuket was one of the areas most affected by the 2004 tsunami events. In Phuket, the tourist industry has become the main contributor of its economy. In addition, Phuket has been subjected to tin mining in western tin-bearing granite belt of Thailand. The tourism industry and tin mining may destroy both paleo- and recent tsunami deposits in Phuket (Fig. 1). So this study will record and observe where an appropriate place for finding tsunami deposits in Phuket.

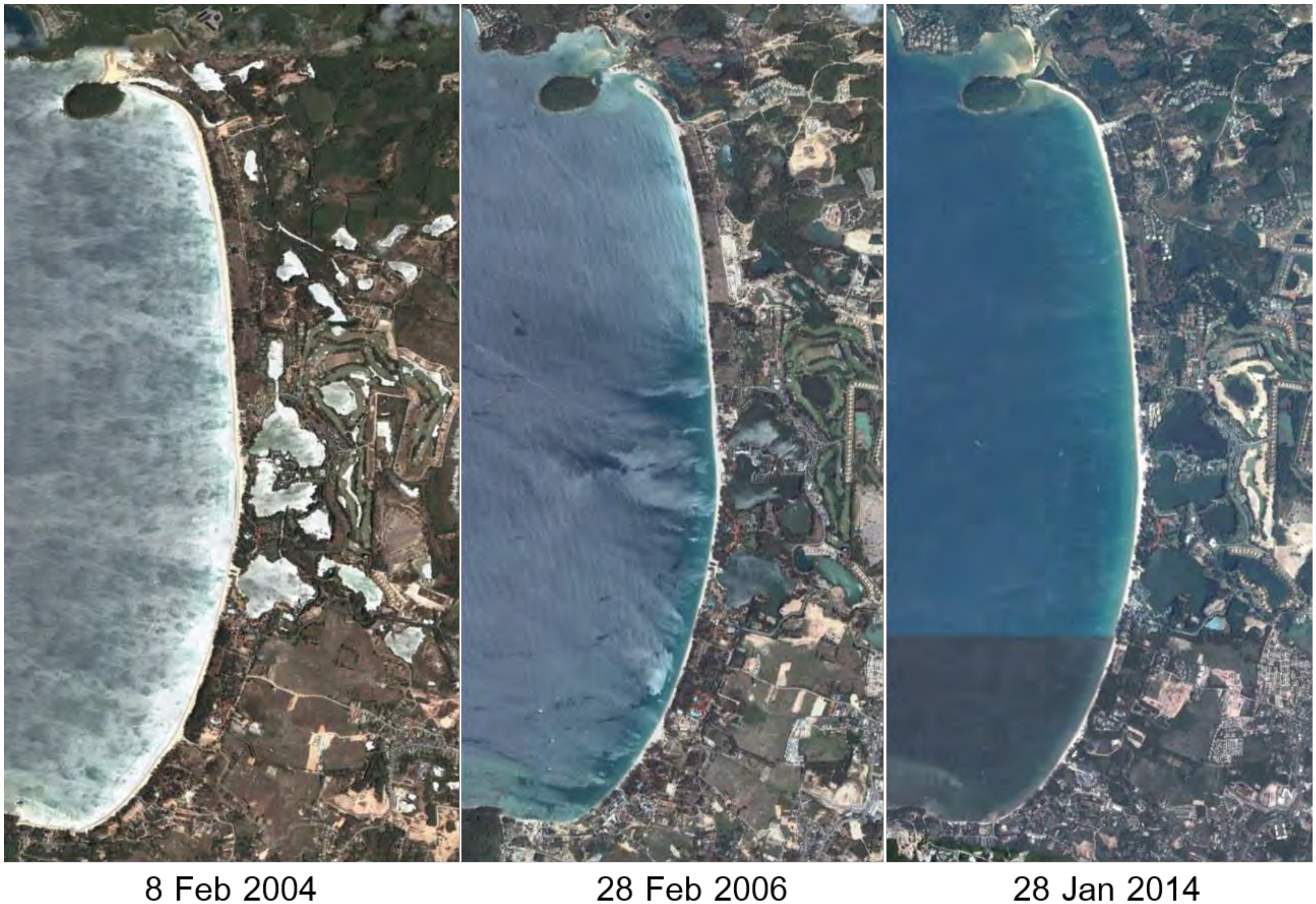

Fig.1 Satellite images from Google Earth show changes in Le Phang bay coastal area due to land development in the past 10 years.

1.2 Objectives

1. To record and observe preservation potential of the 2004 Indian Ocean tsunami deposits in low-lying areas, Changwat Phuket, Thailand.
2. To estimate the deposition rate of sediments after the 2004 tsunami events in low-lying areas, Changwat Phuket, Thailand.

1.3 Scope of Work

In this study, the 2004 tsunami sediments will be observed, recorded and collected from low-lying areas in Phuket.

1.4 Expected results

1. Evaluation of the preservation potential of 2004 Indian Ocean tsunami deposits in low-lying areas, Changwat Phuket.
2. Sedimentation rate of the sediment in low-lying areas after the 2004 tsunami deposit.

1.5 Physical geography and geology of Phuket

1.5.1 Geographic features

Phuket, the study area, is the largest island in Southern Thailand. Phuket is located between latitude and longitude of $7^{o}45'$N - $8^{o}15'$N and $98^{o}15'$E - $98^{o}40'$E. It consists of the island of Phuket, the country's largest island, and another 32 smaller islands off its coast. It lies off the west coast of Thailand in the Andaman Sea. Phuket Province has an area of 576 square kilometers, approximately the same as Singapore.

The island's length, from north to south, is 48 kilometers and its width is 21 kilometers. Seventy percent of Phuket's area is covered with mountains which stretch from north to south, also there are white sand beaches mainly lining the west coast such as Patong beach. The remaining 30% are plains in the central and eastern parts of the island which consists of tidal flat and mangroves at east coast of island.

Tin mining was a major source of income for the island from the 16th century until petering out in the 20th century, however evidence of tin mining still exists as tin-mining ponds around west coasts parts of Phuket, for example, Bangtao beach. Nowadays tourism has become the largest contributor to Phuket's economy.

1.5.2 Climate

Under the Köppen climate classification, Phuket features a tropical monsoon climate. Due to its proximity to the equator, in the course of the year, there is little variation in temperature. The city has an average annual high of 32 °C and an annual low of 25 °C (Table 1). Phuket has a dry season with predominantly northeasterly winds that runs from December through March and a wet season that covers the other eight months.

Climate data for Phuket (Mueang Phuket District) (1981–2010)												
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average high (°C)	32.7	33.6	34	33.9	32.8	32.4	32	32	31.5	31.5	31.7	31.7
Average low (°C)	24.5	24.9	25.4	25.8	25.6	25.5	25.1	25.3	24.6	24.5	24.7	24.4
Average rainfall (mm)	30.3	23.9	73.5	142.9	259.5	213.3	258.2	286.8	361.2	320.1	177.4	72.4
Avg. rainy days (≥ 1 mm)	4	3	5	11	21	19	19	19	23	22	16	8
Average relative humidity (%)	70	69	71	75	79	79	79	79	82	82	79	75
Mean monthly sunshine (hours)	286.2	271.5	282.3	247.9	188.5	139.5	172.6	174.1	143.2	179.8	197.1	244.3
Source: Thai Meteorological Department (Normal 1981-2010), (Avg. rainy days 1961-1990)												

Table 1 General climate data of Phuket town between 1981 and 2010.

1.5.3 Geology

The three dominant stratigraphies on Phuket are 2 groups of Permo-Carboniferous sedimentary and metamorphic rocks, 5 groups of Cretaceous granites, and 7 groups of unconsolidated sediments (Fig. 2a, 2b; DMR, 2014).

1. Quaternary: the geological units can be divided into 7 groups of unconsolidated sediments are as follows:

(1) **Residual deposits (Qr)** is the major sediment of Phuket, it covers undulations and steep piedmonts in an N-S directional geometry.

(2) **Colluvial deposits (Qc)** found along both coasts and mine zone.

(3) **Tidal inlets deposits (Qtf)** found as an elongated ellipsoid within Chalong Bay and the southwestern Amphoe Talang.

(4) **Beach ridge (Qb)** found to be different on both shores, the west coast contains medium-coarse sand with heavy minerals, and in contrast, plant fragments were commonly found on the east coast.

(5) **Back mangrove deposits (Qmb)** found at Ban Bang Neaw.

(6) **Mangrove swamp deposits (Qtm)** found on the current east coast next to an intertidal zone.

(7) **Back beach deposits (Qtb)** found on Mai Khao and Kata Beaches.

2. Kaeng Krachan Group found as thin sandstone and thin mudstone. The group can also be classified into the 3 following formations:

(1) **Laem Mai Phai Formation** - a gray, thinly laminated mudstone and massive mudstone formed in channel - emerges on the eastern-central part of Phuket.

(2) **Spillway Formation** - a thin pebbly mudstone with a thin fine grain greywacke, an interfingering fine sand - siltstone and mudstone with load cast, worm burrow, bioturbation and slump structure, lies above Laem Mai Phai Formation on the east coast.

(3) **Ko He Formation** - diamictites (pebbly-silty mudstone and a boulderish sandstone) deposited in subaqueous environment – continuously and alternately bedded with Spillway Formation on He island.

3. Cretaceous granites which can be divided into 5 groups are as follows:

(1) Khao Prathiu Granite (gr_1)

(2) Kata Beach Granite (gr_2)

(3) Naithon Beach Granite (gr_3) is the oldest granite here with 100±6 Ma

(4) Khao Tosae Granite (gr_4)

(5) Khao Rang Granite (gr_5) is the youngest group with 78±4 Ma

1.6 Theory and relevant research

1.6.1 Tsunami deposits

A tsunami deposit (or tsunamiites) is a sedimentary unit deposited as the result of a tsunami. Tsunami can be classified into 3 types, according to their causes; earthquake tsunamis, slide-generated tsunamis and bolide impact tsunamis (Dawson and Stewart, 2007). Tsunami sediments have been found both offshore and onshore. Onshore deposits can be laid down immediately after a tsunami in coastal environments, such as in swales or lagoons. Sedimentary features indicate that fine-grained onshore tsunami deposits can exhibit a number of characteristics, such as erosive lower contacts, rip-up clasts, normal grading, lamination (e.g. from heavy mineral layers), mud caps, and landward thinning and fining (Dawson and Shi, 2000; Morton et al., 2007; Phantuwongraj and Choowong, 2011).

1.6.2 Tsunami studies at Phuket

Choowong et al. (2008b) reported the 2004 Indian Ocean tsunami produced a repeated sequence in which rapid inflow and outflow occurred at Bangtao Beach, Phuket (location shown in Fig.5). The tsunami left behind a sand sheet as much as 25 cm thick that was composed of medium to coarse sand that grades upward to fine, landward-inclined laminae, mud rip-ups, and a sharp lower contact (Fig.3). The deposit contains multiple fining-upward sequences possibly due to multiple surges but a number of multiple grading structures may not represents a number of inflows (Phantuwongraj and Choowong, 2012).

The tsunami wave train first reached Phuket about 1hr 40 mins after the earthquake (about 9.40am local time) in a form of a trough, lasting for about 11 minutes, causing sea withdrawal to below normal low tide levels. The first tsunami wave arrived at about 10 am local time. The wave off Thailand travelled obliquely along the coast from south to north. Maximum tsunami height along the western beaches of Phuket was about 5-6 meters, shown in Fig.4 (Tsuji et al., 2006; Bell et al., 2005; Choowong et al., 2007).

