การวิเคราะห์ตะกอนพายุโบราณในจังหวัดประจวบคีรีขันธ์

นายสถาปนา กองเซ็น

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาธรณีวิทยา ภาควิชาธรณีวิทยา
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2559

ANALYSIS OF ANCIENT STORM DEPOSITS IN CHANGWAT PRACHUAP KHIRI KHAN

Mr. Stapana Kongsen

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Geology
Department of Geology
Faculty of Science
Chulalongkorn University
Academic Year 2016

Thesis Title	ANALYSIS OF ANCIENT STORM DEPOSITS IN CHANGWAT PRACHUAP KHIRI KHAN
By	Mr. Stapana Kongsen
Field of Study	Geology
Thesis Advisor	Professor Montri Choowong, Ph.D.
Thesis Co-Advisor	Sumet Phantuwongraj, Ph.D.

Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Faculty of Science

(Associate Professor Polkit Sangvanich, Ph.D.)

THESIS COMMITTEE

....Chairman

(Assistant Professor Thanop Thitimakorn, Ph.D.)

....Thesis Advisor

(Professor Montri Choowong, Ph.D.)

....Thesis Co-Advisor

(Sumet Phantuwongraj, Ph.D.)

....Examiner

(Assistant Professor Vichai Chutakositkanon, Ph.D.)

....External Examiner

(Assistant Professor Krit Won-in, Ph.D.)

สถาปนา กองเซ็น : การวิเคราะห์ตะกอนพายุโบราณในจังหวัดประจวบคีรีขันธ์ (ANALYSIS OF ANCIENT STORM DEPOSITS IN CHANGWAT PRACHUAP KHIRI KHAN) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ศ. ดร.มนตรี ชูวงษ์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: อ. ดร.สุเมธ พันธุวงค์ราช, 83 หน้า.

การวิเคราะห์การสะสมตัวของพายุโบราณในจังหวัดประจวบคีรีขันธ์บริเวณพื้นที่ชายฝั่งทางด้านอ่าวไทย มีจุดประสงค์เพื่อวิเคราะห์ลักษณะทางตะกอนวิทยา และหาอายุของการสะสมตัวของพายุที่เคยเกิดขึ้นในอดีต ตะกอนพายุโบราณที่เกิดจากพายุรุนแรงสะสมตัวอยู่ในบริเวณพื้นที่ลุ่มต่ำด้านหลังแนวสันทรายซึ่งอยู่ห่างเป็นระยะทาง 350 เมตรจากชายฝั่งทะเลในปัจจุบัน การสะสมตัวของชั้นตะกอนพายุโบราณมีความหนาตั้งแต่ 0.5-50 เซนติเมตร โดยจำนวนการสะสมตัวของชั้นทรายในแต่ละชั้นน่าจะบ่งบอกถึงจำนวนการเกิดเหตุการณ์ของพายุรุนแรง ในการศึกษานี้พบชั้นทรายของพายุโบราณสะสมตัวมากถึง 27 ชั้น ขนาดทรายของตะกอนพายุโบราณมีขนาดตั้งแต่ขนาดทรายหยาบไปถึงทรายละเอียดมาก โครงสร้างทางตะกอนประกอบด้วย รอยสัมผัสแบบไม่ต่อเนื่องชัดเจนทั้งด้านบนและด้านล่างของชั้นทราย การเรียงตัวของขนาดเม็ดตะกอนในแนวดิ่งแบบปกติจากขนาดใหญ่ไปขนาดเล็ก และแบบผกผันจากขนาดเล็กไปขนาดใหญ่ พบมีชั้นทรายบางซ้อนกันในแนวขนาน และเศษตะกอนโคลนจากชั้นดินเดิมถูกกัดเซาะนำพาขึ้นมาสะสมตัวปนอยู่กับตะกอนในชั้นทราย ความหนาของชั้นทรายมีลักษณะบางลงและขนาดทรายมีลักษณะละเอียดขึ้นในทิศทางจากชายฝั่งเข้าสู่แผ่นดิน นอกจากนี้ในชั้นตะกอนพายุโบราณยังประกอบไปด้วยซากดึกดำบรรพ์ขนาดเล็ก คือ ฟอแรมมินิเฟอราและออสตราคอด และซากดึกดำบรรพ์ขนาดใหญ่พวกหอยฝาเดียวและหอยสองฝาจำนวนมาก องค์ประกอบของพายุโบราณประกอบด้วยแร่ควอตซ์ แร่หนัก และเศษเปลือกหอย

ผลการหาอายุด้วยวิธีกระตุ้นด้วยแสงจากตะกอนของสันทราย และการเทียบเคียงผลอายุกัมมันตรังสีโดยวิธีเอเอ็มเอสจากเปลือกไม้ในพื้นที่ใกล้เคียงกับพื้นที่ศึกษาพบว่า มีชั้นตะกอนพายุโบราณ 4 ชั้นที่มีอายุการสะสมตัวอยู่ในช่วงระหว่างสมัยโฮโลซีนตอนกลางถึงสมัยโฮโลซีนตอนปลาย และในช่วงอายุมากกว่าสมัยโฮโลซีนตอนกลางมีการสะสมตัวของพายุโบราณจำนวน 23 ชั้น การผันแปรของจำนวนการสะสมตัวของพายุในอดีตระหว่างช่วงอายุสองช่วงของพื้นที่ศึกษานี้มีปัจจัยที่ควบคุมคือ ศักยภาพของพื้นที่ในการสะสมตัว ลักษณะของพายุ ความรุนแรงของพายุ ความเร็วลมของพายุ ความสูงของคลื่นพายุซัดฝั่ง และสภาพภูมิอากาศในอดีต

ภาควิชา ธรณีวิทยา	ลายมือชื่อนิสิต ....
สาขาวิชา ธรณีวิทยา	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
ปีการศึกษา 2559	ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

5672179523 : MAJOR GEOLOGY
KEYWORDS: ANCIENT STORM DEPOSIT/ PALEOTEMPESTOLOGY/ GULF OF THAILAND

STAPANA KONGSEN: ANALYSIS OF ANCIENT STORM DEPOSITS IN CHANGWAT PRACHUAP KHIRI KHAN. ADVISOR: PROF. MONTRI CHOOWONG, Ph.D., CO-ADVISOR: SUMET PHANTUWONGRAJ, Ph.D., 83 pp.

The analysis of ancient storm deposits in Changwat Prachuap Khiri Khan along the Gulf of Thailand is aimed to analyze the sedimentological characteristics and to define depositional age of ancient storm. Ancient storm sediments were found within a distance of 350 m landward from the present shoreline. Thickness of ancient storm deposits varies from 0.5 to 50 cm. The numbers of ancient storm layers possibly indicate the numbers of storm occurrences through time. In this research, ancient storm layers were found up to twenty-seven layers. Grain size of ancient storm sediments ranges from coarse- to very fine-grained sand. Sedimentary structures of ancient storm deposits contain sharp upper and lower contact, normal and reverse grading, parallel lamination and mud rip-up clasts. The thicknesses and grain size of deposit are thinner and finer landward. Furthermore, ancient storm layers contain several microfossils (foraminifera and ostracod) and macrofossils (gastropod and bivalve). The ancient storm sediments contain mostly quartz, heavy minerals and shell fragments.

The results of Optically Stimulated Luminescence ages from beach ridges and the correlation of AMS radiocarbon age from a wood fragment from the adjacent area indicate that there are four ancient storm layers occurred in the late-Holocene to the mid-Holocene. There are twenty-three ancient storm layers older than the mid-Holocene. The variability in number of ancient storm deposit during two periods may due to several controlling factors including potential preservation of the area, storm characteristic, the intensity of storm, wind speed, surge height, and climatic condition in the past.

Department:	Geology	Student's Signature	....
Field of Study:	Geology	Advisor's Signature	....
Academic Year:	2016	Co-Advisor's Signature	....

ACKNOWLEDGEMENTS

Doing this research is considered as a list of my wonderful once-in-a-lifetime experiences. This research will never succeed without these. Firstly, my special thanks go to Department of Geology, Faculty of Science, Chulalongkorn University for various equipment in pre-fieldwork, fieldwork and laboratory work. Most importantly, I am immensely grateful to Professor Montri Choowong (my adviser) and Ajarn Sumet Phantuwongraj (co-adviser) for strong support, invaluable guidance and notable experiences in working with them throughout the time of my master study.

Additionally, my gratefulness goes to all experts who helped and gave their useful suggestions, Associate Professor Punya Charusiri for OSL dating, Assistant Professor Thasinee Charoentitirat for microfossil, Assistant Professor Thanop Thitimakorn for shallow seismic investigation, Mr. Peerasit Surakietchai for OSL dating and fieldwork and friends of mine at Department of Geology, Chulalongkorn University for strong encouragement.

My special thanks also go to the 90th Anniversary Ratchadapiseksomphot Endowment Fund of Chulalongkorn University (GCUGR1125582071M) and Climate Change and Disaster Management Cluster (CU-57-058-CC) and Thailand Research Fund (BRG5780008) for providing research funds.

Lastly, a special note of appreciation and gratitude goes to my family members who gave me financial supports especially my mom, dad and aunt. It is relatively difficult to thank to all people who provided me with inspiration, support and excellent guidance to produce this research. However, thank you everyone for everything.

CONTENTS

Page

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1
INTRODUCTION

1.1 Background

Coastal areas all over the world are very significant because they keep the history of coastal evolution including geology, geomorphology, sedimentology, landforms and even washover deposits. Washover deposits are the major result of high energy wave that transport nearshore sediments across beach or dune and deposit on the land. Washover deposits also can be used to call two high energy processes – coastal storm and tsunami. Therefore, it is very obvious that the presence of washover deposits in the coastal areas becomes the primary indicator of geological evidence that those areas ever experienced high energy event.

Even though coastal storm and tsunami are a natural phenomenon, however their occurrences are so different. That is to say, coastal storm were generated from the movement of two air masses rapidly and severely due to two different temperatures of air circulation. This leads to the crash of two air masses between high temperature, low pressure and low temperature, high pressure and make a landfall such as 1989 Typhoon Gay in Thailand, 2005 hurricane Katrina in USA, 2008 Cyclone Nargris in Myanmar, 2009 Typhoon Morakot in China and Taiwan, 2013 Typhoon Hainan in Philippines and so on. Whereas tsunami were generated from the major earthquake (> 7 amplitude), volcanic eruption, landslide, meteorite and etc. such as 1946 Pacific tsunami, 1960 Chilean tsunami, 1964 Good Friday tsunami, 2004 Sumatra tsunami, 2011 Great East Japan tsunami and so on.

Definitely, these two high energy waves are very disastrous to coastal community. They not only destroy abruptly coastal community that result in coastal ecosystem, environment, morphology but they also ruin country's economy, property and even casualty. Therefore, the understanding of coastal storm and tsunami processes as well as the history of occurrence can no longer be overlooked.

Although there are both coastal storm and tsunami deposits, but in this study will mainly focus on storm deposits only by mean of "paleotempestology". Paleotempestology is focused primarily on identifying and dating washover sand layers in costal marshes located immediately landward of sandy barriers (Donnelly, 2005, 2001a, 2004, 2001b; Lane, 2011; Liu and Fearn, 1993, 2000b; Yu, 2013). This geologic proxy approach is based on the premise that a tropical cyclone storm surge overtops the barrier and wind-driven waves transport dune, beach, intertidal and sub-tidal sand onto a muddy, organic-rich marsh to form an anomalous sand layer (Williams, 2010; Williams, 2013). Over time, during which normal marsh aggradation occurs, multiple tropical cyclones are recorded by multiple sand layers separated by muddy, organic-rich marsh sediments (Williams, 2016). Tropical cyclone storm surge deposits present in the subsurface are typically distinguished by a coarser texture and lower organic content and enclosing marsh sediments, by sharp upper and lower contracts, by marine microfossils and by a wedge-shaped profile that thins and fines landward. Identified storm surge deposits can be readily dated by radiocarbon (^{14}C) dating, Optically Stimulated Luminescence (OSL) and Tephrochronology (Goto, 2015; Sawai, 2009a, b).

In Thailand, the trustworthy data of meteorological records of typhoon strikes cover only about the 70 years ago. This means there are many limitations of a time span to provide insights into centennial to millennial-scale tropical cyclone variability (Joint Typhoon Warning Center, 2014)(Center, 2014). Only a few reports on the storm deposits have been publish (Phantuwongraj, 2010; Phantuwongraj, 2012; Phantuwongraj et al., 2008; Phantuwongraj, 2013; Williams, 2016). Phantuwongraj et al., (2008), subsequently, reported the possible storm deposits found along the coast at Surat Thani and Nakhon Si Thammarat on the Gulf of Thailand (GOT). The discovery in investigating the storm deposits was extended northwards along this coastline to Chumphon where Phantuwongraj et al., (2010) found multiple layers of paleo-storm sand sheets in a swale located 1 km inland and far away from the present shoreline. However, more detailed studies of the sediment characteristics, topographical and flow condition of the washover deposits induced by storms are still required, particularly for Thailand where so little is known.

Magnitude and frequency of storm activity tend to increase in the future because of the effect of recent enhanced greenhouse climate based on the study of Nott (2001). It is definitely obvious that in the area that has records of the coastal storm events. The prediction of storm potential hazard map can be created consequently (Phantuwongraj and Choowong, 2012).

Lastly, in Thailand, as described above, consideration of this natural disaster the study of this field should be supported more because the discovery of storm deposits can be used to create storm hazard map, proper evacuation plan, and even warning system for protecting people and property from this disastrous event in time.

1.2 Objectives

In this research, the sedimentary characteristics and age determination of ancient storm washover deposits from Amphoe Kui Buri, Changwat Prachuap Khiri Khan are mainly focused. The measurements of the local topography at each site will also be carried out.

1. To investigate and analyze sediment layers of ancient storm deposits in coastal area of Prachuap Khiri Khan.
2. To define age determination of ancient storm sediment in the study area.

1.3 Scope and limitation

This study focused on the sedimentological analysis in the ancient washover storm deposits found from the coastal area of the Gulf of Thailand. The representative study site is located at Amphoe Kui Buri, Changwat Prachuap Khiri Khan. The recognition will be based primarily on the observation in fieldwork and sedimentological evidences got from ancient washover sand sheet characteristics.

1.4 Assumption

In the past decades, the coastal areas in the Gulf of Thailand (GOT) have been suffered severely by high energy event (storm) at least 4 times, for example, Harriet 1962, Ruth 1970, Gay 1989 and Linda 1997. If we have considered from historical storm track data in the present and the past, we would have seen that the coastal areas in Prachuap Khiri Khan is located in storm track way too. Normally, storm surge will transport eroded sediment from foreshore and sea floor to deposit on the beach due to the overwash sea water that flows penetrate in landward direction.

If these sediments were in the extent between swale and beach ridge or low land and were preserved by the normal mud deposition, they will be the historically important data of storm deposits. They also are the indicator of ancient storm deposits. Although it is not easy to find suitable place for doing this work, but we can carry out with proficiency of aerial photo interpretation. This work hypothesizes that the sedimentological and geological data will indicate anomalous sand layers from coastal deposition in this study area.

1.5 Outputs

This thesis will provide sedimentological evidences of ancient washover deposits induced by storm in the past from the southern peninsular of Thailand. The major expectation is to understand the characteristics of ancient washover deposits as the key analogue leading to identify and distinguish it from other sediments deposits. Expected results are as follow:

1. Realize the sedimentological data from ancient storm deposits from Amphoe Kui Buri, Changwat Prachuap Khiri Khan.
2. Realize the history of the storm surge in the study area.

CHAPTER 2

LITERATURE REVIEWS

2.1 Modern washover deposits

Coastal storm is one of natural hazards that can severely influence coastal morphology, ecosystems, communities, infrastructure on the coast all over the world. Whenever it occurs, it can also generate an intense surge in direct towards to the coast. Normally, the stronger intensity of storm can generate the higher storm surge (Leatherman and Williams, 1983; Liu, 2007). The occurrence of intense storm surge normally causes high energy wave flooding across beach or dune that transport sediments and living fauna from seafloor, beach, and foreshore deposited inland. Additionally, the deposits from high energy event when they overwashed landward and deposited in muddy environment such as marsh, swale or other lowlands were preserved well. These sediments are called washover sediment that become the key indicator of historical storm occurrence.