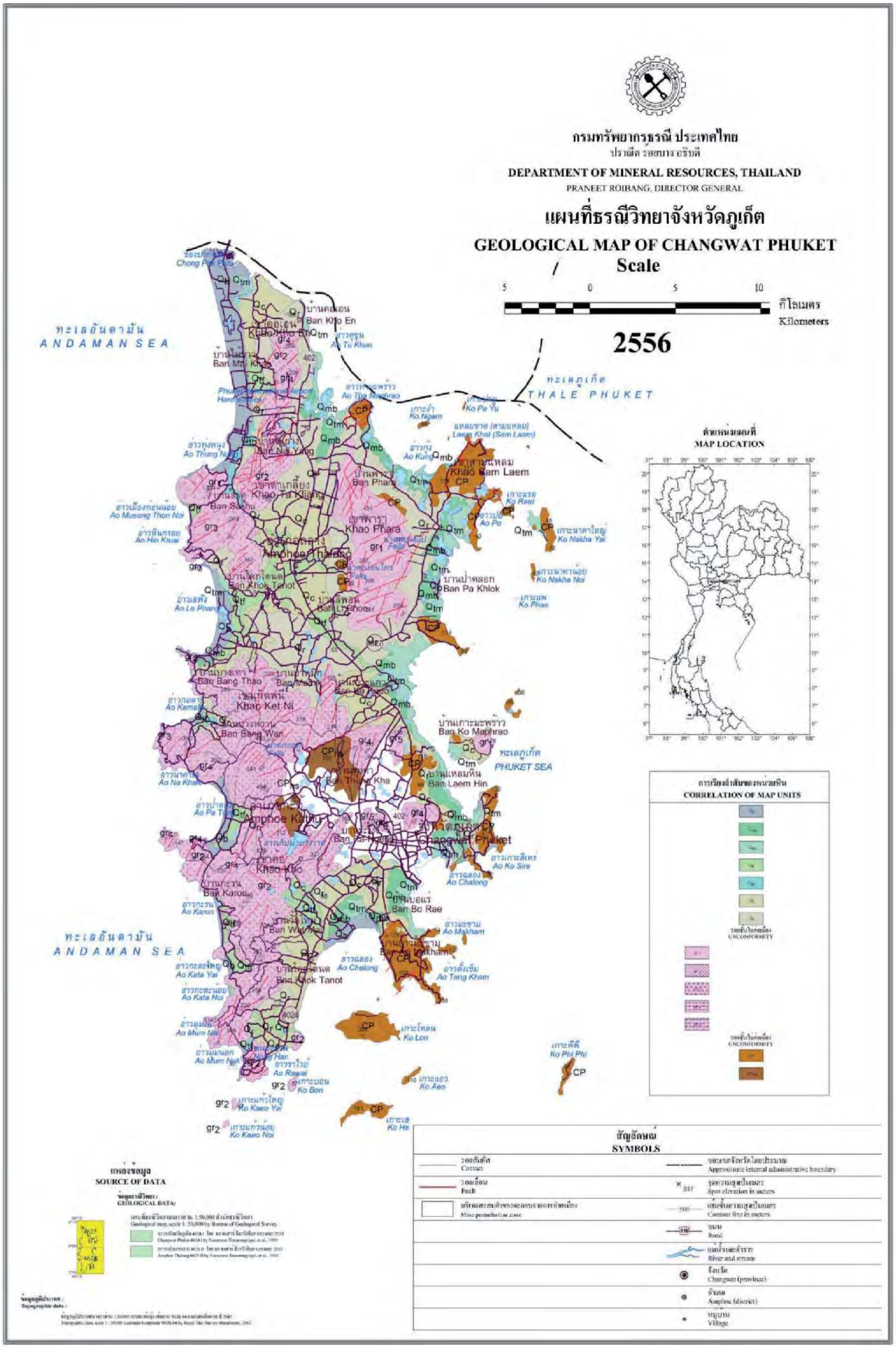

Fig.2a Geologic map of Phuket (DMR, 2014).

SEDIMENT, SEDIMENTARY AND METAMORPHIC ROCKS	FORMATION/ GROUP	PERIOD	AGE (my.)
Q_b Beach deposits : sand, loose, gravelly, sand size 100 - 1,200 micron, well sorted, gravel size 2 - 5 mm.		QUATERNARY	0.01-1.6
Q_{mb} Back mangrove deposits: sandy, gray to dark gray, small amount plant remains, bioturbation structure.			
Q_{tm} Mangrove swamp deposits : clay, peaty, dark gray to blank, sand lenes.			
Q_{tl} Tidal inlets deposits : sand and gravel, size 800 - 1,500 micron, poorly sorted, abundant shell fragment and plant remains.			
Q_{tb} Back beach deposits : clay and silt, gray to brown, find sand interbedded, abundant mottles.			
Q_c Colluvial deposits : sand and clay, light gray, poorly sorted, secondary cassiterite occured.			
Q_r Residual deposits : rock fragments, silt and clay, angular poorly sorted.			
CP Pebbly mudstone, pebble sandstone, laminated mudstone and sandstone, silicify mudstone, slump structure and filled burrow.	KAENG KRACHAN Gp.	PERMIAN to CARBONIFEROUS	245-360
CP_{hs} Hornfelsic rock and schists at contact zone.			
IGNEOUS ROCKS	PERIOD		
gr_1 Prathiu granite : Biotite - hormblende granite, medium - coarse-grained, equigranular to porphyritc, pink feldspar with allanite and sphene accessories, Rb - Sr whole rock isochron age is at 82±4 Ma.	CRETACEOUS		66.4-140
gr_2 Kata granite : Biotite - hornblende grante, coarse-to very coarse-grained, porphyritic, with sphene accessory, Rb - Sr whole rock isochon age is at 98±7 Ma			
gr_3 Nai Yang granite : Muscovite - biotite granite, coarse grained, equigranular to porphyritic, Rb - Sr whole rock isochron age is at 100±6 Ma.			
gr_4 (Rb - Sr whole rock isochron) To Sae granite : biotite - musovite granite, fine-to medium-grained, equigranular to porphyritic, Rb - Sr whole rock isochron age is 84±1 Ma.			
gr_5 Khao Rang granite : Tourmaline - muscuvite granite, fine-to-medium grained, equigranular, grayish white at 78±4 Ma.			

Fig.2b Stratigraphy and description of Geology of Phuket (DMR, 2014).

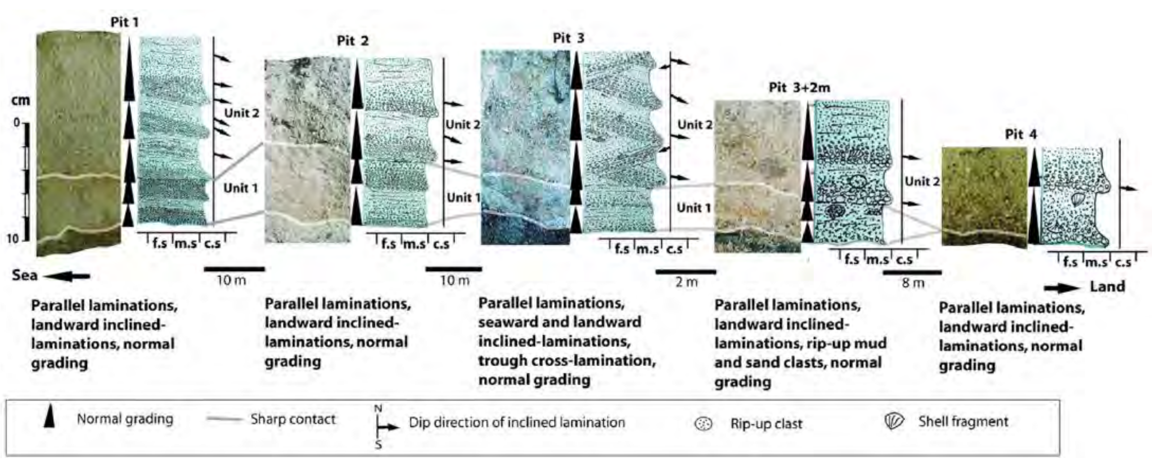

Fig.3 Bedforms and stratigraphic columns near the Bangtao Beach along a 30-m-long transect showing coastal deposit and 2004 tsunami deposit (Choowong et al., 2008b).

1.6.3 Preservation potential of tsunami deposits

Wheatcroft (1990) proposed the meaning of preservation potential of sedimentary event layers (e.g., ash layers or tempestites) is a function of net sedimentation rate and biogenous mixing rate. The deposition and preservation of tsunami deposits is upon an appropriate supply of sediment from the near shore and offshore zones (Dawson and Shi, 2000).

Szczucinski (2006) mentioned that the preservation of a tsunami layer in mangrove setting is minimal, in contrast, preservation potential in lake, lagoon or marsh and also offshore is high (Dawson and Stewart, 2007). Furthermore, Phantuwongraj and Choowong (2012) classified the depositional features and preservation potential of the 2004 tsunami and storm deposits into four types with respect to the different topographical configurations as follows; (1) Type A: Gentle and flat topography, (2) Type B: Tidal channel embayment, (3) Type C: Swale and beach ridge, and (4) Type D: Large-scale irregular topography. This classification relate to the depositional setting mentioned in Szczucinski (2006) which have high preservation potential.

Szczucinski (2012) graded the preservation potential into: low preservation (generally no deposits left or are very difficult to recognize), moderate preservation (deposits exists but are altered in several ways), and good preservation (preserved in terms of thickness but also structures etc.). He suggested that post-depositional changes seem to be strongly related to the environment, setting and climate. Moreover, the sedimentary record of tsunamis with a run-up of less than 3m and the layers that are thinner than 10 cm are less well preserved.

Spiske (2013) suggested that the preservation potential is generally determined by (1) composition and genetic type of the tsunami deposits, (2) coastal topography and depositional environment, (3) co- and post-seismic uplift or subsidence, (4) climate, and (5) anthropogenic modification of the coast. In addition, the preservation of onshore event deposits is a complex issue with a combination of these factors.

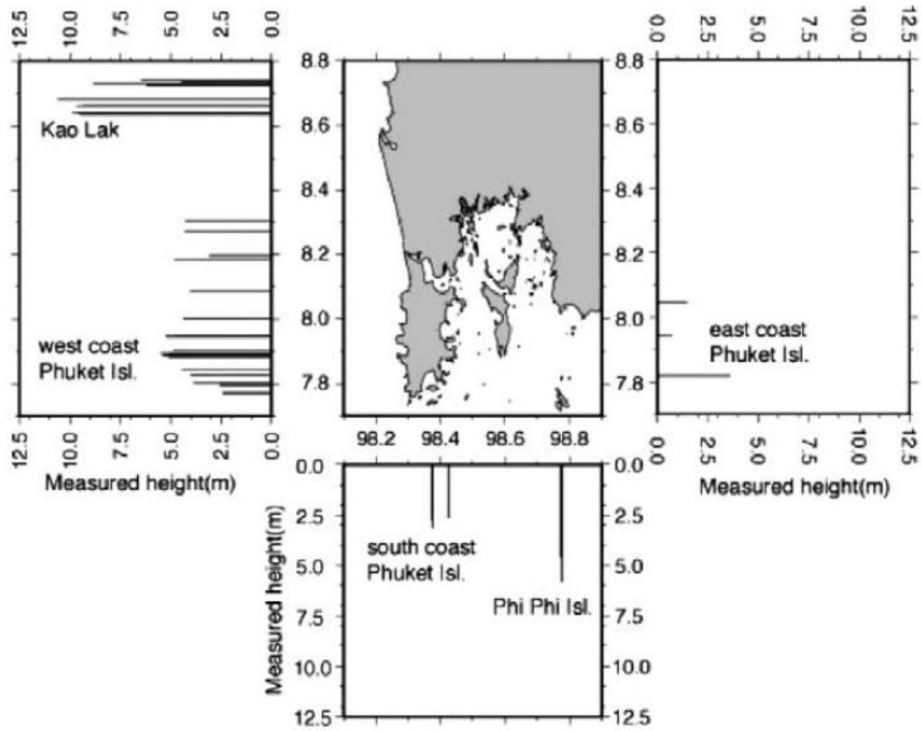

Fig.4 Tsunami heights from the Andaman coast of Thailand (Choowong et al., 2007).

CHAPTER 2: METHODOLOGY

2.1 Pre-field investigation

2.1.1 Study area selection

2.2 Data acquisition

2.2.1 Sample collection

2.3 Laboratory works

2.3.1 Sample preparation

2.3.2 Loss on ignition (LOI)

2.3.3 Grain size analysis

Chapter 2: Methodology

This chapter explains the methodology of study which is used in this project. The workflow shows 5 steps of methodology as follows (Fig.5).

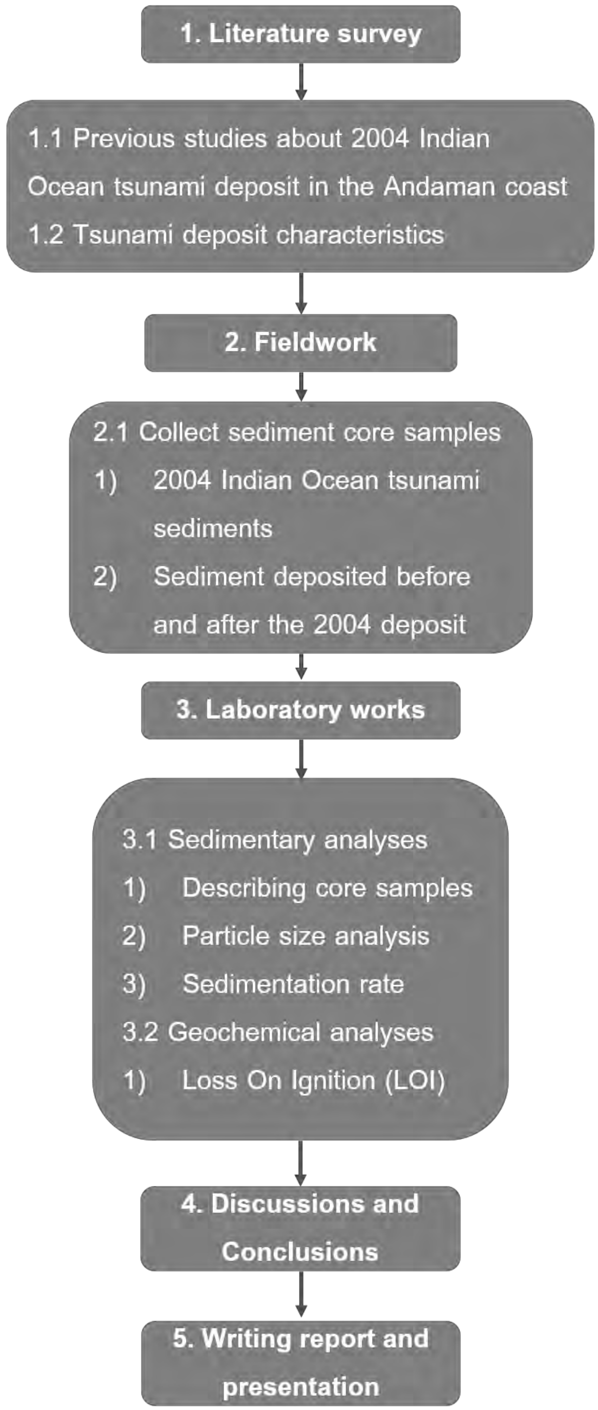

Fig.5 Flowchart shows steps in this senior project methodology.

2.1 Pre-field investigation

Literature survey of related information is the beginning of this study. The relevant research is mentioned in the previous chapter.

2.1.1 Study area selection

According to the inundation map of the 2004 tsunami in Phuket (Fig.6), almost all of the beaches on the west coast of the island sustained major damage, especially Kamala, Patong, Karon and Kata beaches. Most of the beaches have many buildings, so good sites which may contain 2004 tsunami deposit is rare.

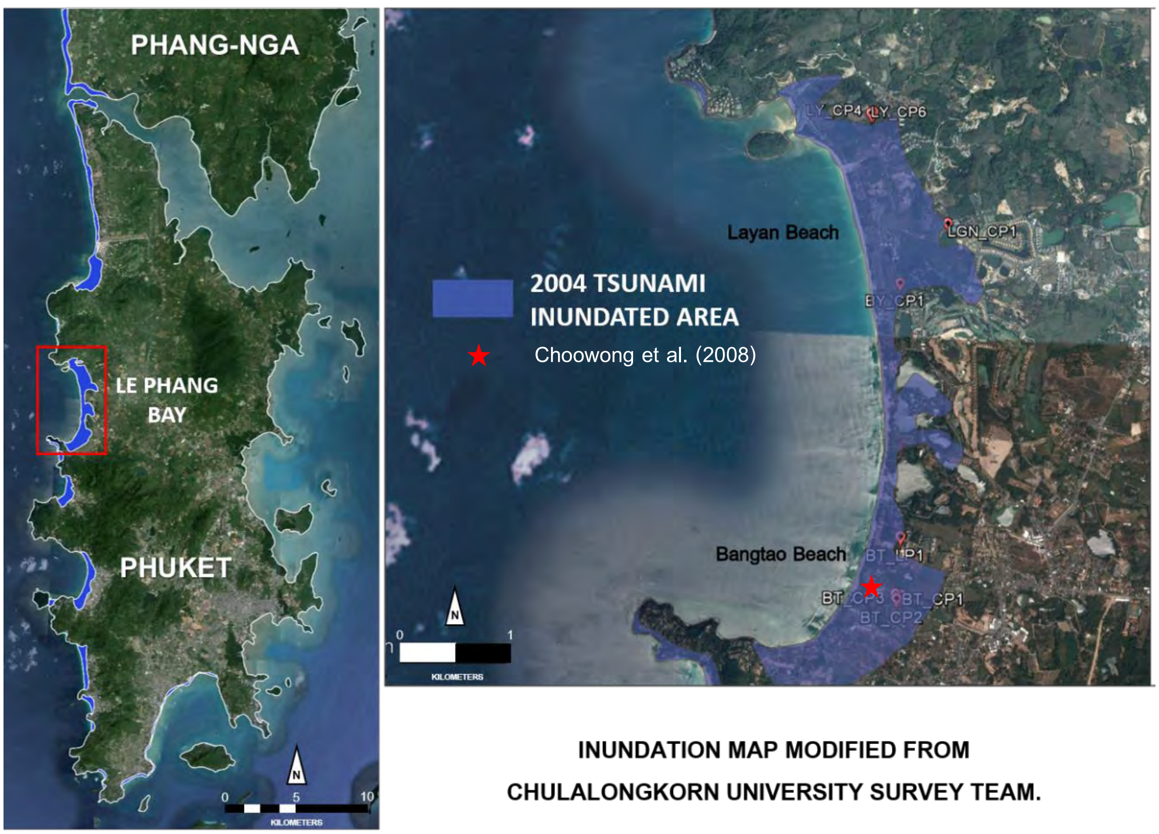

Fig.6 Location of study area (left) and sampling point (right) overlaying with 2004 tsunami inundation area surveyed by Chulalongkorn University survey team (satellite images from Google Earth: 28 Jan 2014).

Le Phang Bay, consisting of Bangtao Beach and Layan Beach, is an exceptional area because the coastal area is less developed. There are some low-lying areas, such as fields and lagoons, which may contain 2004 tsunami deposits.

2.2 Data acquisition

2.2.1 Sample collection

Sediment samples were collected from 3 main areas which are (1) Layan Lagoon, (2) Laguna Area, and (3) Bangtao Area. Almost all of the sampling areas are lagoons so a Russian core sampler set (Fig.7) was used to collect core samples. Core samples were collected in 1m-long sections starting at the sediment surface until bedrock is reached and another core sample was collected nearby the previous core but starting at 0.5m for making composite depth cores. The entire sediment core samples are described in terms of physical properties and samples are collected at 1 centimeter interval for loss on ignition and grain size analysis.

Fig.7 Coring point in lagoon (top), Russian core sampler set (middle) and sediment core samples (bottom).

2.3 Laboratory works

2.3.1 Sample preparation

Core samples are divided into 2 sets for grain size analysis and loss on ignition (LOI). For grain size analysis, samples were treated with 10% HCl followed by 10% H_2O_2 to remove calcium carbonates and organic materials, respectively. The second sample set was placed in an oven at 105°C for drying between 12-24 hours until it was completely dry.

2.3.2 Loss on ignition (LOI)

Sequential loss on ignition (LOI) is a common and widely used method to estimate the organic and carbonate contents of sediments. In the first reaction, organic matter is oxidized at 500-550 °C to carbon dioxide and ash. The weight loss should then be proportional to the amount of organic carbon contained in the sample. In a second reaction, carbon dioxide is changed from carbonate at 900-1000 °C, leaving oxide. The weight loss during the reactions is easily measured by weighing the samples before and after heating and is closely correlated to the organic matter and carbonate contents of the sediment (Heiri et al., 2001).

The LOI is then calculated using the following equations:

$$LOI_{550} = [(DW_{105} – DW_{550})/DW_{105}]*100 \text{ ----------- } (1)$$

$$LOI_{950} = [(DW_{550} – DW_{950})/DW_{105}]*100 \text{ ----------- } (2)$$

Where LOI_{550} represents LOI at 550 °C (as a percentage)

LOI_{950} represents the LOI at 950 °C (as a percentage)

DW_{105} represents the dry weight of the sample before combustion

DW_{550} represents the dry weight of the sample after 6 hours heating to 550 °C

DW_{950} represents the dry weight of the sample after 4 hours heating to 950 °C

2.3.3 Grain size analysis

After treating the sediment samples with 10% HCl and 10% H_2O_2, the samples are sent to analyze the grain size diameter by using a Particle Size Analyzer, Laser Diffraction (Fig.8), at the Department of Industrial Chemistry, Faculty of Science, Chiang Mai University.

Each sample is analyzed in 500ml of deionized water. The grain size is detected by pumping into the Particle Size Analyzer 2,600 times per minute and 14 Hz ultrasonic in 2 minutes. The results are shown in volume of grain diameter of 0.0582 - 878.675 micron. The grain size data can then be calculated in terms of statistic values using equations shown in Table 2 (mean, standard deviation, skewness and kurtosis) and grain size distribution plots relative to depth can be made.