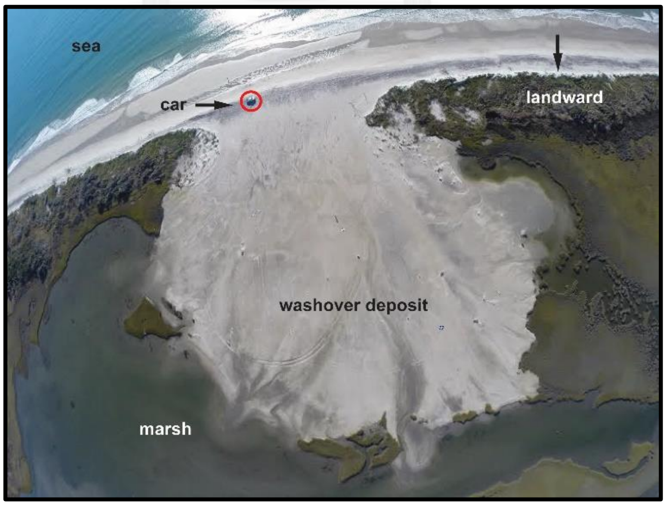

Figure 2.1 Oblique photo from quadcopter showing washover sediment deposited in Middle Marsh, North Carolina, USA.

(http://rodriguez.web.unc.edu/files/2014/02/unnamed-3.jpeg)

2.1.1 Processes

There are two types of processes of washover deposits. 1) washover deposits that occur from coastal storm and 2) washover deposits that occur from tsunami. Nevertheless, in this study will describe only washover deposits from coastal storm.

Overwash is the flow of sea water that transported sediment and living fauna across a beach crest that does not flow back directly to ocean, sea, bay, or lake; hereafter, ocean where it originated (Donnelly, 2004; Donnelly and Webb Iii, 2004; Phantuwongraj, 2012). It was generated from storm surge that create unusual high wave and exceed the beach and dune crest height. Normally, storm surge was generated from coastal storm i.e. tropical storm and typhoon. Moreover, seasonal and monsoonal wind can generate unusual surge such as Northeast monsoon surge.

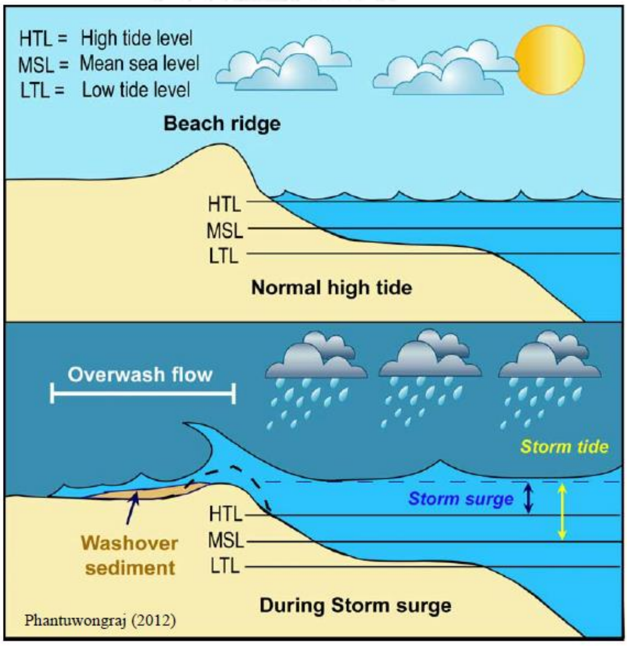

Figure 2.2 Cross-section model of beach showing the sea water level during the fair weather and storm weather period. a) In the fair weather condition, sea water lever is in the tidal range (HTL, MSL and LTL). b) In the storm weather, sea water level flows over beach ridge and carries eroded sediments at the same time (Phantuwongraj, 2012).

The intensity of overwash is dependent on the intensity of storm such as tropical cyclone and typhoon. Generally speaking, the stronger the storm, the higher the wave. However, tropical cyclones are classified from maximum sustained wind speed based on AOML, 2007.

Category	Sustained Wind Speed
1. Tropical depression	61 km/h (38 mph)
2. Tropical storm	62-119 km/h (39-74 mph)
3. Tropical typhoon (Pacific and Indian Oceans)	>119 km/h (>74 mph)
4. Tropical hurricane (Atlantic Ocean)	>119 km/h (>74 mph)

Table 2.1 maximum sustained wind speed of tropical cyclone (modified from AOML, 2007).

Additionally, typhoons and hurricanes are further categorized using the Saffir-Simpson Hurricane Scale.

Category	Sustained Wind Speed	Types of Damage Due to Hurricane Winds
1	119-153 km/h (74-95 mph)	Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, and vinyl siding and gutters.
2	154-177 km/h (96-110 mph)	Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage.
3	178-208 km/h (111-129 mph)	Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends.
4	209-251 km/h (130-156 mph)	Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most the roof structure and/or some exterior walls.
5	> 251 km/h (> 157 mph)	Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse.

Table 2.2 Saffir-Simpson hurricane wind scale (modified from Phantuwongraj, 2012).

In the modern time of washover deposit can be observed along the coast and can be divided into two types (erosional features and depositional features) as the study of Morton and Sallenger (2003) as follows (Figure 2.3):

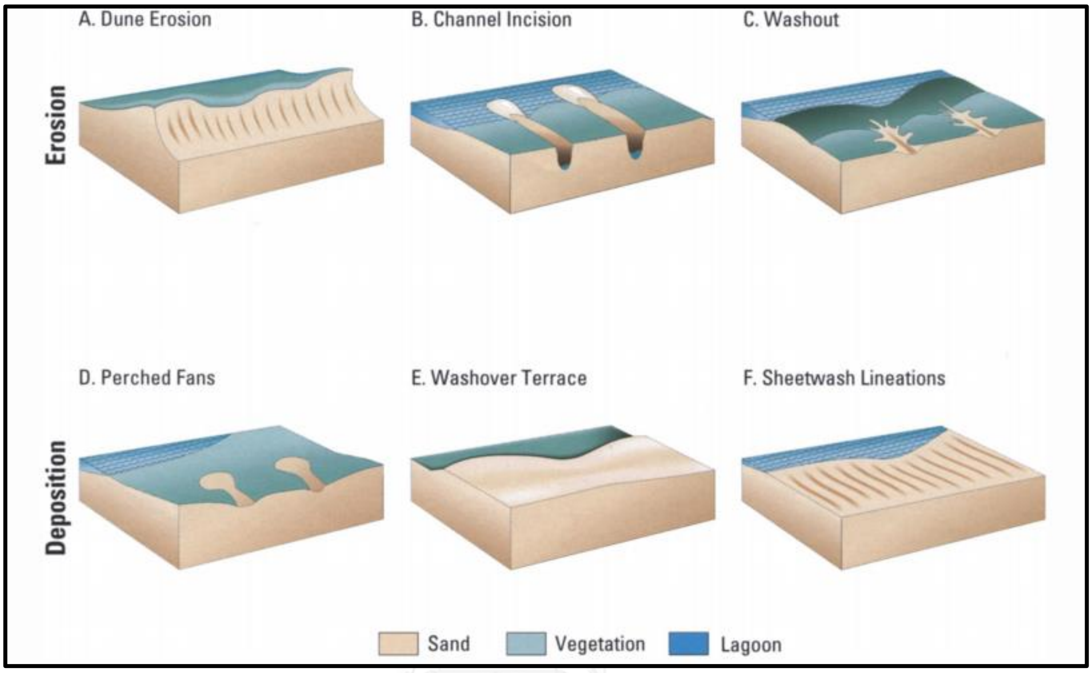

Figure 2.3 Types of erosional and depositional features produced by extreme storm; A) Dune erosion; B) channel incision; C) washout; D) Pearched fans; E) Washover terrace and F) Sheet wash lineation (Morton and Sallenger, 2003).

"**<u>Erosional features</u>**

Dune scarp erosion (Figure 2.3a) occurred when storm surge and wave runup is higher than back beach, but lower than the height of the dune or bluff. The runup will collide with the dune causing erosion and dune retreat.

Channel incision (Figure 2.3b) commonly occurred when storm surge and superimposed wave heights exceed height of primary dunes, then the entire headland or barrier island is inundated and the response is commonly sheetwash, or for barrier island, incision of washover channels through the barrier core.

Washout (Figure 2.3c) involves channel erosion across the beach and foredunes as a result of floodwaters flowing from the lagoon to the ocean. The term washout is used because the process is opposite to that of overwash ((Morton, 1985)Morton and Paine, 1985). This relatively rare phenomenon occurs where the lagoon is higher than the ocean and also higher than the foredunes (Elashry, 1968; Pierce, 1970).

Depositional features

Perched fans (Figure 2.3d) are small lobate to elongate washover features that are oriented perpendicular to the shore which constructed when wave runup superimposed on the storm surge exceeds the lowest dune elevations, but elsewhere the surge is blocked by higher dune elevations. Morphological criteria that favor construction of regularly spaced fans include a narrow barrier island, low dunes, and minor alongshore differences between dune gaps and dune crests. At some locations, perched fan are so closely spaced that they merge to form a washover terrace (Morton, 2002).

Washover terraces (Figure 2.3e) are elongate deposits oriented parallel to the shore (Morton, 1985; Schwartz, 1975)(Schwartz, 1975; Morton and Paine, 1985). Terraces from where land elevations are relatively uniform alongshore and lower than the maximum storm surge. They may form a uniformly wide band, or their landward margins may be highly irregular, depending on the interactions between breaking waves and currents during washover deposition.

Sheetwash (Figure 2.3f) involves laterally unconfined flow where sediment transport is continuous across the barrier island. Sheetwash may result in either deposition of sand eroded from the adjacent beach/dune system or redistribution of sand eroded locally. Common bedforms resulting from sheetwash are narrow elongate zones of erosion and deposition that form lineations parallel to the direction of flow." (Phantuwongraj, 2012)

These are two features of storm surge that impact beach morphology and can be observed clearly after coastal storm event. However, in the ancient washover deposit (several centuries to millennia) these observable features are relatively rare during modern time because they might be covered by normal sedimentation. Therefore, paleotempestology was conducted in this study.

2.2 Paleotempestology

Paleotempestology is an emerging field of science that studies past tropical cyclone activity beyond the period of instrumental observations, typically spanning the last several centuries to five millennia. Tropical cyclones are known by different names in different regions of the world – hurricanes in North America, typhoons in the Northwest Pacific, and cyclones in South Asia and Australia. Here the term hurricane is sometimes used interchangeably with all other types of tropical cyclones (Liu, 2007).

The records of tropical cyclone activity both in the United States and other parts of the world are confined to the last 150 years especially in Thailand last 70 years (William et al, 2016). This record is too short to fully capture the occurrence of the rare but most destructive hurricanes – the catastrophic hurricanes of category 4 and 5 intensity base on Saffir-Simpson scale. Therefore, by providing a long-term, empirical record of hurricane activity back to 5,000 years, paleotempestology is useful for revealing the spatial and temporal variability of hurricane activity and deciphering its relationship with global climatic changes. Two main sources of data are available for reconstructing past hurricane activity to beyond the instrumental period – geological proxy records, and historical documentary records. Therefore the underscore two major approaches to the study of paleotempestology – geological and archival (Liu, 2007).

2.2.1 Geological proxy records

When a hurricane or typhoon makes a landfall in the past. This is a cause that can severely impact coastal landforms, ecosystems, sedimentary and hydrological processes on the coast. These impacts which left on the coast can be decoded by means of proxy techniques (Figure 2.4). Many geological and biological proxies are potentially beneficial in reconstructing past hurricane or typhoon strike. However, the proxy that has proven the most useful is overwash sand layer deposited in the sediments of coastal lake or marsh (Donnelly and Webb Iii, 2004; Liu, 2007; Liu and Fearn, 1993).

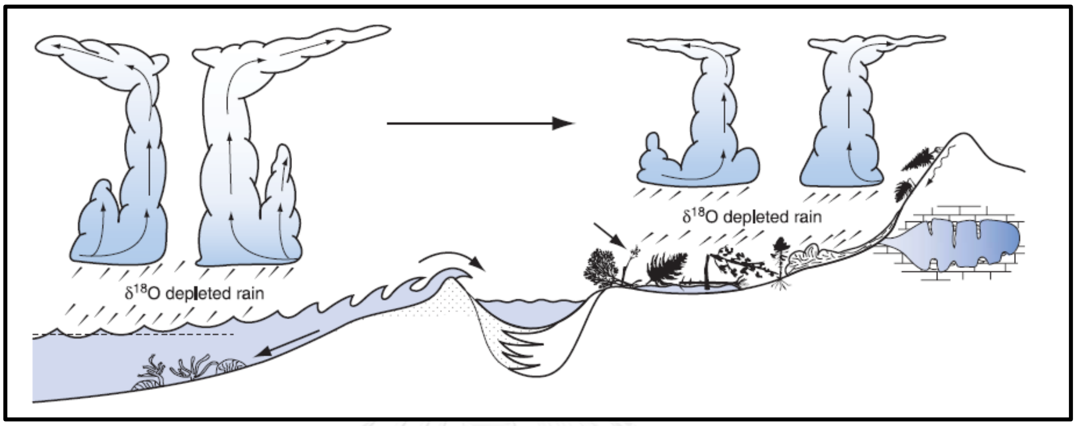

Figure 2.4 Environmental impacts of catastrophic hurricanes (Liu, 2004).

A landfalling hurricane may cause a storm surge that overtops beach barriers, resulting in the formation of an overwash fan and the deposition of a sand layer in the sediments of a back barrier lake or marsh. The strong wind may cause massive damage or mortality to trees, leaving a paleoecological record of disturbance and succession, including the occurrence of post-hurricane fires. Heavy precipitation may cause flooding in the lowlands, and soil erosion and landslide in the uplands. The O^{18} isotope-deplete signal in the hurricane rains may be recorded in the cellulose of tree rings and the calcium carbonate of speleothems and coral skeletons if it is not attenuated by hydrological processes (Liu, 2007).

2.2.2 Overwash sand layer in the coastal lake

During a hurricane or typhoon event, the strong onshore winds, particularly in the forward-right quadrant of the intense low-pressure system, generate a storm surge directed towards the coast as foregoing description above. For intense hurricane causing sand to be eroded from the beach or dunes and deposited in the lake or marsh behind it. Stratigraphically, the overwash fan will be preserved and formed as a sand layer which thickest near the shore and gradually thinner landward (Liu, 2004, 2007; Liu and Fearn, 1993; Liu and Fearn, 2000a; Liu and Fearn, 2000b). In a coastal lake that had been subjected to repeated overwash events in the past, the sediment stratigraphy should contain multiple sand layers that contain a stratigraphic record of intense hurricane strikes (Figure 2.5). These sand layers are composed of very fine to very coarse sand that is usually well-sorted, and have abrupt contacts both above and below. Thickness's sand layer may range from a few mm to more than 10 cm (Figure 2.6). They can be identified either visually or by means of sedimentological techniques such as loss-on-ignition analysis of core samples (Liu and Fearn, 2000). A chronology of past overwash event or hurricane strikes can be established by means of radiometric dating techniques such as radiocarbon (^{14}C), lead-210 (^{210}Pb), or cesium-137 (^{137}Cs) dating which may be supplemented by using stratigraphic markers such as pollen ad lead pollutants (Donnelly and Web, 2004). For any particular location, the return period of hurricanes of a specific intensity category can be calculated by tallying up the number of event occurring over a given period of time.

The intensity of paleohurricanes may be much harder to infer from the proxy record than their frequencies. As a first approximation, it can be assumed that stronger hurricanes tend to produce higher storm surges and thus more extensive overwash fans. Therefore, within the same core, sand layer thickness can be used as a rough indicator of storm intensity (Figure 2.7). The sedimentary impact of recent hurricanes of known intensity can be used as a modern analog for calibrating the intensity estimate of paleohurricanes. For example, based on sediment-stratigraphic evidence that the overwash sand layer deposited by Hurricane Frederic, a category 3 hurricane that struck Alabama in 1979, was only confined to the nearshore sediments, Liu and Fearn (1993) inferred that older sand layers that occurred in cores taken from the center of Lake Shelby (where the Frederic sand layer was absent) must have been deposited by prehistoric hurricanes of category 4 or 5 intensity. Coastal lakes from Alabama and northwestern Florida have yielded proxy records of catastrophic (category 4 and 5) hurricane strikes that span the last 5,000 years (Liu and Fearn, 1993; Liu and Fearn, 2000a; Liu and Fearn, 2000b).