Fig.8 Particle Size Analyzer, Laser Diffraction service in

Department of Industrial Chemistry, Faculty of Science, Chiang Mai University.

Table 2 Statistical formulae used in the calculation of grain size parameters modified from Krumbein and Pettijohn (1938) and Folk and Ward (1957) (f is the frequency in percent; m_{ϕ} is the mid-point of each class interval in phi unit (Blott and Pye, 2001).

(c) Logarithmic method of moments

Mean	Standard deviation	Skewness	Kurtosis
$\bar{x}_\phi = \frac{\Sigma f m_\phi}{100}$	$\sigma_\phi = \sqrt{\frac{\Sigma f (m_\phi - \bar{x}_\phi)^2}{100}}$	$Sk_\phi = \frac{\Sigma f (m_\phi - \bar{x}_\phi)^3}{100 \sigma_\phi{}^3}$	$K_\phi = \frac{\Sigma f (m_\phi - \bar{x}_\phi)^4}{100 \sigma_\phi^4}$

Sorting (σ_ϕ)		Skewness (Sk_ϕ)		Kurtosis (K_ϕ)	
Very well sorted	<0·35	Very fine skewed	>$^{+}$1·30	Very platykurtic	<1·70
Well sorted	0·35–0·50	Fine skewed	$^{+}$0·43 to $^{+}$1·30	Platykurtic	1·70–2·55
Moderately well sorted	0·50–0·70	Symmetrical	$^{-}$0·43 to $^{+}$0·43	Mesokurtic	2·55–3·70
Moderately sorted	0·70–1·00	Coarse skewed	$^{-}$0·43 to $^{-}$1·30	Leptokurtic	3·70–7·40
Poorly sorted	1·00–2·00	Very coarse skewed	<$^{-}$1·30	Very leptokurtic	>7·40
Very poorly sorted	2·00–4·00				
Extremely poorly sorted	>4·00				

CHAPTER 3: RESULTS

3.1 Tsunami sediments

3.1.1 Layan Lagoon

3.1.2 Laguna area

3.1.3 Bangtao area

3.2 LOI and grain size distribution

3.3 Sedimentation rate of post-event deposits

Chapter 3: Results

From field investigation, low-lying areas such as lagoon or paddy field which may contain 2004 tsunami sediment were chosen as sampling points. The sediment core samples in the study area were observed and described in terms of their physical properties including sedimentary structure, grain size and composition. The samples were collected from 3 main areas from North to South which are Layan Lagoon, Laguna area and Bangtao area (Fig.9). 5 of the 10 core samples contained a sand layer (details shown in Table 3) that is overlain and underlain by fine-grained sediment. The sand sediments were treated and analyzed for their particle size and loss on ignition. The sites of sample collection were located by using hand-held GPS and plotted on Google Earth as shown in Fig.9.

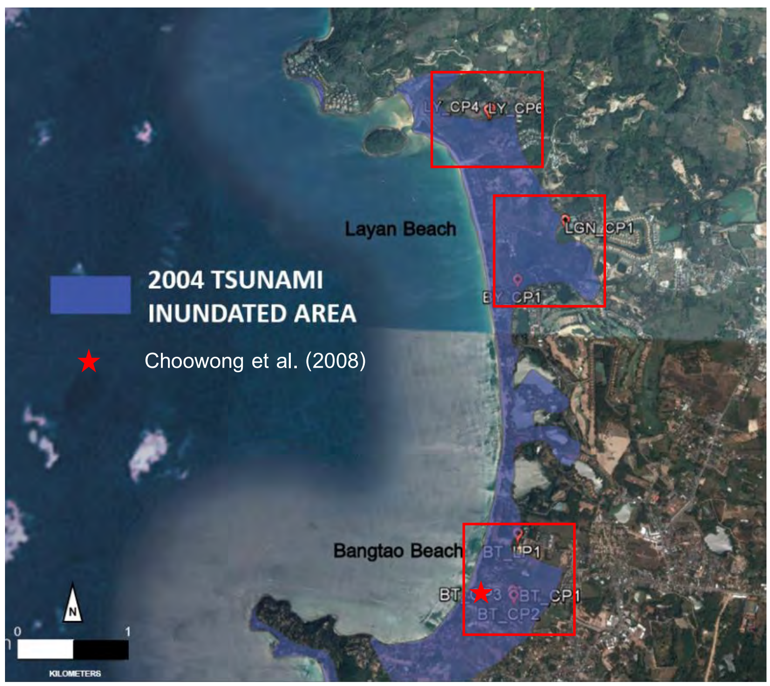

Fig.9 Satellite image from Google Earth (28 Jan 2014) of Le Phang Bay shows locations where samples were collected. From North to South; Layan Lagoon, Laguna area and Bangtao area.

Table 3 Lists of collected samples, their geographic coordinates, total thickness recovered and sand layer thickness in this study.

Location	Core Name	Geographic coordinate		Total thickness	Sand layer thickness
		Latitude	Longitude		
Layan Lagoon	LY_CP1	8°01'56.3" N	98°17'30.6" E	150 cm	12 cm
	LY_CP2	8°01'59.7" N	98°17'33.4" E	200 cm	-
	LY_CP3	8°01'56.2" N	98°17'31.1" E	160 cm	3 cm
	LY_CP4	8°01'56.3" N	98°17'30.8" E	100 cm	15 cm
	LY_CP6	8°01'56.8" N	98°17'30.2" E	100 cm	18 cm
Laguna Area	LGN_CP1	8°01'16.2" N	98°17'54.3" E	100 cm	-
	BY_CP1	8°00'56.0" N	98°17'38.7" E	25 cm	22 cm
Bangtao Area	BT_LP1	7°59'33.5" N	98°17'36.6" E	-	-
	BT_CP1	7°59'15.5" N	98°17'36.6" E	40 cm	-
	BT_CP2	7°59'14.7" N	98°17'34.9" E	56 cm	-
	BT_CP3	7°59'16.0" N	98°17'34.6" E	40 cm	-

'-': not exist in core sample

3.1 Tsunami sediments

From all sediment samples, a sand layer is believed to be 2004 tsunami sediment. The 2004 tsunami sediment can be identified based on sedimentary characteristics (shown in Fig.10) such as sharp basal contact, rip-up clasts, normal grading and containing shell fragments.

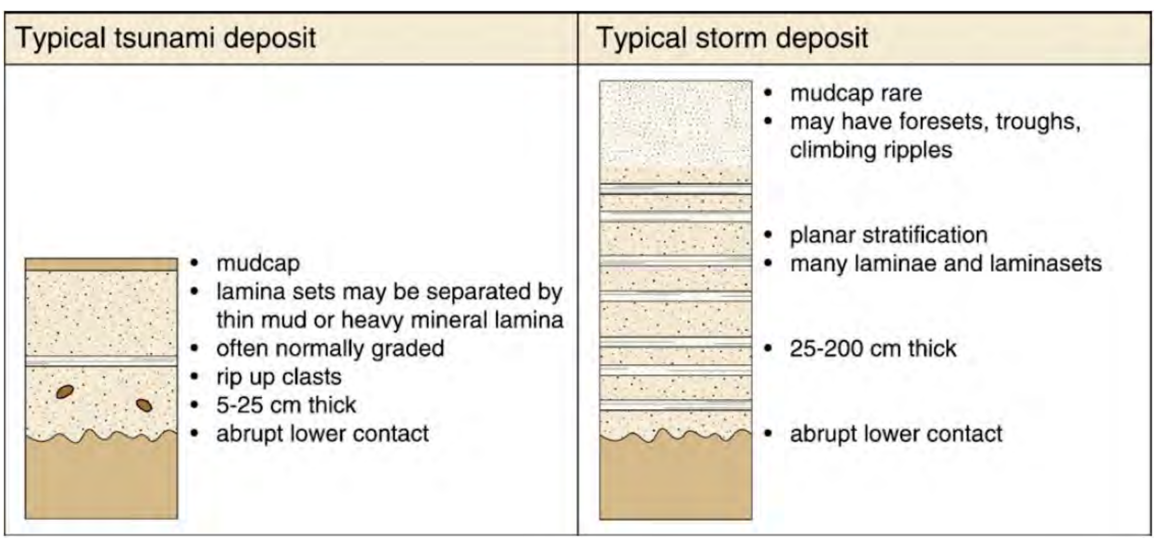

Fig.10 Composite characteristics of typical sandy tsunami and storm deposits (Morton et al., 2007).

3.1.1 Layan Lagoon is located in the north of Le Phang Bay. The lagoon comprises of 3 small lagoons (Fig.11). Five cores were collected, 4 cores in the middle and another core further into the lagoon. Sand layers are found in almost all of core samples except LY_CP2 which contains only laminated clay (Fig.17a). The sand layers are interpreted as 2004 tsunami sediments which are fine to coarse sand with parallel lamination and mud coating. Normal grading and mud rip-up clasts are commonly found. Quartz is the main component of these sediments, shell fragments are minor. The clay and silty clay above and below the tsunami sediments play an important role in preserving the tsunami deposits. There is no other sand layer, which may imply paleotsunami. The stratigraphic columns and their description of all core samples are shown in Fig.12 to Fig.15 and Fig.17a.

Fig.11 Satellite image shows all coring points in Layan Lagoon (from Google Earth: 28 Jan 2014).

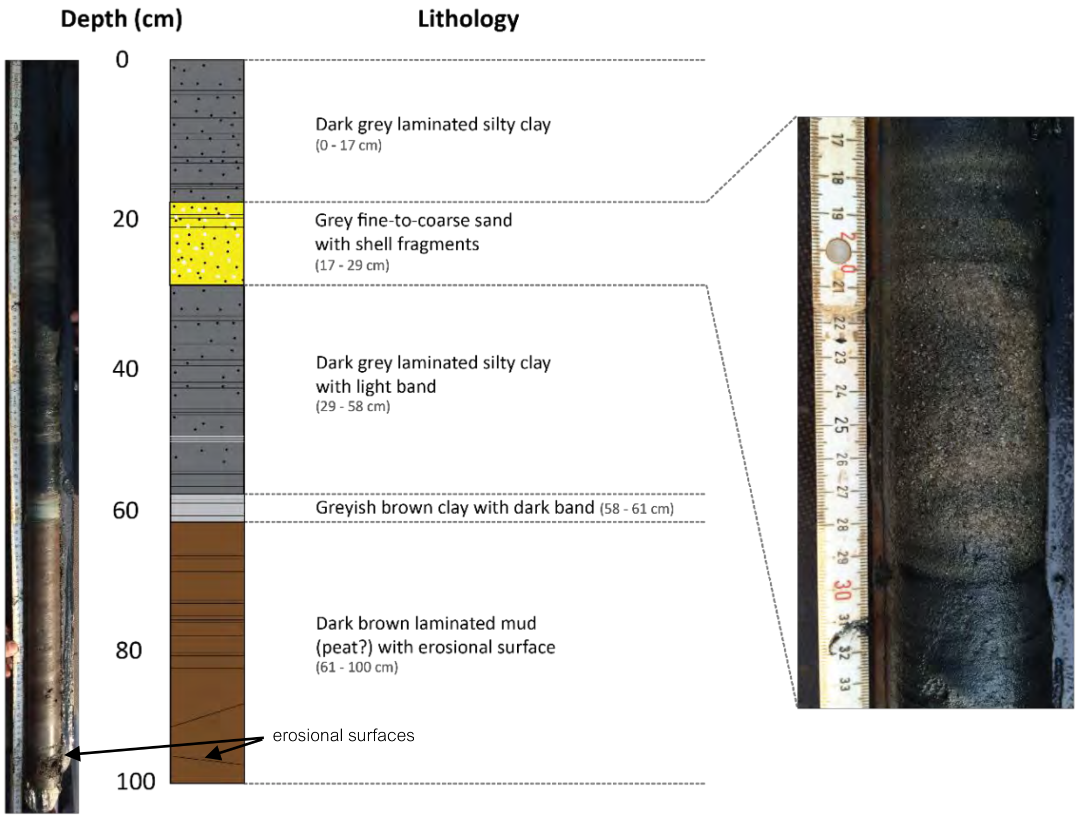

Fig.12 Stratigraphic column and lithology of LY_CP1 shows sand layer and its sedimentary features which are interpreted as 2004 tsunami deposits.