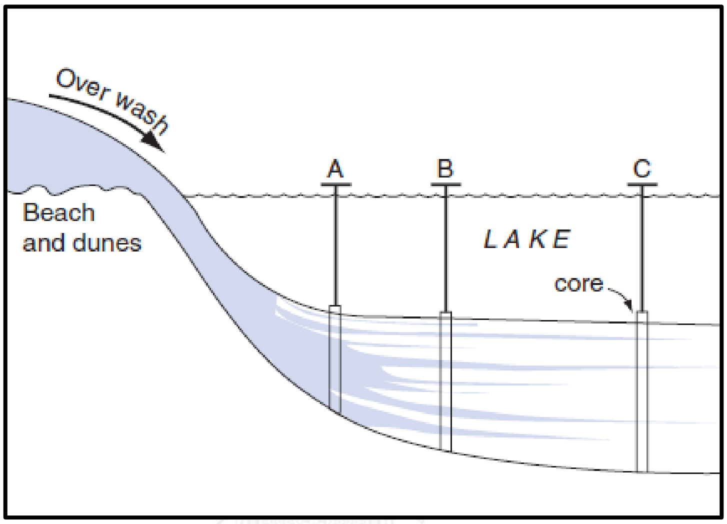

Figure 2.5 Hypothetical characteristics of sand-layer deposition in a coastal lake subjected to repeated storm overwash events in the past. The overwash sand layers are normally thicker near the sand barrier and become thinner towards the lake center. A core taken from point B will contain more and thicker sand layers than one taken from point C. A core taken from point a, however, may consist of all sand without discrete layers (Liu, 2007).

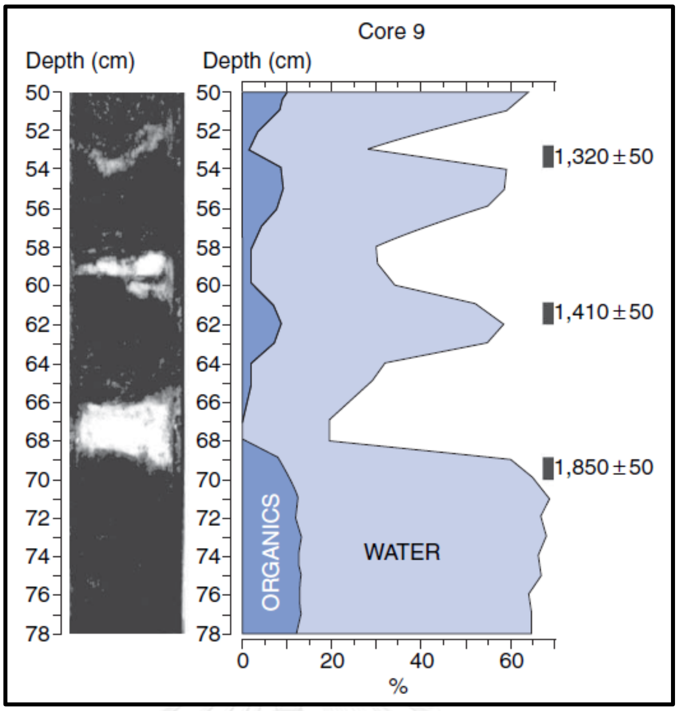

Figure 2.6 Photo showing the three prominent sand layers at depth 50-78 cm of core 9 from western Lake, northwestern Florida, and the corresponding water and organic matter content curves determined by loss-on-ignition. Radiocarbon dates are on the right (after Liu and Fearn, 2000a) Liu, 2007.

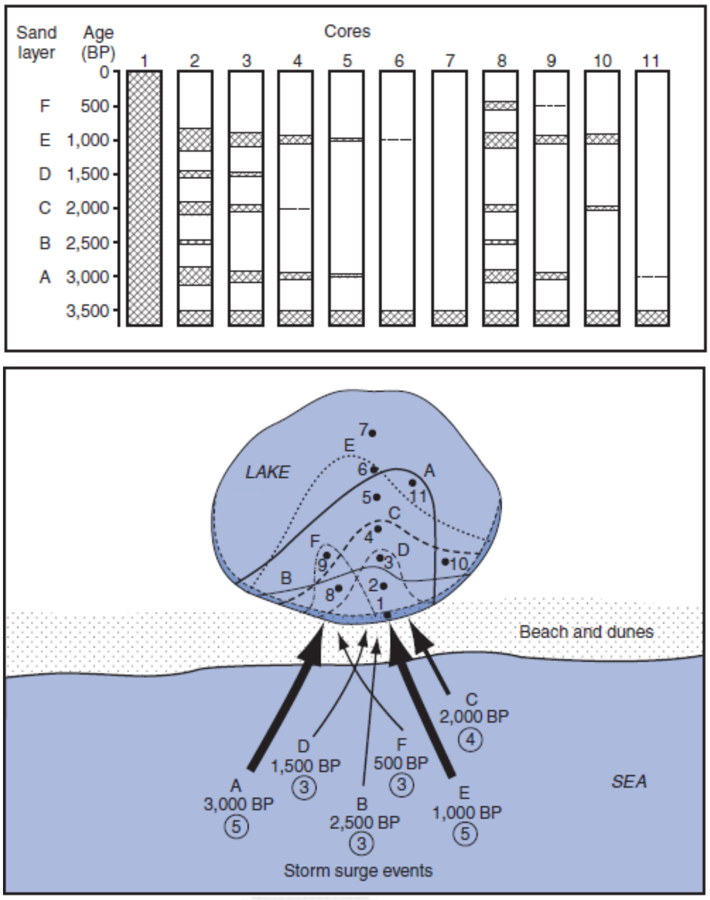

Figure 2.7 Model showing the positive relationship among hurricane intensities, extent of overwash fans, and thickness of sand layers in sediment cores (after Liu and Fearn, 2000).

From Figure 2.7, Top: Hypothetical sedimentary stratigraphies of eleven cores (#1-11) taken from different parts of a lake impacted by intense hurricanes and associated overwash events six times during the past 3,000 years. Thick and thin sand layers are represented by cross-shaded bands and dotted lines, respectively. Bottom: Hypothetical pattern of overwash sand deposition in the lake where the eleven cores were taken. Solid, dotted, or dashed line inside the lake denote the horizontal extents of the six overwash fans (labeld A-4–F) corresponding to the six hurricane strikes and overwash events (arrows). Thicknesses of the arrows are proportional to the intensity of the hurricanes according to the Saffir-Simpson scale, the latter also designated by circled number below each arrow. Numbered black dots represent cores taken from the lake.

2.2.3 Proxy records from coastal marshes

The same principle and research methods can be applied to coastal back-barrier marshes for generating proxy records of past hurricane strikes (Donnelly et al., 2001a; Donnelly, 2004; Donnelly et al., 2001b; Donnelly and Webb Iii, 2004). These back-barrier marshes are typically peat accumulating environments situated behind barrier beaches. As in coastal lakes, overtopping of the barrier beach by storm surge will lead the formation of an overwash fan behind the barrier, which will be expressed stratigraphically as a sand layer sandwiched between marsh peat (Figure 2.8). If the barrier beach is breached by the storm surge to form an inlet, a large flood-tidal delta may be formed across the back barrier marsh, which may even extend into the lagoon or bay behind it (Donnelly and Webb, 2004). Like overwash sand layers, these flood-tidal delta deposits are usually composed of fine to coarse sand with sharp contact with the underlying peat. But unlike overwash sand, the mean grain-size of these flood-tidal delta deposits tends to be more spatially variable, and they often contain ripple laminations, detrital organic laminae, shell hash layer, and disarticulated shells (Donnelly and Webb, 2004).

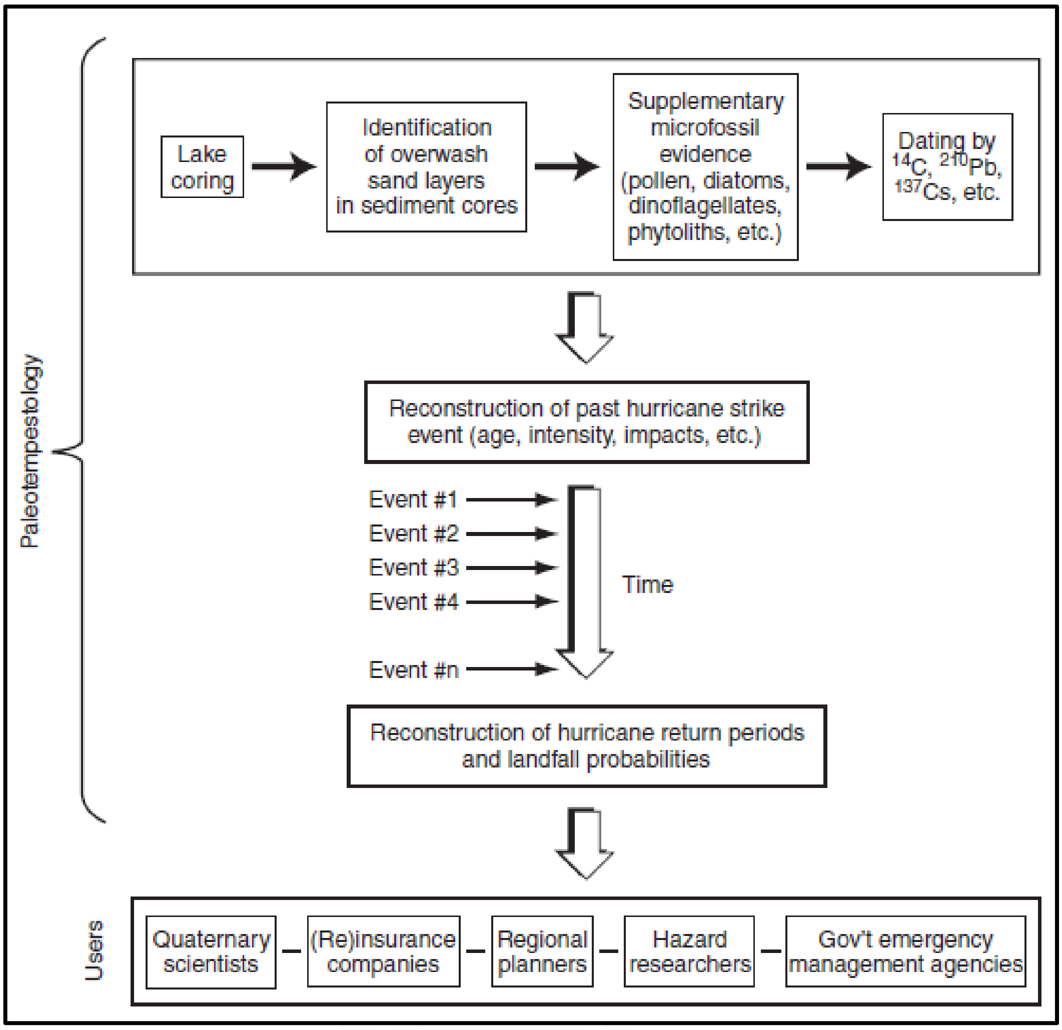

Figure 2.8 Schematic diagram showing the general principles and method employed in reconstructing past hurricane strike event from sedimentary proxies and archives (top panels). The return periods or landfall probabilities of hurricanes can be calculated from the chronology of past hurricane strikes (middle panels). The bottom panel shows some of the potential users of information derived from paleotempestology (Liu, 2007).

2.3 Ancient washover deposits

Ancient storm deposits are one of geological evidences that indicate once in the history that coastal area used to undergo coastal storm.

2.4 Ancient storm deposits in Thailand

In Thailand, at least 8 extreme coastal storms that can be divided into three types –three depressions, four tropical storms and one typhoon – influenced coastal and non – coastal area including 1952 Depression Vae, 1962 Tropical storm Harriet, 1989 Typhoon Gay, 1997 Tropical storm Linda, 1998 Tropical storm Gil, 2003 Tropical storm 23W, 2004 Depression Muifa and 2006 Depression Durian respectively.

2.5 Study area

KuiBuri (KB), Changwat Prachuap Khiri Khan

The study site is located at a swale, KuiBuri area, Changwat Prachuap Khiri Khan Province, the Gulf of Thailand.

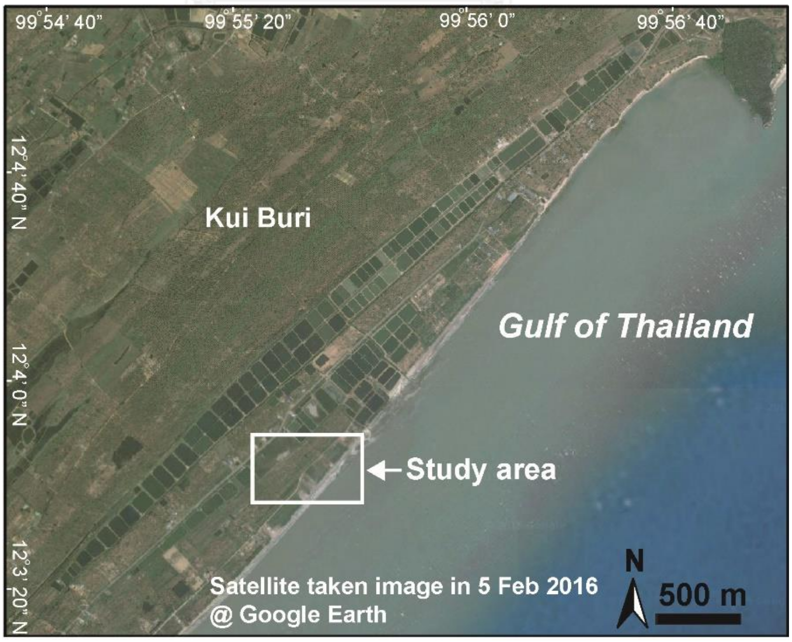

Figure 2.9 Satellite image showing study area (Kui Buri).

CHAPTER 3
METHODOLOGY

The methodology in this study was mainly carried out in three parts, including 1) Pre-field work, 2) Field work, and 3) Laboratory analysis. However, in the part 4) Analyzing and concluding data will be discussed in the chapter IV, chapter V and Chapter VI. Three parts of methodology can be divided into sub-steps as follows (Figure 3.1):

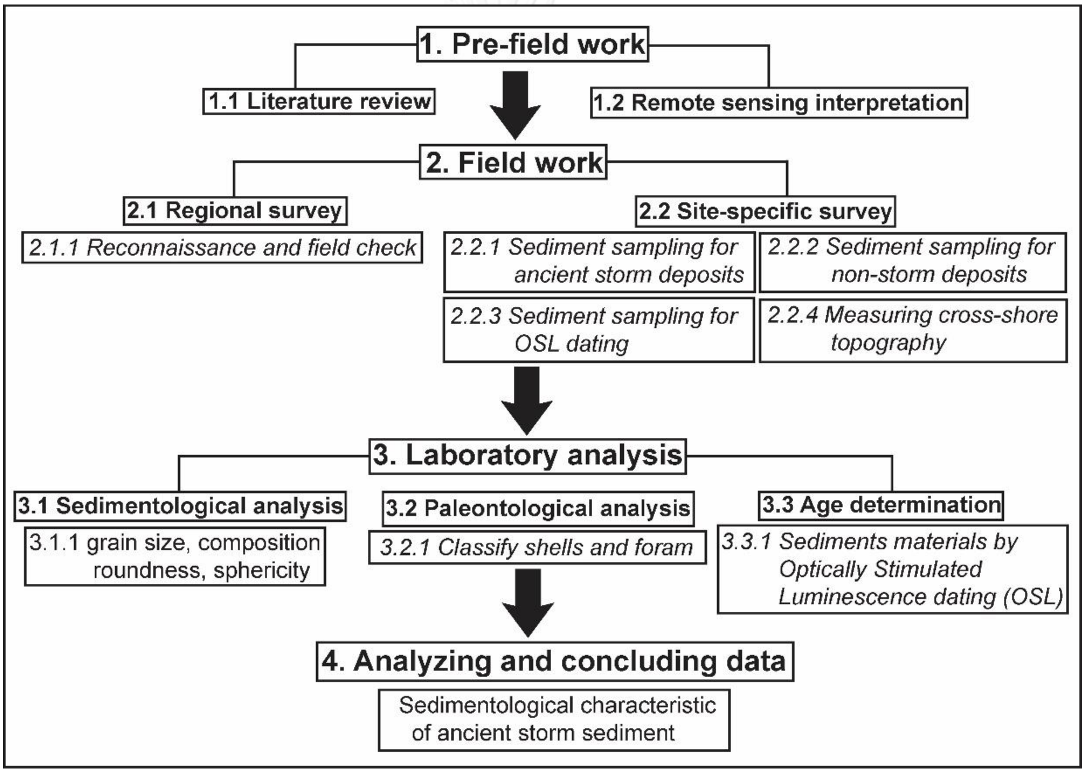

Figure 3.1 Flow chart showing methodology using within this research (modified from Phantuwongraj, 2012).