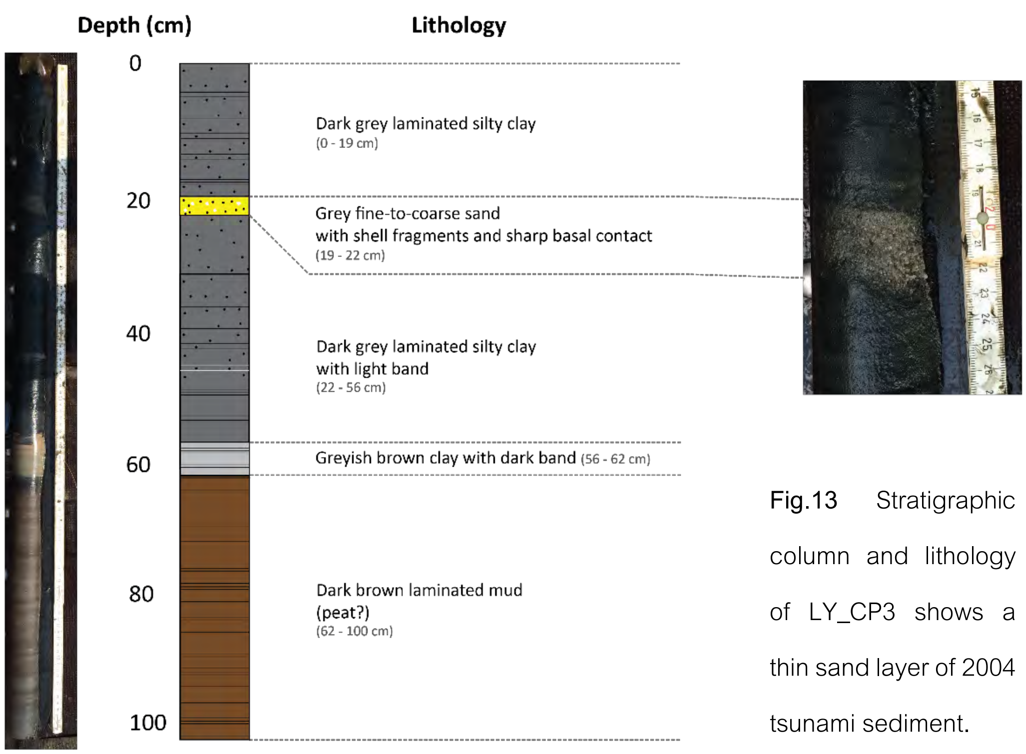

Fig.13 Stratigraphic column and lithology of LY_CP3 shows a thin sand layer of 2004 tsunami sediment.

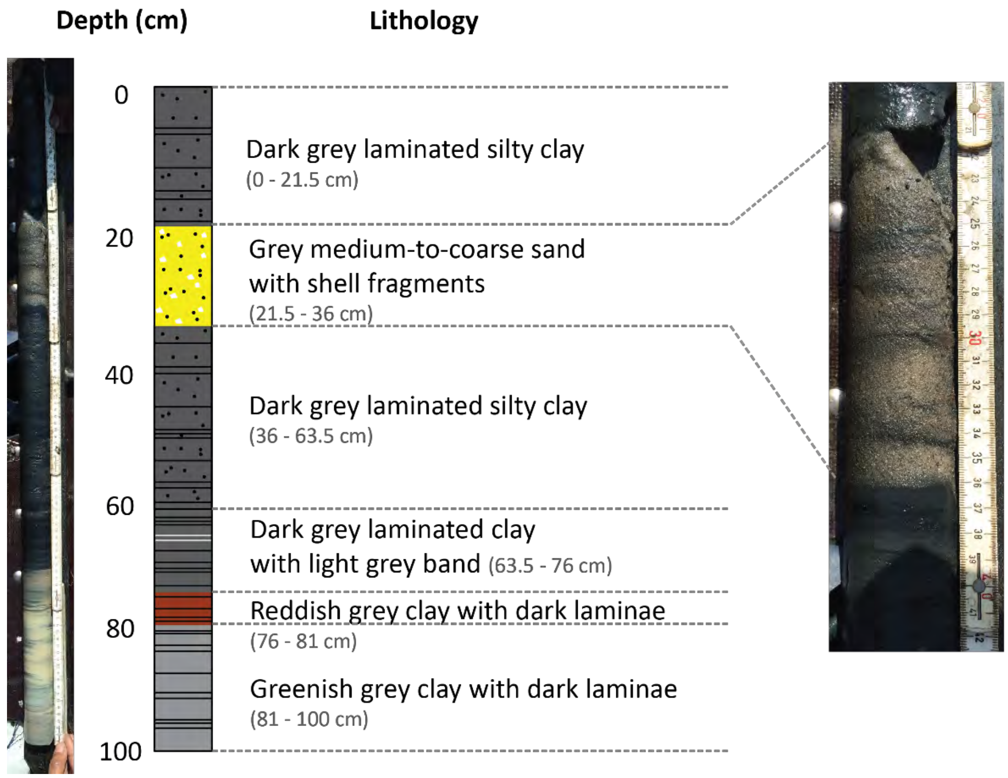

Fig.14 Stratigraphic column and lithology of LY_CP4 shows a thick 14.5 cm sand layer with sedimentary features which implies 2004 tsunami deposit.

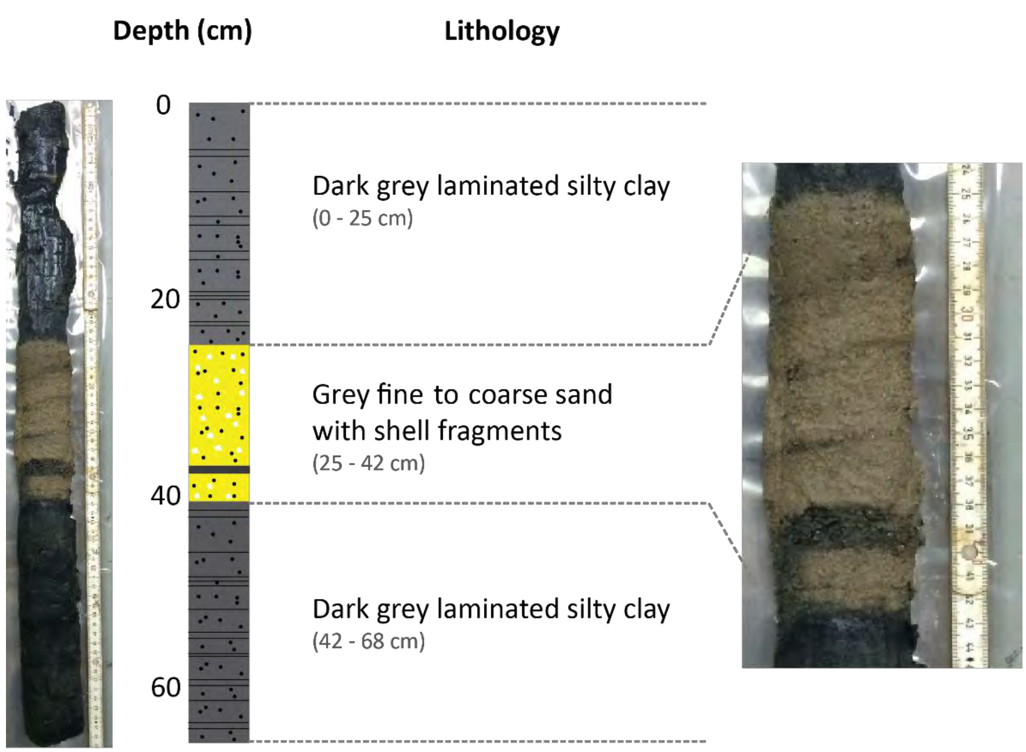

Fig.15 Stratigraphic column and lithology of LY_CP6 shows a very thick 17 cm 2004 tsunami sand layer.

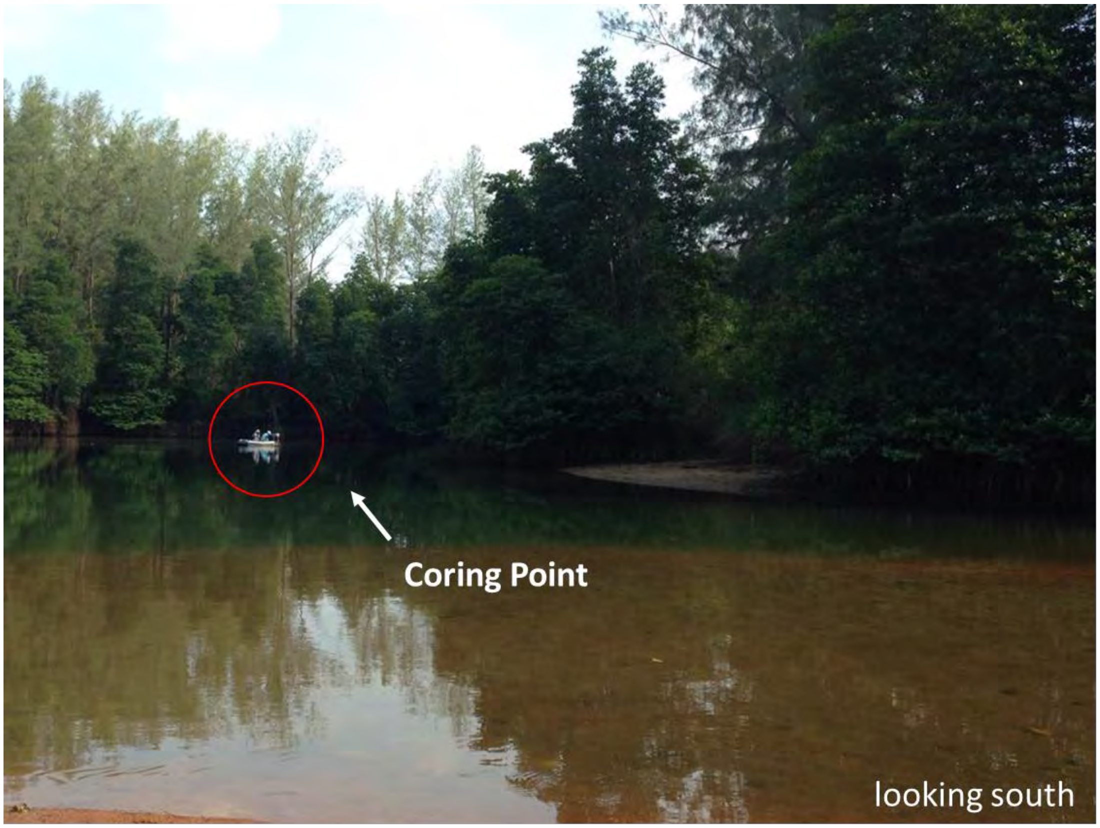

Fig.16 Location of coring point LY_CP4 (red circle) in Layan Lagoon.