3.1 Pre-field work

3.1.1 Literature review

To begin with, literature of this study about high-energy event that form washover deposit sand theirs processes such as storm and tsunami, paleotempestology, tropical cyclone, the different characteristics of storm and tsunami sediment, the storm genesis, and coastal storm hazard in Thailand were reviewed in detail.

3.1.2 Remote sensing interpretation

Geomorphologic units of study area (Kui Buri, Prachuab Khiri Khan) were interpreted from Satellite images and aerial photos for finding the best potential location where preserved ancient storm deposits well. Google earth satellite image was input and interpreted from ArcMap 10 program and aerial photos were interpreted by mirror stereoscope (Figure 3.2). Normally, the best location where preserve the ancient washover sediments is lowlands such as swale, marsh, lake or even tidal delta (Liu, 2007). However, the chosen place in this thesis is a swale between former beach ridge and present beach ridge.

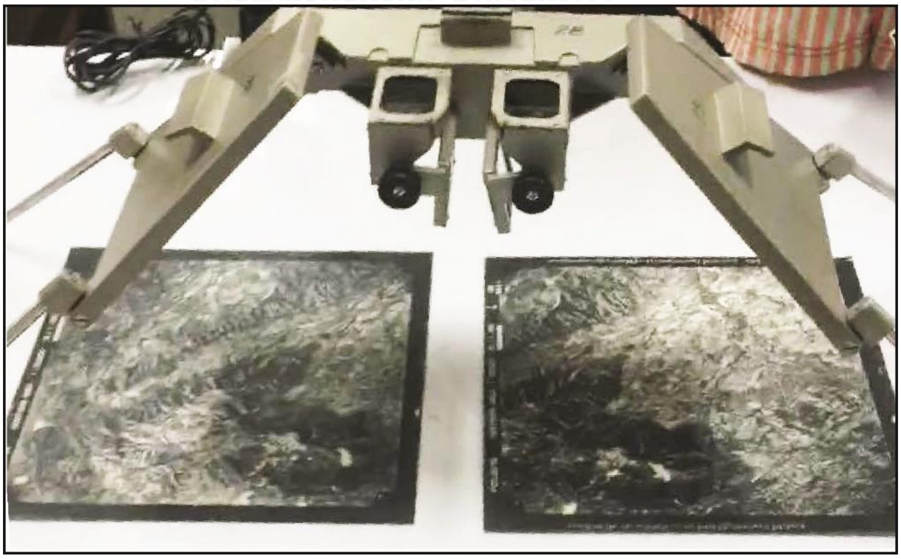

Figure 3.2 Picture showing aerial photo interpretation by mirror stereoscope.

3.2 Field work

3.2.1 Regional survey

After specifying the best potential location from remote sensing interpretation, Kui Buri area was chosen as the potential location. Preliminary investigation and field check were carried out by gauge core for detecting the possible ancient storm deposits from stratigraphy of the chosen place (Figure 3.3). If the ancient storm deposits were discovered, site specific survey was carried out sequentially.

Figure 3.3 Gauge core using for detecting the ancient storm deposits.

3.2.2 Site-specific survey

Topographic survey

The coastal topographic survey was carried out by digital topographic survey camera (total station survey camera) that starting from the present sea level shoreline across beach ridges with spatial coordinates and true elevations of all stations (Figure

3.4). After that, topographic profiles were referenced to local tide level at the time of surveying and were conducted for establishing mean tide level (MTL), high tide level (HTL) and low tide level (LTL) using calculation of tide level obtained from tide gauge station at Prachuab Khiri Khan (Ko Lak station). At the study site, mean tidal range is 1.05 m. Moreover, this study area can be divided into three transects. All transects were measured topographic profile.

Figure 3.4 Total station survey camera measuring topographic profile along measurement at the study area.

Sample collection

After discovering ancient washover deposit from gauge core. Aluminium tubes - 2 meters long, 2 inches wide, 2 millimeters thick- were brought to collect samples by percussion in the first place (Figure 3.5). Aluminium cores were sealed and transported to laboratory. Then, gauge core were carried out along three transects in the study site. The difference between sampling from aluminium tube and gauge core is aluminium tube can appear the sedimentary structure clearer, but cannot be deepened that much from subsurface. Gauge core can go down deeper from subsurface with approximate depth 3 meters, yet it can recognize the sedimentary structure within core less. All cores both aluminium and gauge cores were provided spatial coordinates and were designated respectively.

With reference to aluminium cores, electric saw was brought to cut aluminium tube lengthwise and sediments within cores were divided into two sides longitudinally at laboratory. Then, stratigraphy of cores was recorded and photographed including sedimentary structure, organic matter (Figure 3.6). After that, the ancient storm sediments were collected systematically layer by layer from top to bottom at the selected depth (every 1 cm for thick sand layer and every 0.5 cm for thin sand layer.

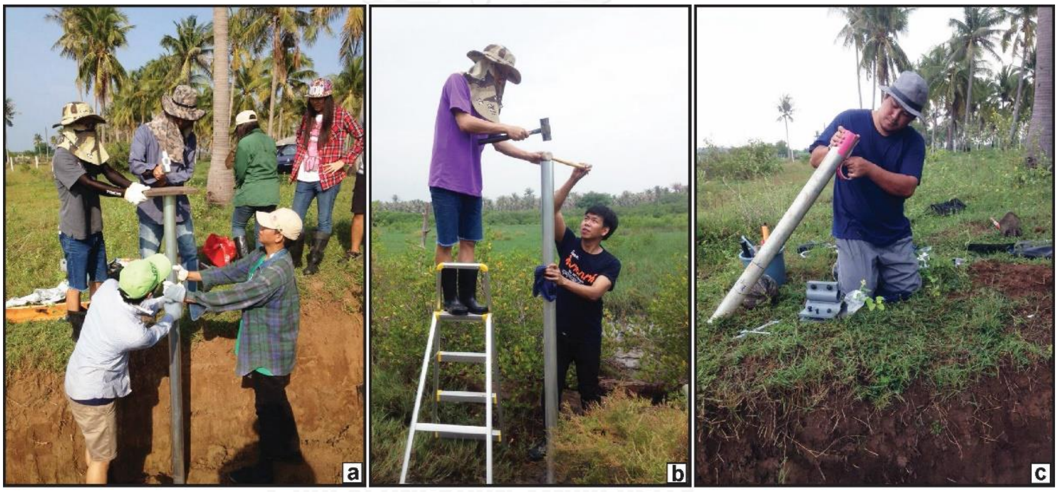

Figure 3.5 Pictures showing collecting sample by percussion coring; a) and b) aluminium tubes were applied to collect ancient storm samples; c) core sample obtained in site was sealed before transporting to laboratory.

Figure 3.6 Pictures showing core sample; a) sample core was cut lengthwise; b) sample core was divided into two sides longitudinally; and c) core was recorded stratigraphy.

In terms of gauge core, the possible ancient storm deposits were collected in the field because gauge core can collect samples deeper than aluminium tube. And then, all samples were carried to laboratory for sedimentary analysis. Additionally, non-ancient washover sediments including the sediments from recent beach, foreshore and backshore were collected for comparing the grain size distribution with the ancient washover sediment (500 g/sample).

Figure 3.7 Pictures showing collecting sample by gauge core; a) ancient washover deposits were found from gauge core; b) ancient washover sample was brought out by a knife; and c) ancient washover sediment.

The samples of age determination were collected between recent beach ridge and former beach ridge (foreshore and backshore) at depth 50 cm from small pit. Since ED (Equivalent dose) samples must not be exposed to the sunlight or any light except for red; therefore, PVC tubes were designed for preventing sunlight. For AD (Annual dose) samples can expose to sunlight as usual. All OSL samples were designated and transport to laboratory. Also, four OSL samples from natural trench were collected for age determination in the vertical depth (Figure 3.8).

Figure 3.8 Pictures showing collecting OSL samples; a) pitting a small pit; b) and c) OSL sample was collected by PVC tube; and d) collecting OSL samples at natural trench.

3.3 Laboratory analysis

3.3.1 Sedimentological analysis

Non-ancient washover sediments collected from field work were systematically performed by sieve analysis at department of Geology, Faculty of Science, Chulalongkorn University because all samples have high volume. However, samples of ancient washover sediments were analyzed grain size by laser granulometric method at Scientific and Technological Research Equipment Centre (STREC), Chulalongkorn University because volume of samples is too low to be performed by sieve analysis. However, all samples were oven-dried at 60° C

All sediment samples were identified under the microscope for analyzing on sedimentology such as composition (Figure 3.9) (Charts for estimating mineral grain percentage composition of rocks and sediments) and roundness (Figure 3.10) (Comparison chart for estimating roundness of sediment) (Fritz, 1988; Powers, 1953).

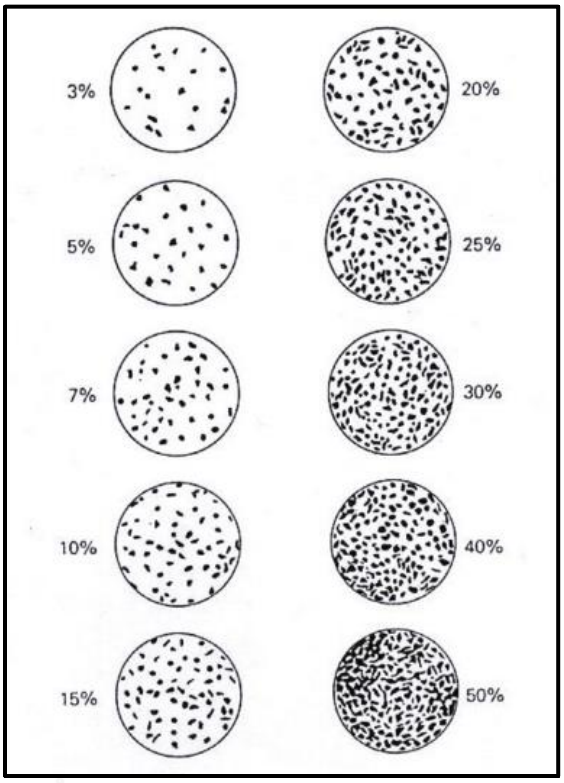

Figure 3.9 Comparison chart for estimating percentage composition (After Fritz and Moore, 1988).

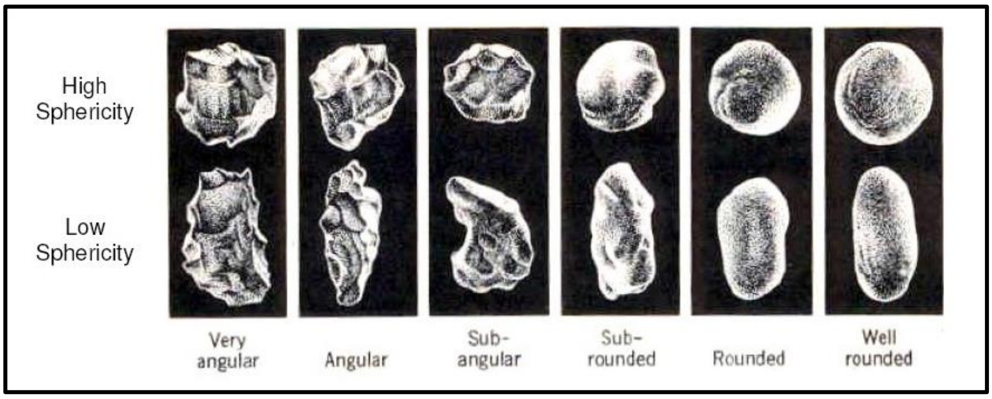

Figure 3.10 Comparison chart for estimating roundness of sediment (Modified from Power, 1953).

3.3.2 Paleontological analysis

To clarify unsuspiciously if sand layers are ancient storm deposits? Paleontological analysis is an important method which is very useful to find that sediment source transported from marine environment. Ancient washover samples obtained from sieving (mesh 18, 35 and 60) were examined to identify under microscope especially benthic living fossil and microfossil such shell, foraminifera and ostracod. All microfossils were classified and photographed by SEM.

Figure 3.11 Pictures showing groups of foraminiferal species; a) group of Spiroculina depressa and b) group of Asterorotalia pullchella.

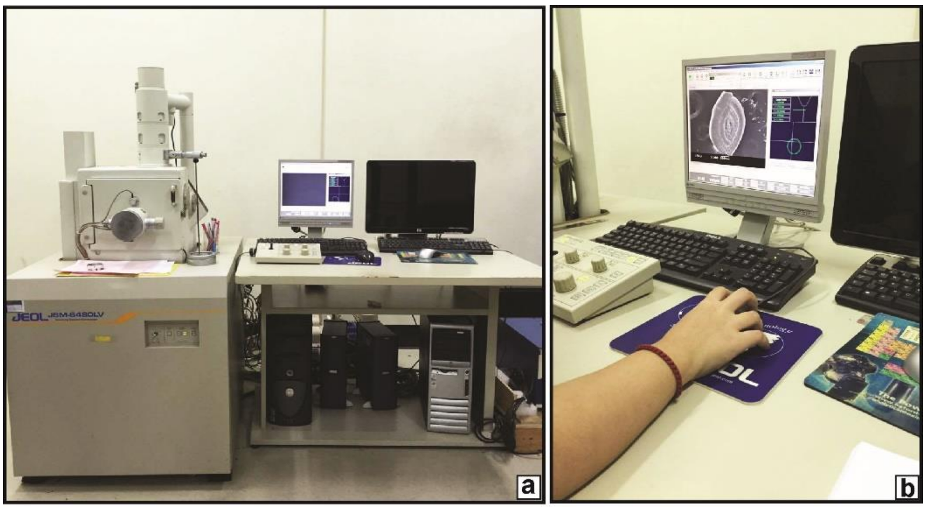

Figure 3.12 Pictures showing SEM equipment and photographing foraminifera; a) scanning electron microscope and b) photographing foraminiferal species by SEM.

3.3.3 Age determination

OSL dating technique is applied to the sediment samples which obtained from recent beach ridge, former beach ridge and natural trench in the study area. Firstly, all AD samples must be oven-dried at 60°C for the determination of water content (water %) and then sieved through mesh 20 to keep sample for 1 month. ED samples were performed in the darkness or red light for preventing sunlight. Preparation and operation of this study were performed as Figure 3.13.

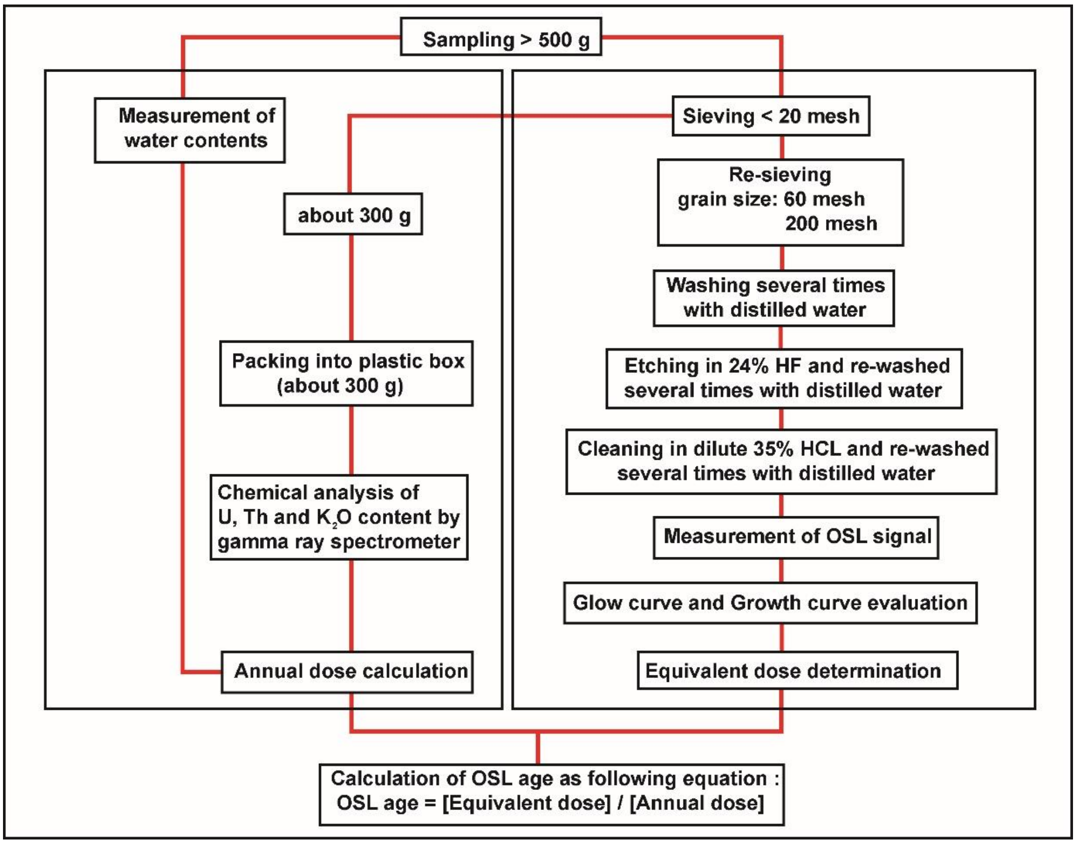

Figure 3.13 Flow chart illustrating the preparation of age determination of OSL sample use in this thesis (Modified from Pailoplee (2004)).