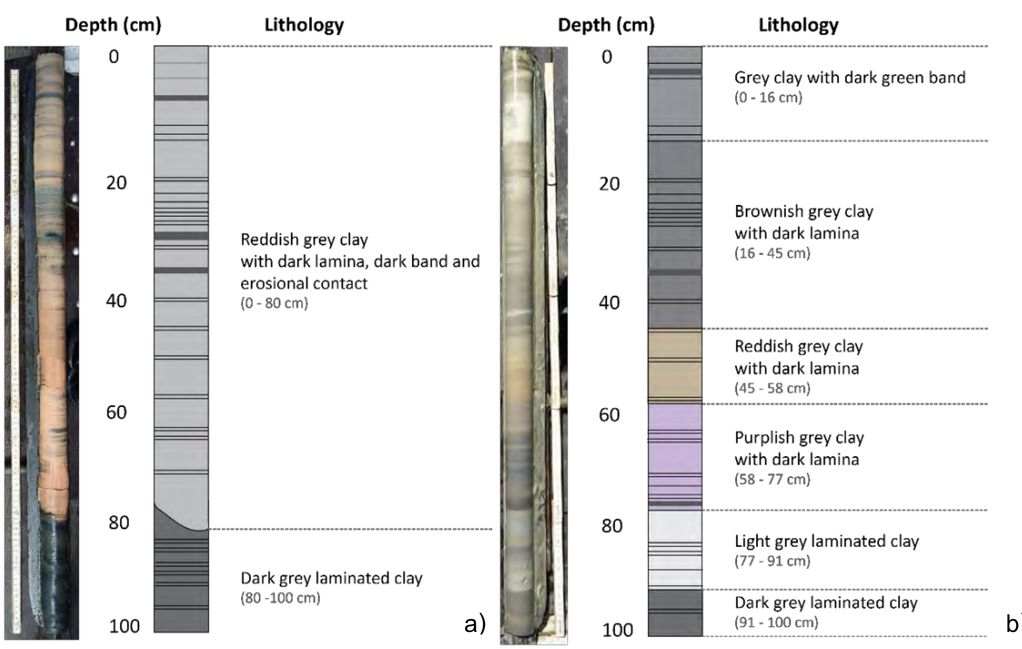

Fig.17 Stratigraphic column and lithology of a) LY_CP2 and

b) LGN_CP1 which do not contain sand layer.

3.1.2 Laguna Area has many lagoons which were affected by the 2004 tsunami event and closer to shoreline than Layan Lagoon so tsunami deposits can be found in these areas unless they have been disturbed by human activity. The coring points are shown in Fig.19 to Fig.21 which are BY_CP1 and LGN_CP1. BY_CP1 is a 25 cm thick sediment core composing of 22 cm of fine to coarse sand layer covered by unconsolidated sediments and underlain by mud and clay. Normal grading, mud rip-up clasts, sharp basal contact and shell fragments are found in this sand layer which implies 2004 tsunami deposits (Fig. 18). LGN_CP1 contains several units of laminated brownish grey clay with no tsunami deposit (Fig.17b).

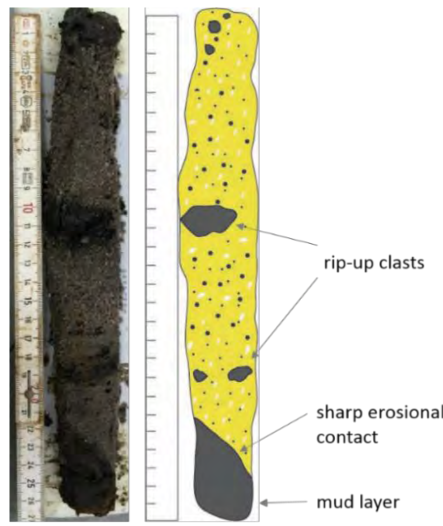

Fig.18 The stratigraphic column of BY_CP1 showing mud rip-up clasts, sharp basal contact and few shell fragments.

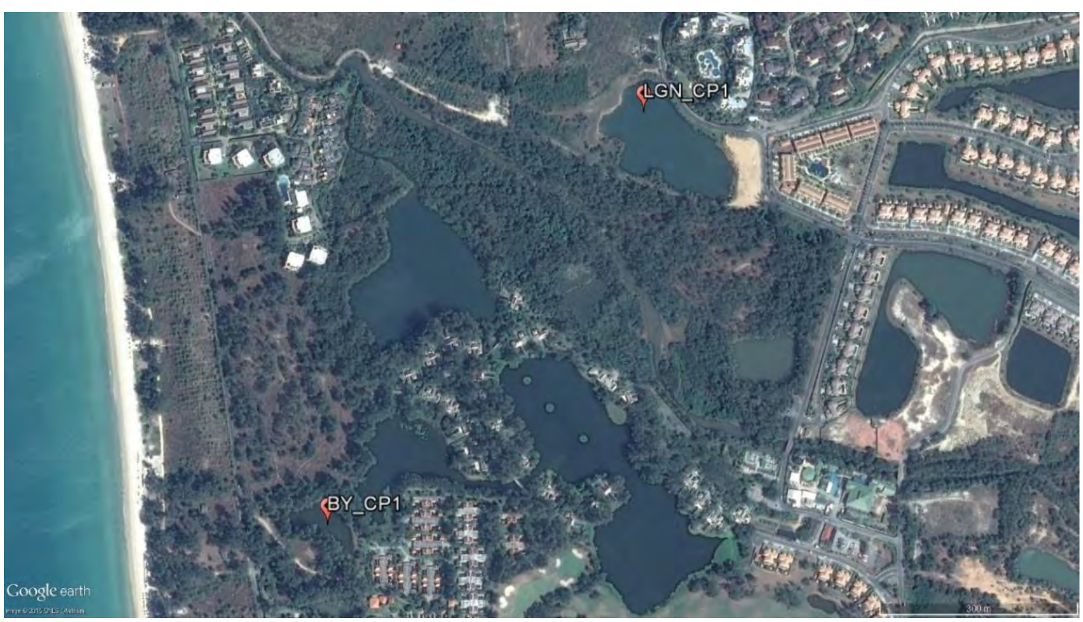

Fig.19 Satellite image shows coring points in Laguna area (from Google Earth: 28 Jan 2014).

Fig.20 Location of BY_CP1 coring point in Laguna area.

Fig.21 Location of LGN_CP1 in Laguna area. The coring point is the southernmost of this picture.

3.1.3 Bangtao Area is the southernmost part of the study area. The sampling points are shown in Fig.22 and Fig.23 which consist of a pond and rice paddy field. All sampling points are within the 2004 tsunami inundation limit. Local eyewitness confirmed that a pond BT_LP1 was constructed after 2004 (Fig.24). Consequently, the tsunami sediment cannot be found here. Another site is BT_CP1-3, which is in a rice paddy field. The 2004 tsunami deposit is not found in this site either (Fig.23). Tsunami sediments may not be deposited here due to very low flow depth, or may be very thin and being disturbed by human activity (rice growing) after 2004.

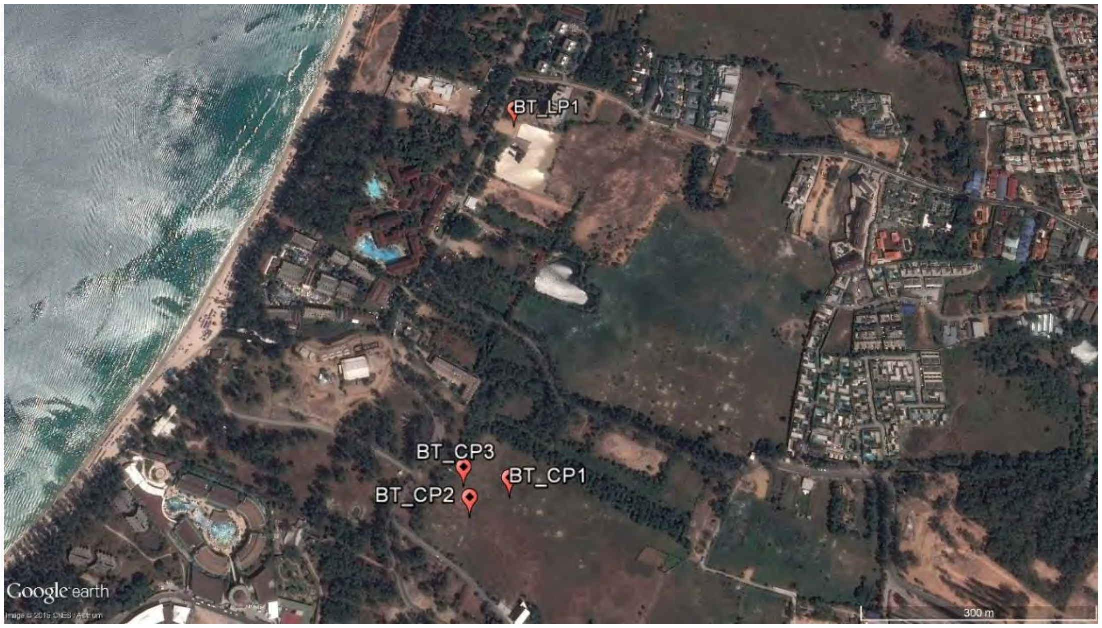

Fig. 22 Location of sampling points in Bangtao Area (from Google Earth: 28 Jan 2014).

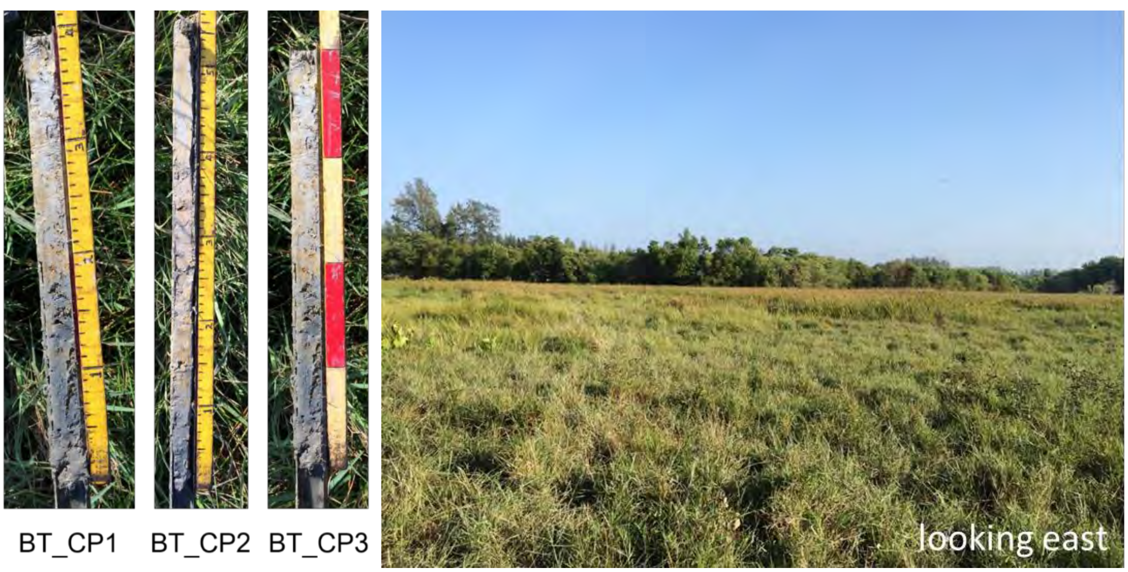

Fig.23 Core samples from Bangtao area show a sticky clay layer with no sand or tsunami deposit (left). Rice paddy field which is a sampling point in Bangtao area (right).