CHAPTER 4
RESULTS

4.1 Description of Kui Buri (KB) area

Hypothetically, from the storm tracks of 4 storm events such as Depression Vae (1952), Tropical storm Harriet (1962), Typhoon Gay (1989) and Depression Linda (1997), Kui Buri area was considered as one of the affected area that suffered from intense storm surge induced by storm frequently (Figure 4.1). Therefore, the preservation of ancient storm deposits in this study area is highly possible to be discovered geological records on somewhere in the last several centuries to millennia.

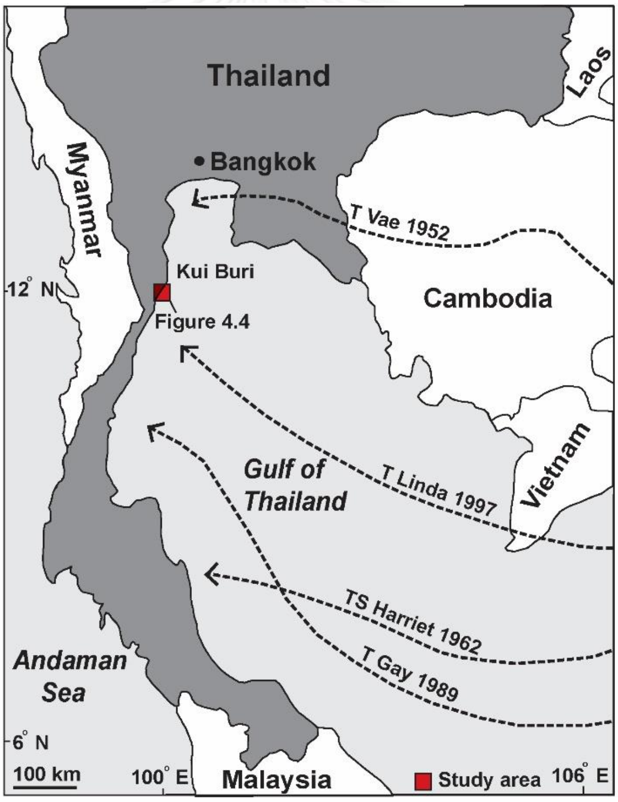

Figure 4.1 Location map showing the study site at Kui Buri, storm tracks of 4 storm events (TS: Tropical storm, T: Typhoon), (Modified from William et al., 2016).

From the result of geomorphological interpretation in the area, the best potential location in proceeding this research is a wet swale that located between two beach ridges. The swale (12°03'47.00" N, 99°55'25.84" E) here located about 260 m inland, 300 m long parallel to shoreline, and 130 wide perpendicular to shoreline. Sightseeing the area, the swale floor was fully filled by fine-grained sediment. Fine-grained particles in swale were transported by heavy rain fall or flooding process from tidal channel during hide tide.

Nevertheless, in the study area, washover sediments mixing shell fragments also were typically observed on the distal part of beach ridge which were presumably expected from the result of high energy event (washover sediment). Although this swale was surrounded by shrimp pond farms on both left side and right side of swale, this site has been not disturbed by human activity. The swale was vegetated generally by sedge and mangrove *(Rhizophora apiculate)* that commonly found at tidal zone. Swale also was flooded during rainy season, so the sedimentation in the swale environment here is relatively stable. Since the elevation of swale surface on the left side is higher than the middle and the right side based on measuring topographic profile, therefore, flow direction of swale water was released through tidal creek on the right side of swale to tidal channel and drained out to the Gulf of Thailand. Water level of swale is varied about 40 – 50 cm. Maximum and minimum of average tidal range in this study are 2.13 and 1.03 m respectively. Furthermore, the alinements of coconut tree on the beach ridge were agriculturally cultivated by land owner.

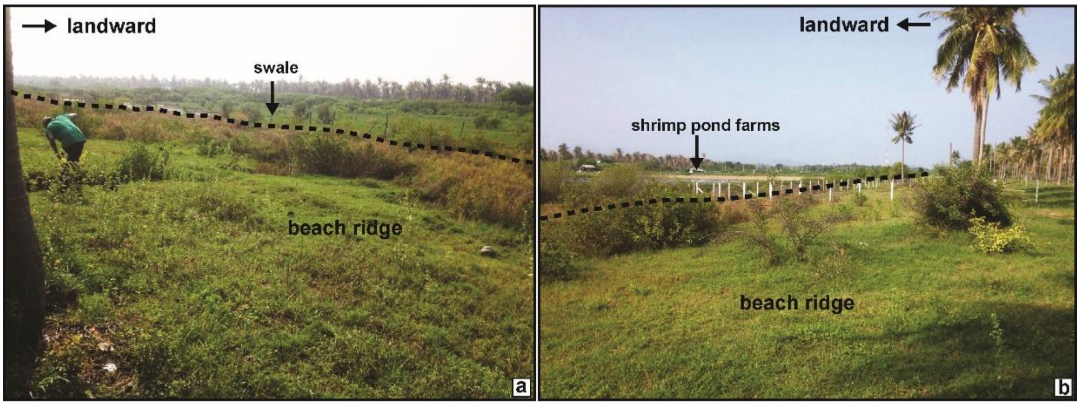

Figure 4.2 Pictures of study area; a) left side of study area and b) shrimp pond farms on the right side of study area. Dashed lines indicate the boundaries between beach ridge and swale.

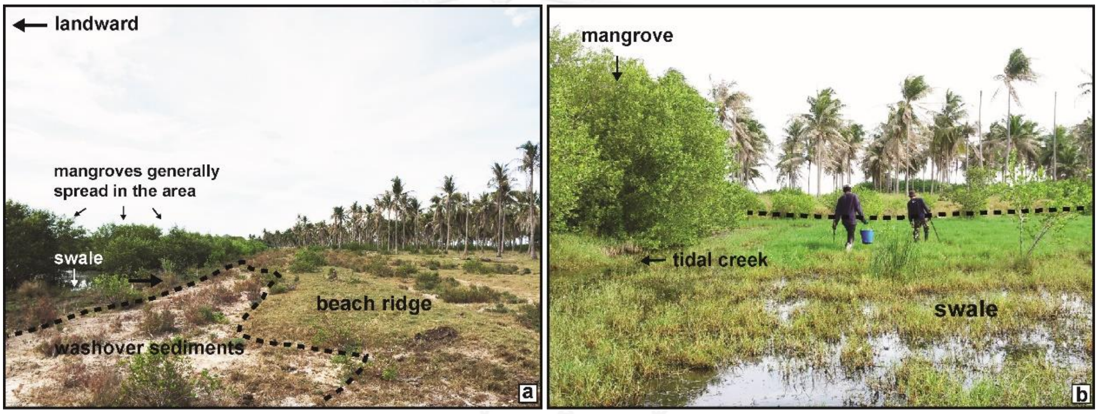

Figure 4.3 Pictures of study area; a) washover sediments deposit on the distal of beach ridge and b) tidal creek in swale environment.

Coastal geomorphology of study area can primarily be divided into six coastal geomorphological units including recent beach, beach ridge, swale, alluvial plain, tidal flat and mountain. Choowong (2004) discovered Holocene biostratigraphical records in coastal deposits from Sam Roi Yod National Park. Sam Roi Yod area is the place where the distance is close to Kui Buri area around 8.5 km. The study site associated with mid Holocene marine transgression and the approximate sea level of area is 3.5 m above present mean sea level. However, this study will emphasis solely data in the swale site.

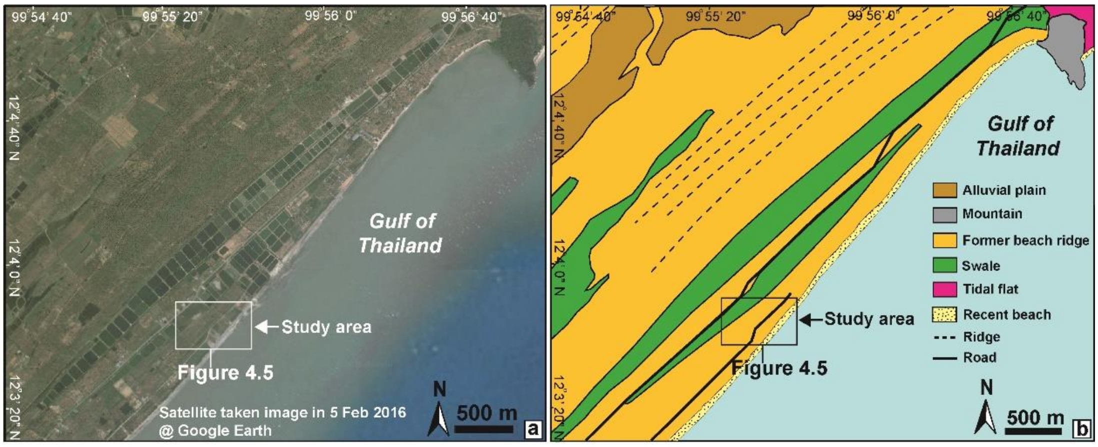

Figure 4.4 coastal geomorphic map showing coastal geomorphic units and study area (Satellite image from Google Earth).

4.2 Swale stratigraphy

In the study site, transects were fallen into 3 transects. The results from logging both gauge cores and aluminium cores of each transect will be presented here in detail. The distance of each transect is around 70 m. Each transect was cored from the distal part of beach ridge to around the middle part of swale. The positions of cores in each transect were determined by handheld GPS units (Figure 4.5b).

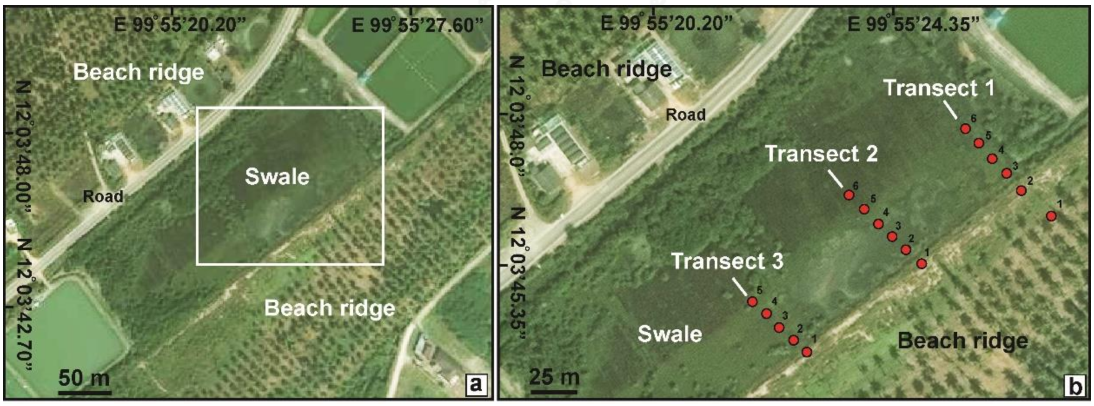

Figure 4.5 Pictures showing transects of study area; a) the overview of study area and b) the positions of cores and transect in the study area. Satellite image from Bing; acquisition period: no available. Red circles indicate the positions of cores.

4.2.1 Transect 1

Transect 1 comprised six cores (KB1C1 – KB1C6) from the distal part of beach ridge to the middle part of swale (Figure 4.5). Core KB1C1 is 140 cm long from surface to subsurface and the most seaward that contains two sand sheet layers at depth 0 – 36 cm, and 127 -128.5 cm. Sedimentary structures of the first sand layer contain parallel lamination, normal grading, reverse grading, shell fragment layer, sharp lower contact with mud layer (Figure 4.6). The second sand sheet is very fine sand of 1.50 cm thick with sub – horizontal stratification. From logging data of core KB1C1, rusty color was observed throughout mud layer that indicated oxidized environment of swale occurred from water level of swale decreased and exposed to the air that cause oxygen in the air reacted with oxide of iron or aluminium mixing up within mud layers, while non-rusty color of mud layer in the deeper part of core indicates the submergence of mud layer under water all the time. Sharp contact with fine-grained layer indicates the normal sedimentation of muddy environment (swale) was interrupted abruptly from overwash process that transported eroded sand sediment from beach or foreshore or even sea floor. While parallel lamination of sand layer indicated wave frequency that transported eroded sand and deposited continually during coastal storm event, depending on water level during time of deposits (Davis Jr, 1989; Schwartz, 1975).

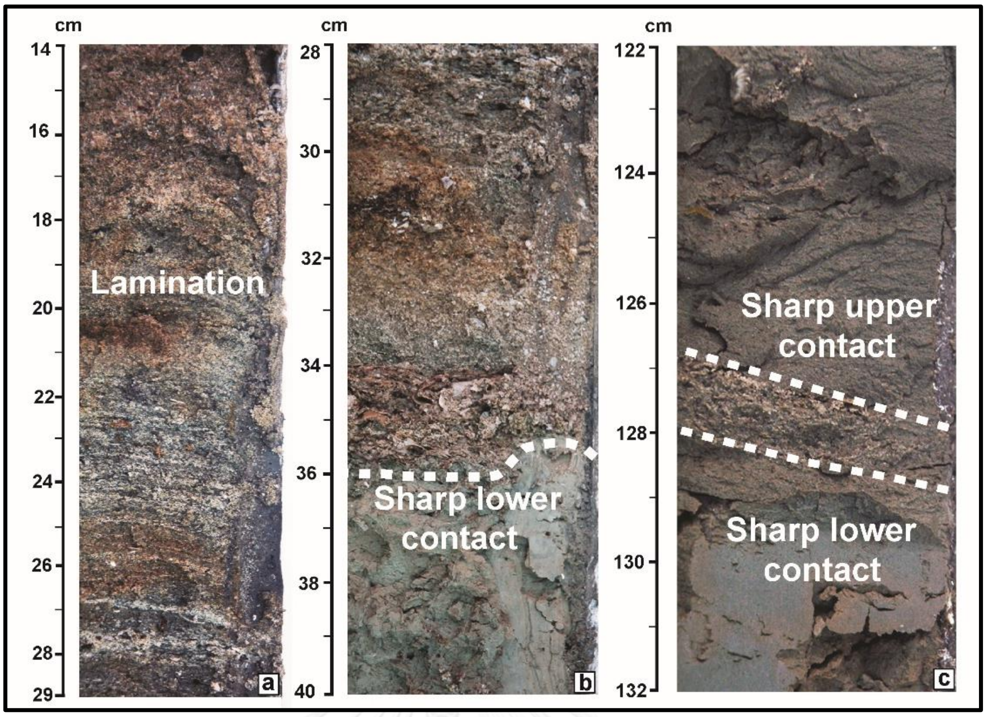

Figure 4.6 Pictures showing sedimentary structure of Core KB1C1; a) Parallel lamination; b) shell fragment layer, sharp lower contact with mud layer and c) sub-horizontal stratification of sand, sharp lower and upper contacts with mud layers.

The longest core of transect 1 is KB1C2 (300 cm) and 20 m inland from KB1C1 that comprise sand sheet up to 27 layers with sharp lower and upper contacts distinctively. Many sand sheets interbeded with mud layers about 1 - 2 cm were found in the deeper part of core. Furthermore, parallel lamination, mud rip-up clast and shell fragment with sharp lower contact are striking at depth 39 cm (Figure 4.5). Coarse pebble also was recognized from core. Mud rip-up clast contained in core indicates the erosion of the local swale surface coincident with emplacement of sand layer by high energy event (William et al., 2016), (Figure 4.7).

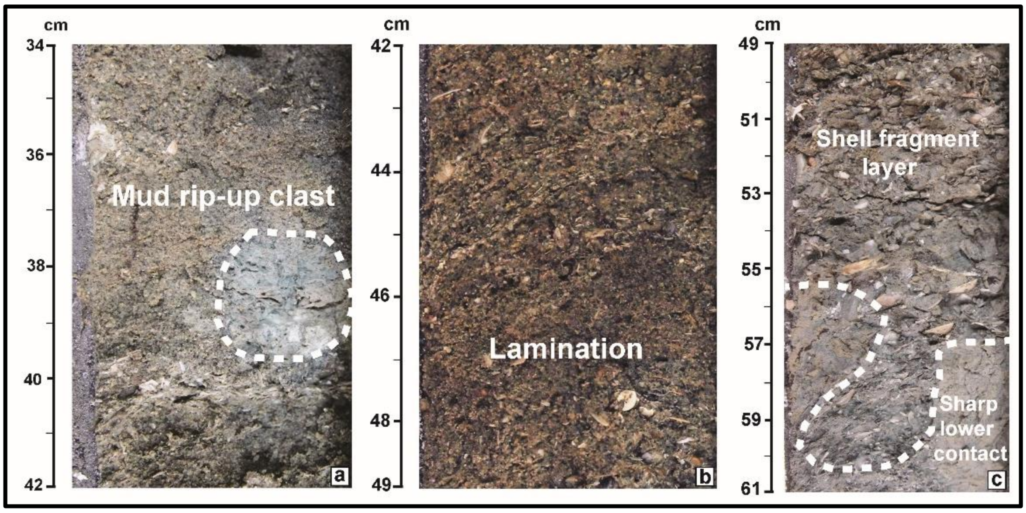

Figure 4.7 Pictures showing sedimentary structures of core KB1C2; a) mud rip-up clast; b) lamination and c) shell fragment layer, sharp lower contact with mud layer.

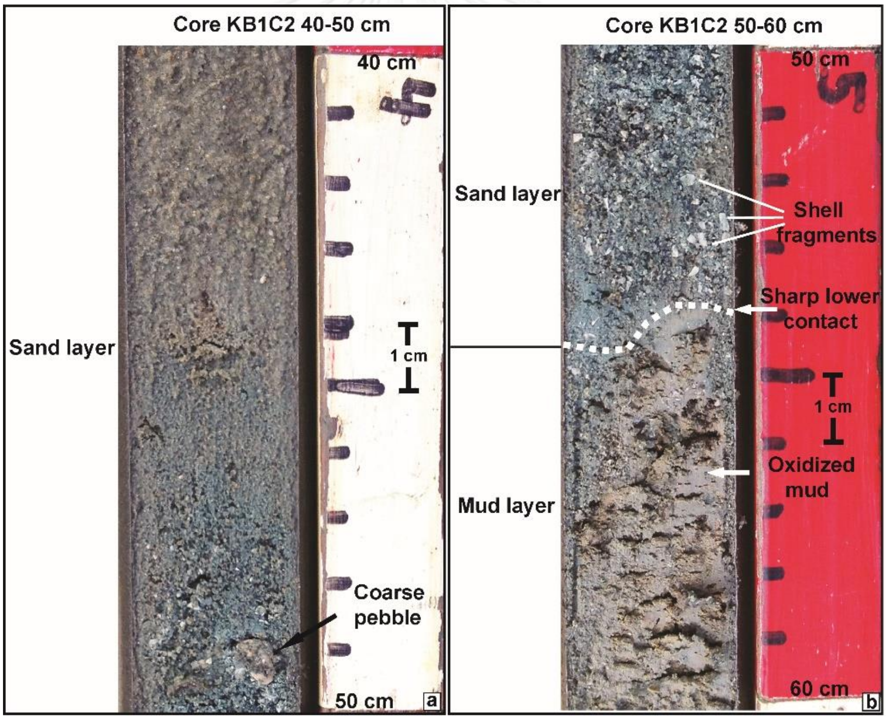

Figure 4.8 Pictures showing sand and mud layers in core KB1C2at depth 40-60 cm; a) sand layer with coarse pebble and b) sand layer and shell fragments, sharp lower contact with oxidized mud layer.

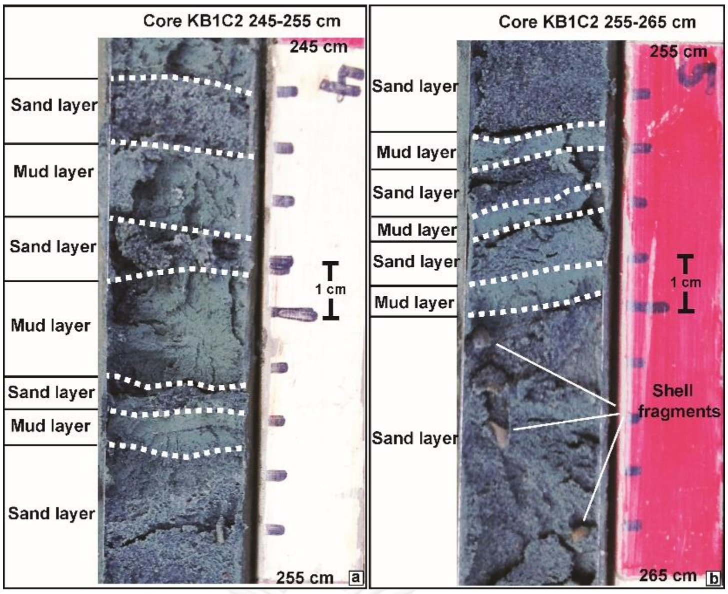

Figure 4.9 Pictures showing sand and mud layers of core KB1C2 at depth 245 -265 cm; a) sand layer, sharp top and basal contacts with mud layers and b) sand layer and sharp lower and upper contacts with layer. Dashed lines indicate sharp lower and upper contacts.

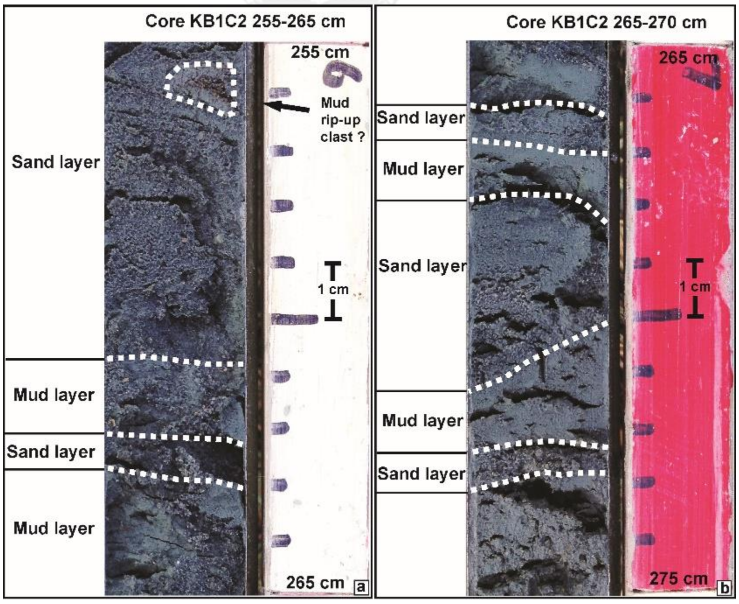

Figure 4.10 Pictures showing sand and mud layers of core KB1C2 at depth 255 – 265 cm from gauge core; a) sand layers, sharp lower and upper contacts with mud layers and b) sand layers, sharp lower and upper contacts with mud layers. Dashed lines indicate sharp lower and upper contacts).

Cores KB1C3 – KB1C4 were cored under inundation of swale water condition, so coring cannot go down deeper due to collapsing of borehole. The length of cores (core KB1C3 – KB1C4) is 79 and 82 cm. One sand sheet layer with sharp lower and upper contacts were observed within both cores. Coarse pebble was also found from core KB1C3 at depth 28 cm. The continuity of sand layer from core KB1C1 – KB1C4 indicated the energy of intense storm surge in direct toward to the coast and transported these sediments across the beach ridge and deposited in the swale up to 350 m from the present beach.

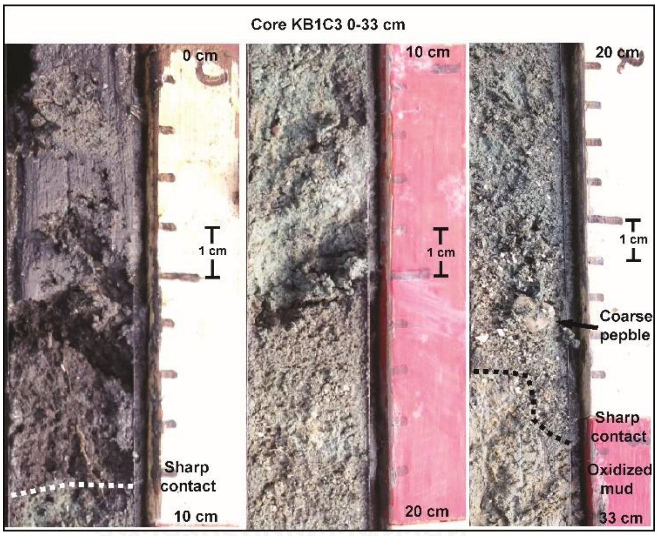

Figure 4.11 Core KB1C3 (gauge core); one sand layer, coarse pebble and sharp lower and upper contacts at depth 9-29 cm. Dashed lines indicate sharp lower and upper contacts.

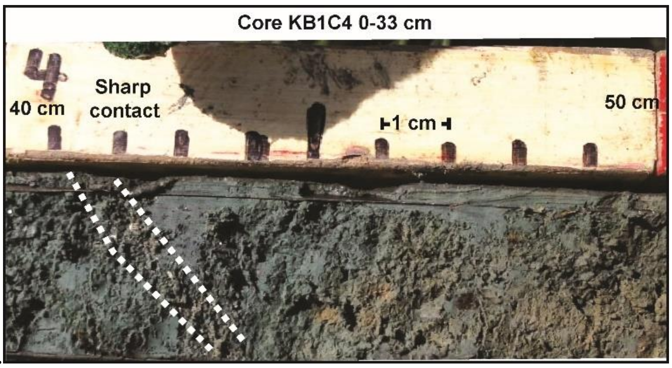

Figure 4.12 Core KB1C4; Inclined sand sheet layer and shell fragments with sharp lower and upper contact at depth 41 cm.

However, core KB1C5 – KB1C6 are 62 and 67 cm long. Sand sheet was not found. Oxidized mud layers were still observable. The absence of sand layer may relate the intensity of storm that has no strength enough.

From the results of swale stratigraphy, layers of ancient storm were correlated across transect 1 and referenced with the elevation from measuring topographic profile (Figure 4.13). Notably, the continuity of the first sand layer is characterized by wedge shape profile. The result of transect 1 correlation indicates thinner inland deposit which is one of characteristics of storm deposits (Nanayama et al., 2000; Tuttle et al., 2004; Williams, 2016).

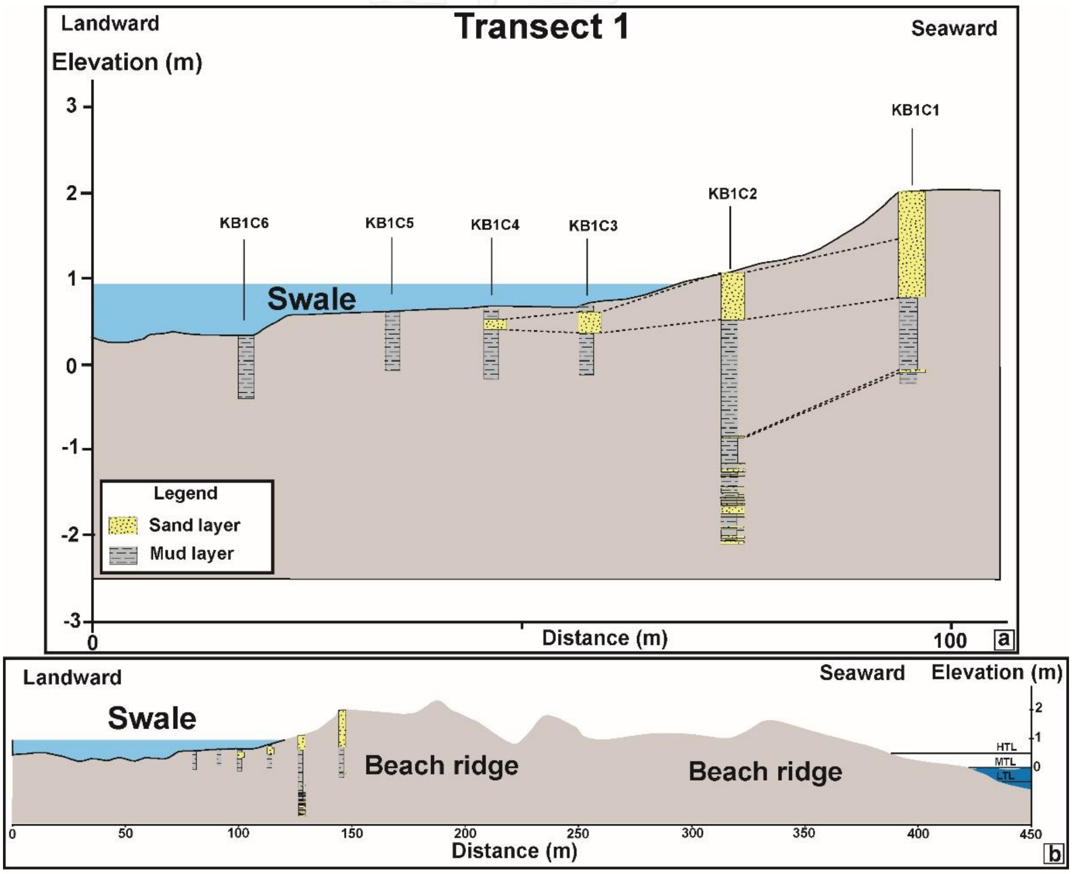

Figure 4.13 Pictures showing correlation and topographic profile of transect 1; a) ancient storm sediment layers were correlated based on stratigraphic positions of sand layers and b) the true elevation of study area based on measuring topographic survey.

4.2.2 Transect 2

Transect 2 contains six cores (KB2C1 – KB2C6) from the distal part of beach ridge to the middle part of swale. Core KB2C1 is the longest core of transect (239 cm) and the most seaward which comprised 11 sand layers with sharp top and basal contacts. Since transect 2 was collect by means of a gauge core; therefore, sedimentary structures within core can be observed sharp contact only. Thickness of the first sand layer is 61 cm that has sharp basal contact with oxidized mud later. Many thin sand layers (1-2 cm) were found in the deeper part of core which similar to the deeper part of core KB1C2. Shell fragments distributed within all sand layers. Oxidized mud layers were also observed like core KB1C2 as well.

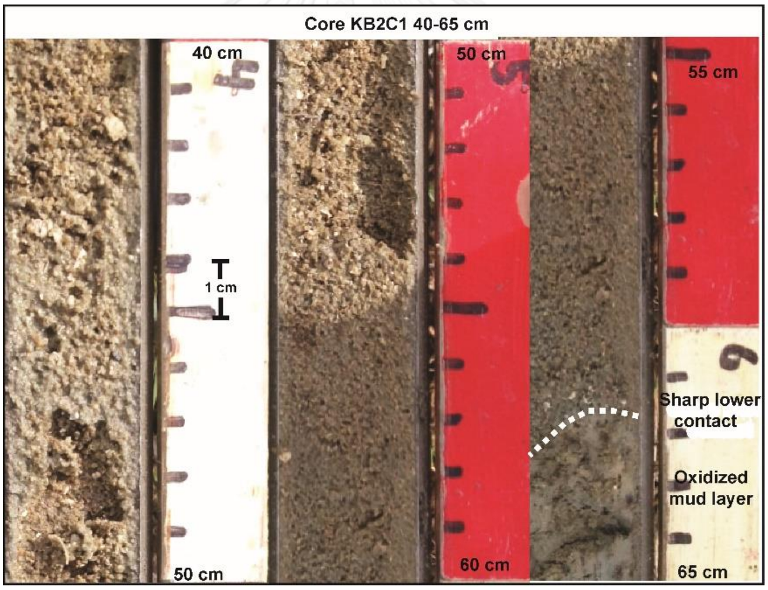

Figure 4.14 Pictures showing sediments layers of core KB2C1 (gauge core); sand bed has sharp lower contact with oxidized mud layer. Dashed line indicates sharp lower contact.