Fig.24 A pond, BT_LT1, which is man-made after 2004.

3.2 LOI and grain size distribution

3.2.1 Loss on ignition (LOI)

LY_CP4 and LY_CP6 were analyzed for LOI to determine the percentage of organic matter and carbonate.

LY_CP4 can be separated into 2 units by using LOI 550 and LOI 950. Lithologic description, %LOI 550, %LOI 950 are presented in Fig.25. LOI 550 values are between 0.75% and 15.61%. LOI 550 value of sand layer is less than 5%, while in clay it is 10%. LOI 950 of sand layer is less than 0.6%. In contrast, LOI 950 of clay is more than 1.7%.

LY_CP6 can also be separated into 2 groups. Fig.26 illustrates LOI 550 and LOI 950 of sand layer in this core sample which is less than 5% and 0.8%, respectively. LOI 550 and LOI 950 of silty clay sediment are more than 10% and 2% respectively.

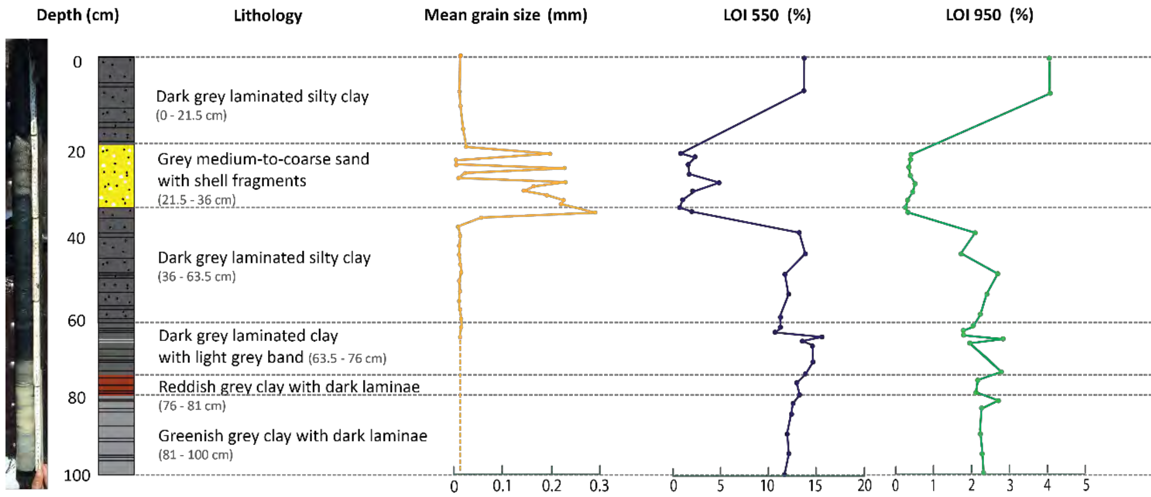

Fig.25 Schematic stratigraphic column, mean grain size, LOI 550 and LOI 950 of LY_CP4.

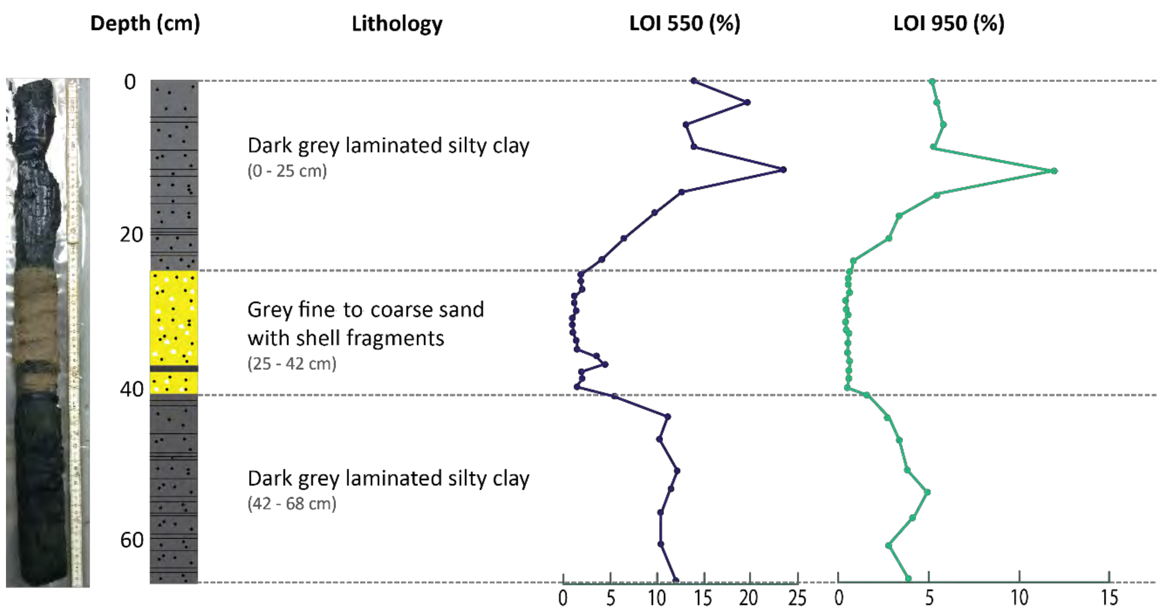

Fig.26 Schematic stratigraphic column, LOI 550 and LOI 950 of LY_CP6.

3.2.2 Grain size distribution

The statistical values of grain size are calculated for each sand layer by using statistical formulae from Table 2. Mean grain size, skewness, and kurtosis were obtained from the calculation and used to describe the grain size distribution of the tsunami deposits. Mean grain size tells the average particle size of each subsample. Skewness measures the asymmetry of the distribution. Kurtosis presents how peaked or flat the distribution is compared to the normal distribution.

For LY_CP4 core sample, 33 grain size samples with their statistic values are shown in Table 4. Normal fining upward trends of grain size of each sand sample are presented. The overall grain size distribution of these samples shows 2 different modes of sediment. The first mode is coarser sediments (about 1 to 2 phi size class) which are medium to coarse sands with broken shell fragments. These sediments were possibly derived from Layan Beach. In contrast, the second mode, about 3 to 6 phi size class sediments, are fine-grained sediment deposited by suspension in the lagoon (Fig.27). Consequently, skewness and kurtosis are also presented in 2 groups; high and low value. In the sand layer, skewness and kurtosis are high, which are -0.29 to 2.91 and 2.19 to 12.3, respectively. Low values of skewness and kurtosis are presented in the silty clay layer. The skewness of silty clay is less than 1, while kurtosis is less than 3.

3.3 Sedimentation rate of post-event deposits

To determine sedimentation rate of post-event deposits after 10 years in each location, the thickness of sediments deposited above the sand layer was measured. There are only 2 areas which we can calculate the sedimentation rate, Layan Lagoon and BY_CP1. The sediment thickness is presented in Table 4. Sedimentation rate are calculated by the following equation; $\mathbf{Sedimentation\ rate\ (R)} = \frac{\mathbf{Average\ thickness\ of\ sediments\ (cm)}}{\mathbf{10\ years}}$

Table 4 Thickness of sediments deposited after 2004 tsunami event.

Location name	Core sample name	Thickness (cm)	Sedimentation rate (cm / yr)
Layan Lagoon	LY_CP1	17	
	LY_CP3	19	= 2.2 cm / yr
	LY_CP4	21	
	LY_CP6	25	
Laguna Area	BY_CP1	25	= 2.5 cm / yr

It is noteworthy that the thickness used in the calculation of the sedimentation rate are of unconsolidated sediments. Compaction will lead to thinner layer. Therefore, calculation of sedimentation rate after longer period of time may appear to be less than the rate reported here.

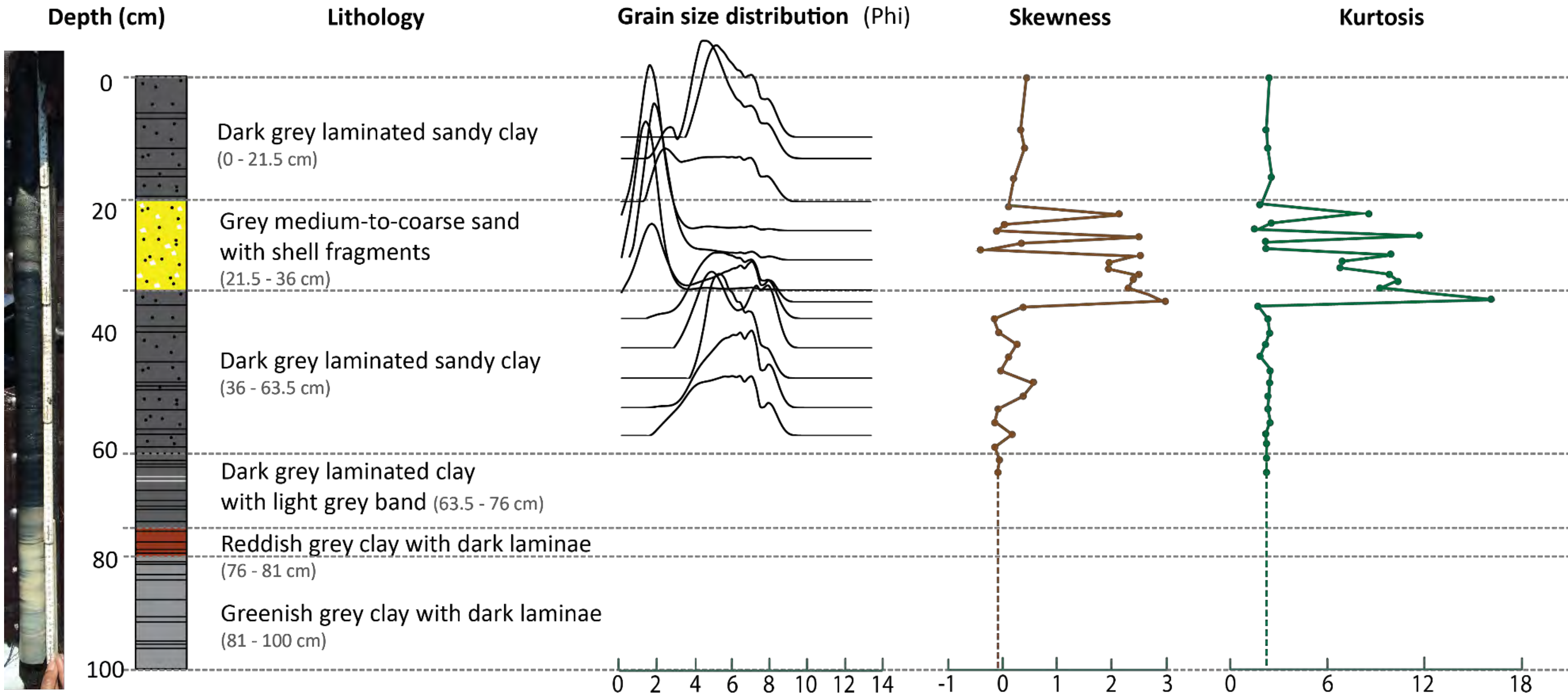

Fig.27 Vertical profile of grain size distribution of LY_CP4.