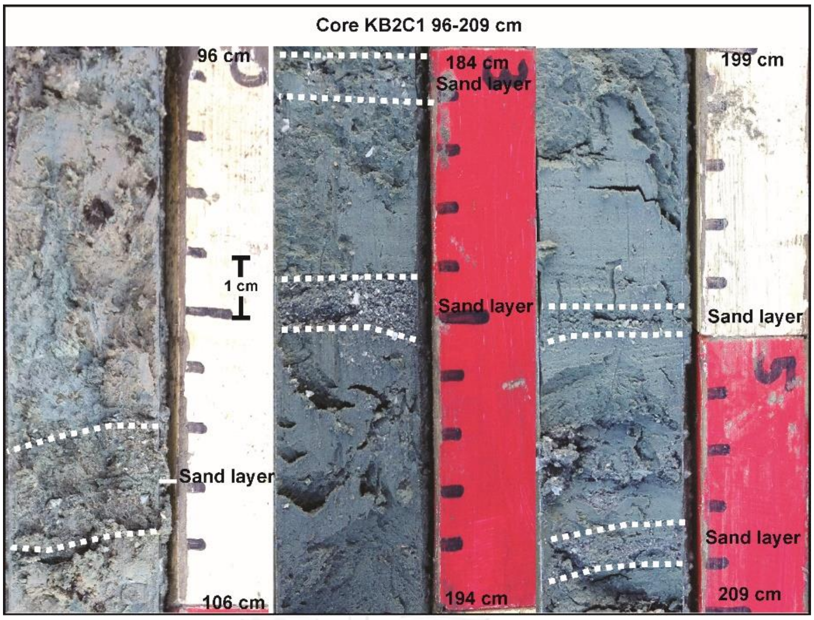

Figure 4.15 Pictures showing core KB2C1 at depth 96-209 cm; sand sheet layers with sharp lower and upper. Dashed line indicates sharp lower and upper contacts.

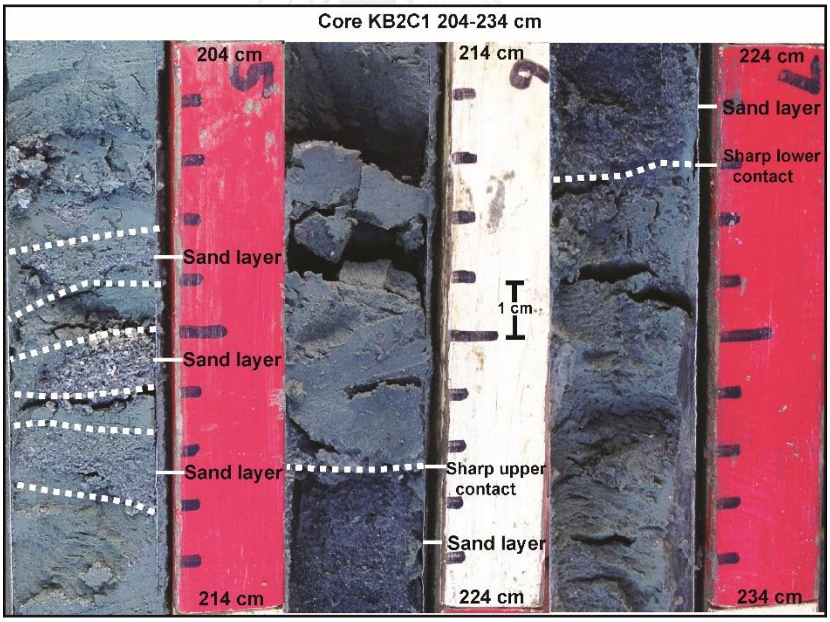

Figure 4.16 Core KB2C1 at depth 204-234cm; sand sheet layers have sharp lower and upper contacts with mud layers. Dashed lines indicate sharp lower and upper contact.

Core KB2C2 and KB2C3 were collected in the inundation of swale water. The lengths of cores are 155 and 82, respectively. Core KB2C2 consist two sand layers mixing with shell fragments at depth 16 – 45 cm and 88 – 91 cm with sharp top and basal contacts. Oxidized mud layers were also observed within core KB2C2. KB2C3 contains one sand layer mixing with shell fragments interbeded with mud layers at depth 26 – 31 cm.

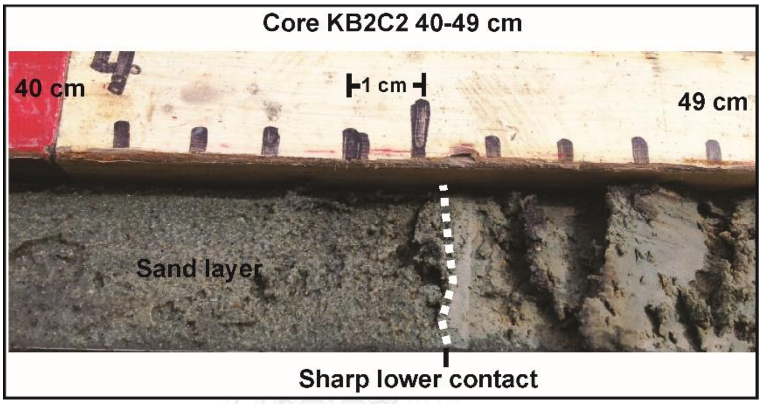

Figure 4.17 sand layer in core KB2C2 displays sharp basal contact with oxidized mud layer at depth 45 cm. Dashed line indicates sharp lower contact.

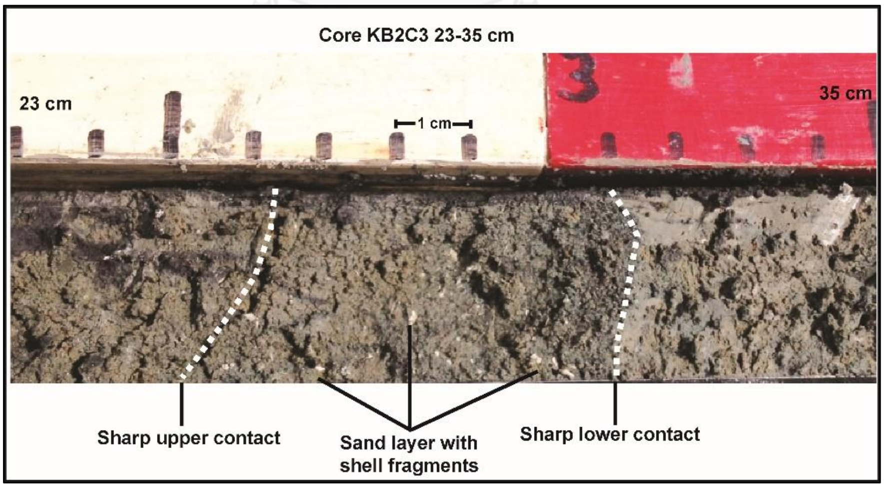

Figure 4.18sand layer and shell fragments of core KB2C3 exhibit sharp upper with finer grain and sharp upper and lower contact with oxidized mud layer at depth 26 – 31 cm. Dashed lines indicate sharp lower contact.

Core KB2C4 – KB2C6 are 47, 46 and 60 long respectively. Sand layer is not observed. But, oxidized mud layers remain recognizable within all cores.

The individuals of ancient storm layers in each core were correlated along transect 2 based on stratigraphic positions of sand layers and referenced to the elevation from measuring topographic profile (Figure 4.19). Notably, Wedge shape profiles also exhibited in landward deposition which thinner inland deposit similar to transect 1.

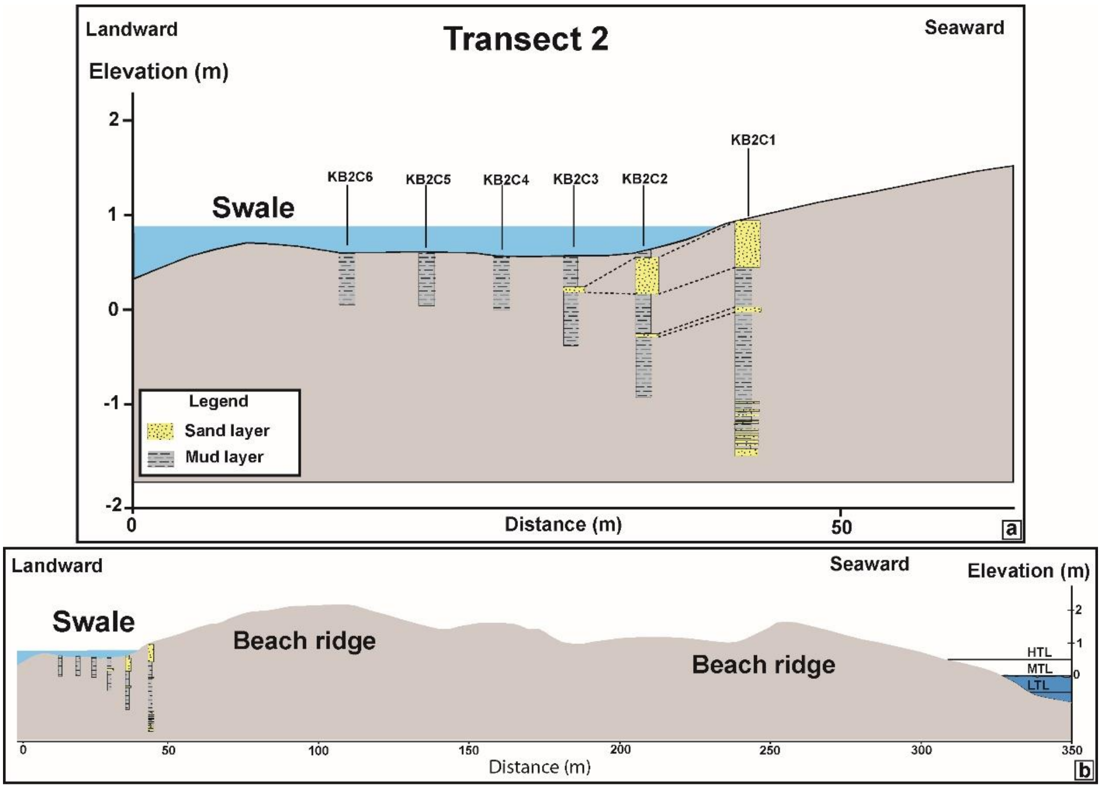

Figure 4.19 Pictures showing correlation and topographic profile of transect 2; a) ancient storm layers were correlated based on stratigraphic positions of sand layers and b) the true elevation of study area based on measuring topographic survey.

4.2.3 Transect 3

Transect 3 consists of five cores (KB3C1 – KB3C5). Similarly, core samples of transect 3 were collected by means of gauge core. Sedimentary structures are featureless except for sharp upper and lower contacts that can be observed strikingly. KB3C1 is the most seaward and the longest core. It consists of 16 sand layers with sharp upper and lower contacts, reaching a depth of 270 cm. The thickness of the first sand layer is 50 cm. Many thin sand layers (0.5 - 1 cm) also were recognized in the deeper part of core, similar to core KB1C2 and KB1C2. Oxidized mud layers remain distinctive on the upper part of core.

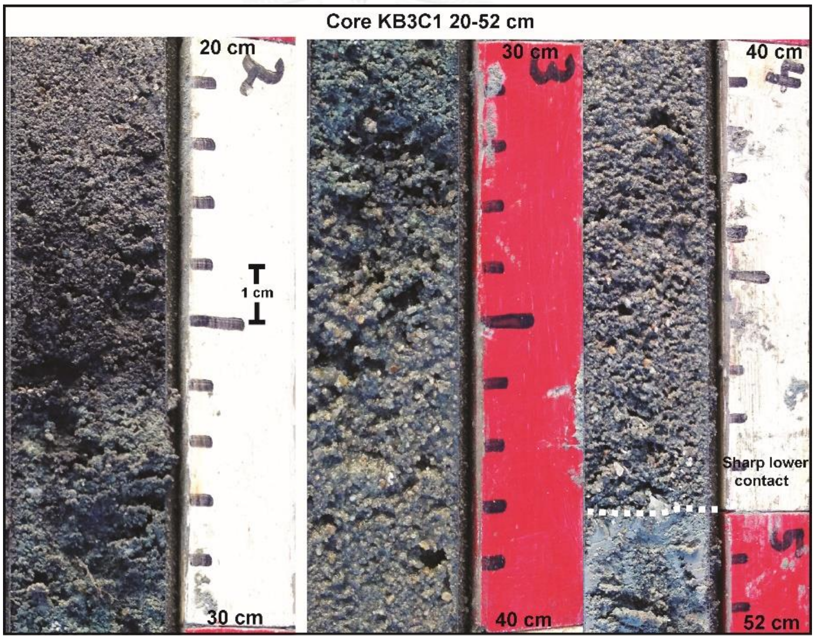

Figure 4.20 Sand layer of core KB3C1 at depth 20 – 52; sharp lower contact is obvious at depth 50 cm. Dashed line indicates sharp lower contact.

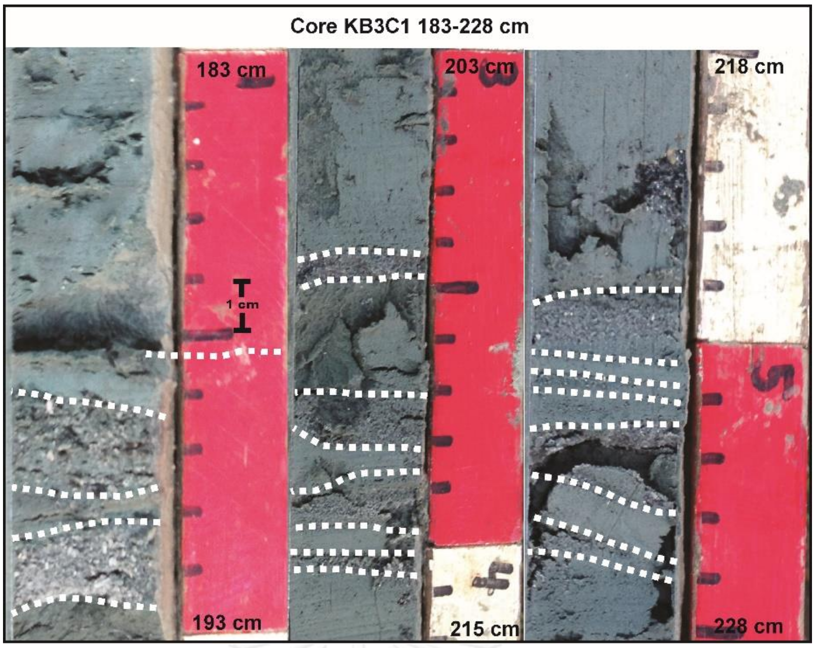

Figure 4.21 multiple sand sheet layers of core KB3C1 with sharp lower and upper contacts at depth 183-228 cm. Dashed lines indicate sharp lower contact.

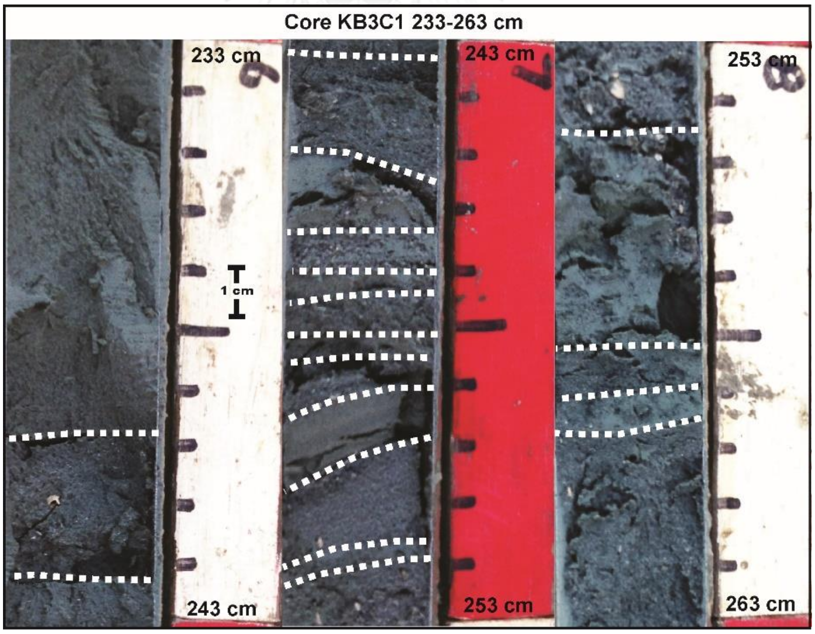

Figure 4.22 Thin sand layers of core KB3C1 at depth 233-263 cm have sharp lower and upper contacts. Dashed line indicates sharp lower contact.