CHAPTER 4: DISCUSSION AND CONCLUSION

4.1 DISCUSSION

4.1.1 Depositional environment

4.1.2 Climate

4.1.3 Anthropogenic modification

4.2 CONCLUSION

4.3 RECOMMENDATION

CHAPTER 4: DISCUSSION AND CONCLUSION

4.1 Discussion

Two of three sampling points in the study area contain 2004 tsunami sediment. This is not too different to a finding by Szczucinski (2012) that at least half of the sites on Kho Khao Island, Phang Nga, had not preserved tsunami sediment. Preservation potential of the 2004 tsunami sediment in onshore area Phuket ranges from low to high. Although Spiske et al. (2013) mentioned that both onshore and offshore have low preservation potential for deposition of tsunami or storm sediment. In this study, Layan Lagoon and pond BY_CP1 represent areas with high preservation potential for the 2004 tsunami sediment whereas BT_CP1 has low preservation potential. The preservation potential of sediments is generally determined by the interaction of physical and biological processes as illustrated in Fig.28 and Table 5 by Spiske et al. (2013).

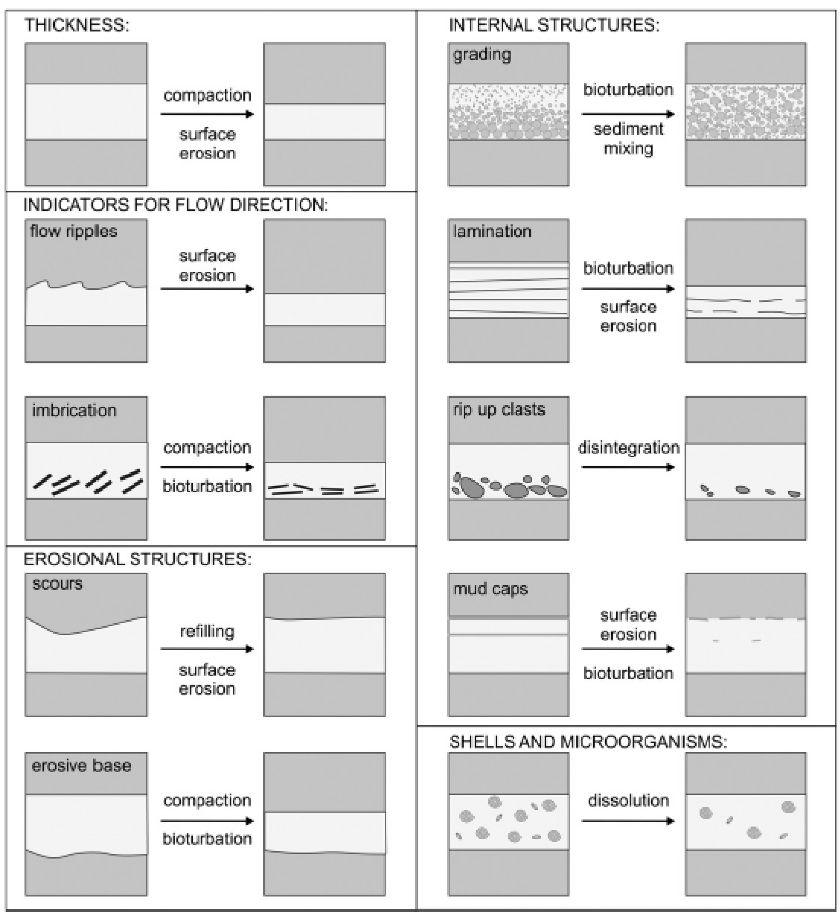

Fig.28 Schematic summary of post-depositional changes of tsunami sediments (Spiske et al., 2013).

Table 5 Criteria that influence the relative preservation potential of onshore tsunami deposits. Note that the relation of these parameters is complex since several criteria can have a combined influence on the sediment preservation (Spiske et al., 2013).

Criterion	Preservation good/bad	Options	Reasons
Climate	−	Arid	Eolian forces
Region	+	Humid, cold	Vegetation, soil moisture
	−	Humid, tropical	Strong weathering, seasonal rain fall
Climate	−	El Nino	Enhanced erosion
Phenomena	−	Flash floods	Enhanced erosion
	−	Rainy season	Enhanced erosion
Eolian	−/+	Very fine grained sediment (mud)	Easy to be transported; but: hard to erode when dry (cohesion of mud particles)
Forces	−/+	Fine grained sediment (sand)	Will be transported; but: rapid burial with eolianites will preserve the deposit
	+	Coarse grained sediment (sand, pebbles)	May not be transported; can remain as residual layer if finer grains get eroded
	+	Boulders	Can only be transported by strong storms or tsunamis
Depositional	+	Coastal lakes, marshland, lagoons, back dune	Sediments are held back/low potential of erosion by backwash
Setting	−	Open coast/beach	Rapid transfer by waves or tides
	−	Narrow beach	Strong backwash
	−	Cliff coasts	Waves may not reach cliff top; sand may not be available for transport
	+	Close to river mouths	High sediment availability
Distance	−	Close	Erosion by tides and storm waves
to coast	+	Further inland	No influence of tides or storm waves
Inclination of	−	Steep	Strong backwash; but: higher for topographical highs, if backwash channelled in lows
coastal plain	+	Flat/planar	Low energetic backwash; water might get ponded so that fine sediment settles down
Tectonic	−	Uplift	Rapid erosion to re-establish an equilibrium
movements	+	Subsidence	Offers accommodation space
Types of	−	Deposits of early waves	Will be eroded by later waves
tsunami	+/−	Deposits of last wave	No erosion by later waves; but: erosion by backwash possible; exposed to surface
Deposits	−	Run-up deposits	Erosion by backwash
	+/−	Backwash deposits	No erosion by later waves; but: exposed to surface
Biogenic	−	Bioturbation	Sediment mixing; loss of internal structures
activity	−	Development of new soil and vegetation cover	Sediment mixing; loss of internal structures
	+	Pre-tsunami vegetation (e.g., grass, trees)	Friction slows down flow and may allow sediment to settle; sediment held back
Anthropogenic	−	Agricultural fields	Ploughing, recultivation
activity	−	Cleaning of beaches	Removal of swash lines or sand
	−	Use of tsunami sand or boulders for rebuilding	Removal of tsunami deposits

4.1.1 Depositional environment

Local topography and depositional setting are critical factors in tsunami deposit preservation. The distance from the coast of the tsunami deposit and coastal morphology, such as flat topography or steep rocky coast, influence its preservation potential. In marshes, back dune areas, coastal lakes or lagoons where the tsunami sediments are enclosed and protected and not subjected to eolian, fluvial or wave erosion, the preservation potential is much higher compared to an open coastal setting (Spiske et al., 2013). Layan Lagoon and Laguna area, where the depositional setting is lagoon, have moderate to high preservation potential. Cohesion of mud particles suspended in the lagoon may impede the erosion by wind-generated current or tidal current in the lagoon. Bangtao area is a rice paddy field located in the 2004 tsunami inundation limit. The preservation potential of the 2004 tsunami deposit is very low in this area. Even though the site of BT_CP1 in Bangtao area is near the study area of Choowong et al. (2008b), the 2004 tsunami sediment is not found. Table 6 is a summary and comparison of features of 2004 tsunami found in Phuket.

4.1.2 Climate

Another factor which affected the preservation of tsunami deposit is the tropical climate of the study area. This fact has also been reported for sediments of the IOT in Thailand, where most of the tsunami sediments along the beaches were washed away during the rainy season about half a year after the event (Szczucinski et al., 2007). On the other hand, in arid coastal regions, such as coastal Peru, they also have a low to moderate preservation potential in arid climate regions, depending upon the exposure to eolian transport (Spiske et al., 2013). Bangtao area is located in a tropical climate so the seasonal rainfall (which covers six to eight months in a year) may destroy the surface of 2004 tsunami deposit or the 2004 tsunami sediment may originally be very thin, so easily destroyed by post depositional events.

4.1.3 Anthropogenic modification

In Phuket, coastal areas are often disturbed by the tourism industry and some agriculture such as farming. These areas represent low preservation potential for tsunami deposits that is a function of population density and associated uses of the beaches.

Nevertheless, the 2004 tsunami sediment still exists in the study area where the tourist industry is not developed.

It is not only the tourism industry which can affect the event deposit but also tin-mining in these coastal regions. Tin-mining was a major industry in Phuket 50 years ago, so paleotsunami deposits along the Andaman shoreline can possibly have been destroyed. Although tin-mining can destroy tsunami deposits, the tin-mining pond (lagoon-like) is an appropriate depositional environment to preserve the event deposit such as tsunami deposit.

Table 6 Summary and comparison of the 2004 Indian Ocean tsunami features in Phuket.

Sedimentary characteristics	Post-event survey[1]	10 years past survey		
		Layan Lagoon	Laguna area	Bangtao area
Sedimentary features				No tsunami deposits
- event deposit thickness	0.1-25 cm	3-18 cm	22 cm	
- normal grading	x	x	x	
- reverse grading	x	-	-	
- cross-bedding	x	-	-	
- ripple cross-lamination	x	-	-	
- parallel lamination	x	x	-	
- landward & seaward inclined lamination	x	-	-	
- mud rip-up clasts	x	-	x	
- sharp basal contact	x	x	x	
- mud drape/ mud coating	-	x	x	
- composition	Quartz common, few shell fragments			
Granulometric data				
- Mean grain size (phi)	0-2	1.78 - 7.75	no data	
- Standard Deviation	0.25-1.25	0.72 - 1.75	no data	
- Skewness	-5 - 6	-0.29 - 2.91	no data	
- Kurtosis	no data	2.19 - 12.3	no data	

[1]Choowong et al., 2008a 'x' = exist '-' = not exist

4.2 Conclusion

This study assesses the preservation potential of 2004 tsunami deposit in the Phuket area where the economy is mainly driven by the tourist industry. Even though land development for tourism in Phuket increases in every year, we can find the 2004 tsunami sediments in closed lakes and lagoons which have higher preservation potential than marshes or paddy field due to the following factors; coastal morphology (e.g. distance from shoreline), depositional environment (e.g. tidal effect), climate (e.g. tropical climate) and anthropogenic modification (e.g. agriculture, tin-mining activity, tourist industry).

The sedimentation rates of post-event deposits after 10 years in Layan Lagoon and Laguna area are 2.2 cm/yr and 2.5 cm/yr, respectively. These sedimentation rates may be less as a result of compaction after decades or centuries.

4.3 Recommendation

The preservation potential of 2004 tsunami deposit of this region may be of better assessment if it is possible to collect data in the same area through time, i.e. use the same study area as Choowong et al., 2008b. However, this is not possible for a busy tourist area like Phuket. Most 2004 tsunami sediments were either removed or destroyed soon after the event by human activities. Hotel accommodation for the tourist industry is developing every year so in the near future these anthropogenic activities will both destroy the sedimentary structures and/or entirely remove the tsunami deposits.

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