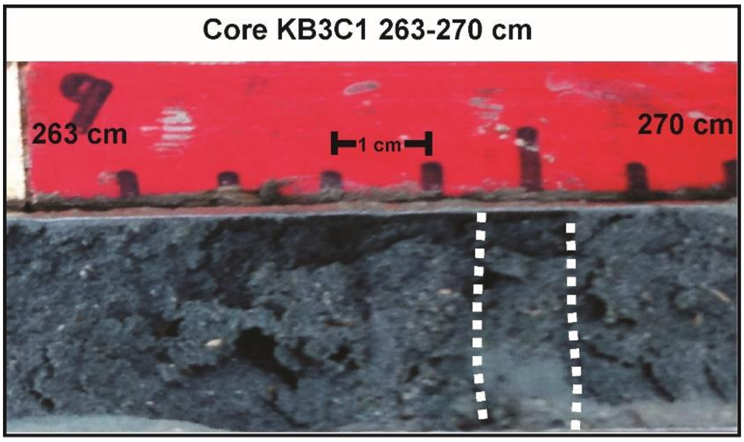

Figure 4.23 Core KB3C1 at depth 263-270 show two sand layers with interbeded mud layer. Dashed lines indicate sharp lower and upper contact.

At core KB3C2 and KB3C3 are 104 and 85 cm long. One sand sheet layer was found at depth 24 – 40 cm with shape top and basal contacts in core KB2C2. At depth 18 – 28 cm, one sand layer, sharp upper and lower with oxidized mud layer remains observable within core KB3C3.

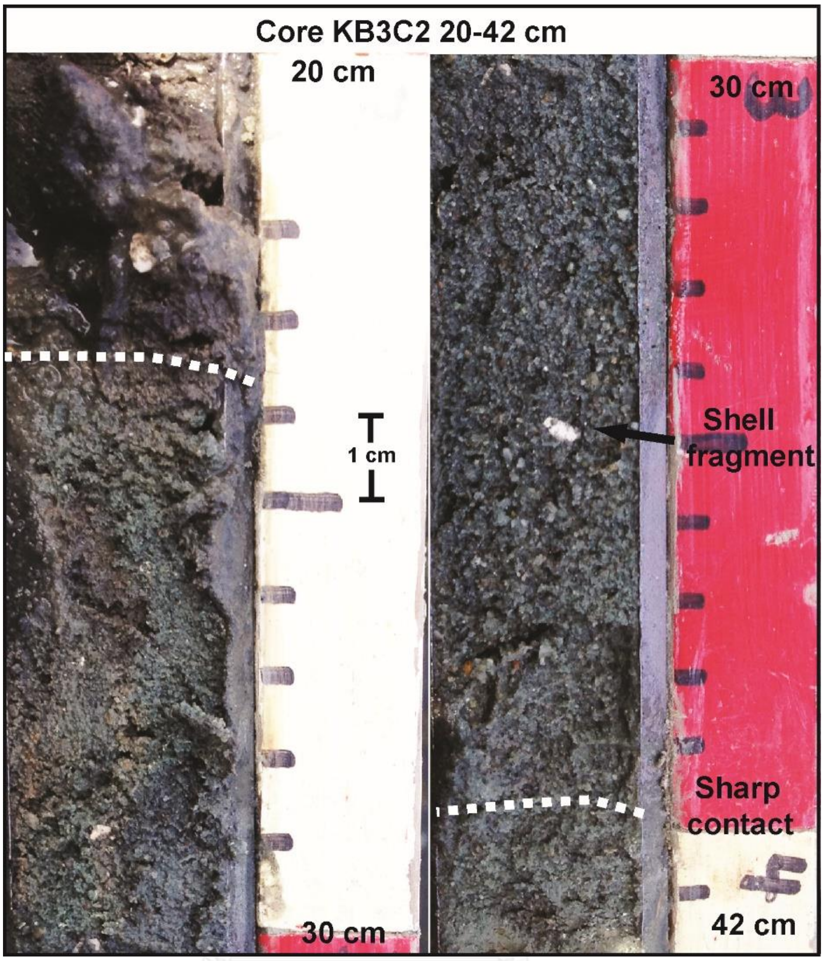

Figure 4.24 Sand layer with shell fragments of core KB3C2 at depth 24-402 cm has sharp top and basal contacts with enclosing organic-rich muddy swale deposits and sharp lower contact mud layer. Dashed lines indicate sharp lower and upper contact.

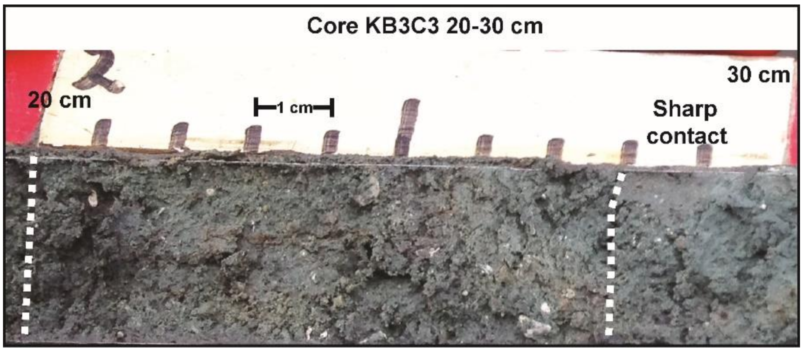

Figure 4.25 Sand layer and shell fragments with sharp upper and lower contacts with mud layer. Dashed lines indicate sharp lower and upper contact.

In contrast, at core KB3C4 and KB3C5, sand layer is not observed. This may be indicated the intense storm surge cannot transport to this point due to elevation on the left side of swale.

Correlation of transect 3 was created and referenced based on measuring topographic profile. Wedge shape profile exhibited in the correlation that indicates thinner inland deposits.

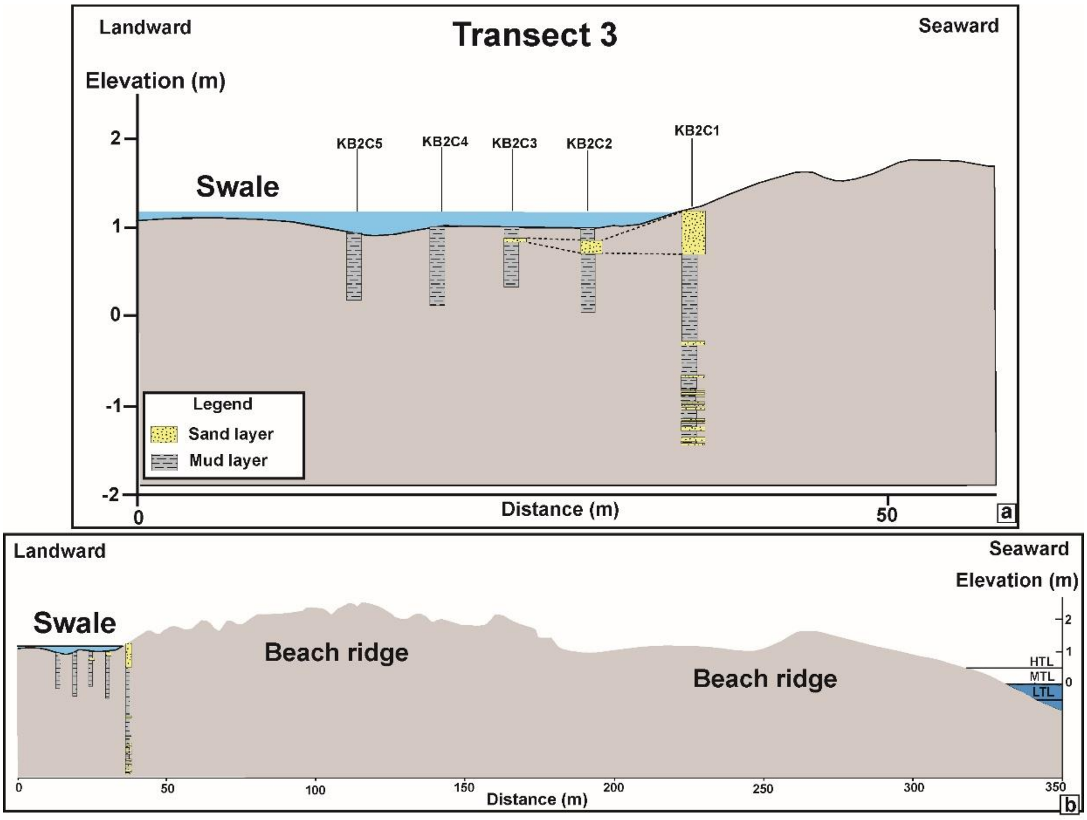

Figure 4.26 Pictures showing correlation and topographic profile of transect 3; a) ancient storm sediment layers were correlated based on stratigraphic positions of sand layers and b) the true elevation of study area based on measuring topographic survey.

Core KB1C2, KB2C1 and KB3C1 were correlated in the parallel position based on stratigraphic position of sand layer, thickness of sand layer and composition of sand sediment.

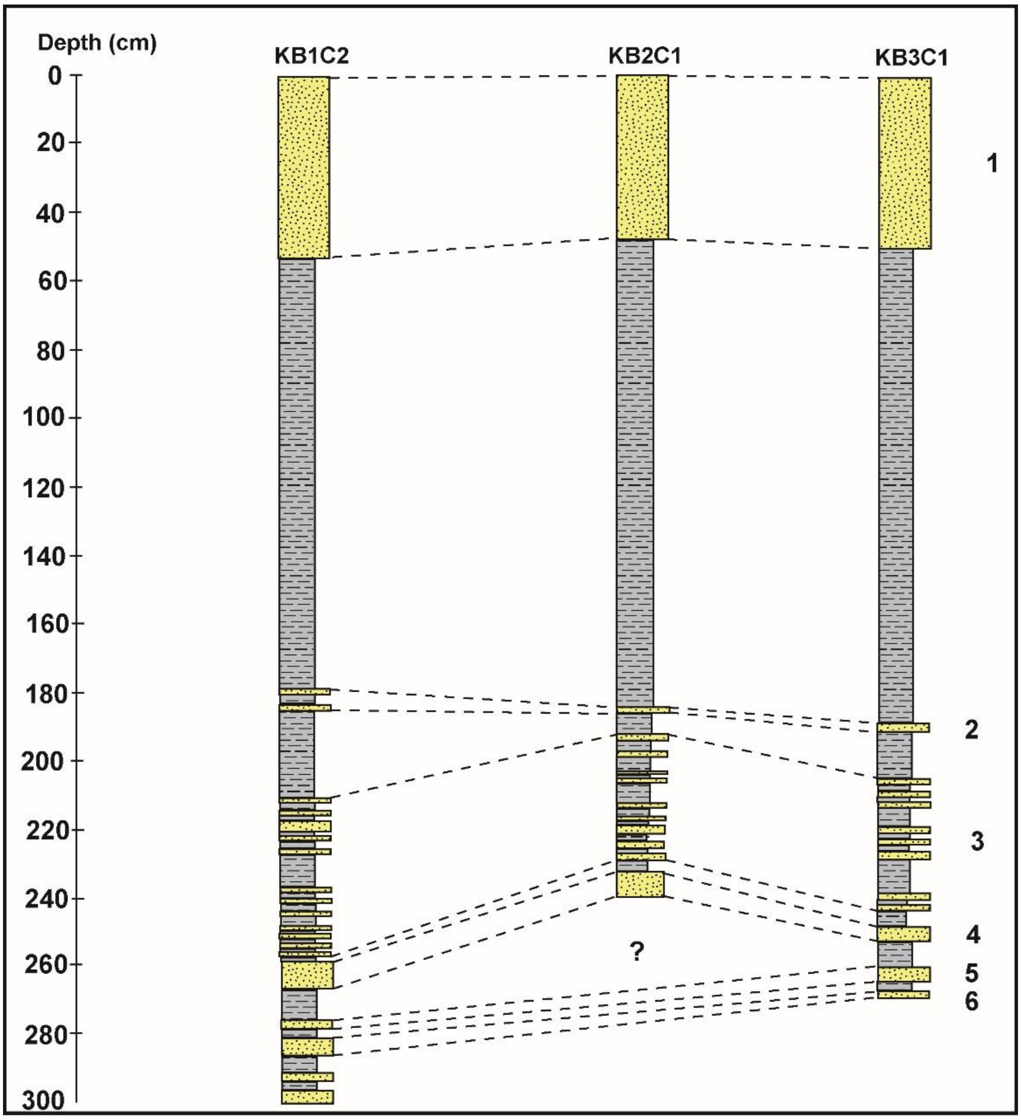

Figure 4.27 Sand layers of core KB1C2, KB2C1 and KB3C1 were correlation based on stratigraphic positions and the characteristics of sand bed.

4.3 Sedimetological analysis

The selected samples were analyzed to examine the disparities and the similarities in physical properties (composition, roundness and sphericity) and grain size characteristics (mean, standard deviation, skewness and kurtosis) between ancient storm and non-storm sediments.

Physical properties (composition, roundness and sphericity)

Generally speaking, quartz, feldspars, rock fragments, heavy mineral and bioclasts such as skeletal fossil fragments of livings marine organisms are commonly found in the composition of coastal deposits. The composition of coastal deposits; however, can be different from place to place where resulted from the difference of source rock and in situ sediment. In this study, sediment samples of storm and non-storm sediments were examined and photograph under a dissecting microscope. The results of composition on both samples are mostly quartz, rock fragment, heavy mineral and bioclasts (Figure 4.28 – 4.32).

Non-storm sediment samples especially foreshore and backshore sediments contained 99% quartz sand. Foreshore sediments 1 and 2 were classified as medium sand and moderately well sorted while backshore sediment was classified as fine sand and well sorted. Recent beach sediments 1 and 2 contained 70% quartz sand and 25% bioclasts and were classified as fine sand and moderately well sorted. The existence of high bioclasts in content from the samples of recent beach sediment 1 and 2 are common. Roundness of non-storm sediment ranges in angular to sub-rounded.

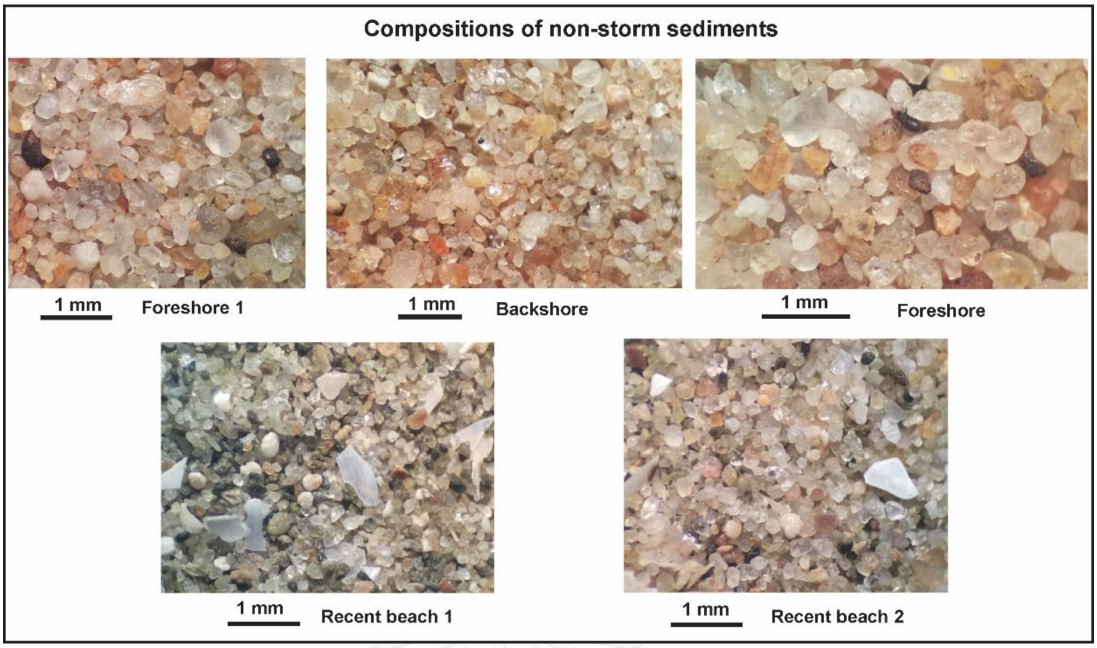

Figure 4.28 Compositions of non-storm sediments.

The main composition of ancient storm sediments mostly contains quartz, bioclast, and heavy mineral that varying in each sediment samples. Bioclasts content of ancient storm sediment consist of shell fragments, bivalvia and gastropoda fossils, spicule, ostracod and foraminifers. Notably, all sand samples in each interval (0.5 – 1 cm) contain bioclasts. The sediment samples from the interval between 22.5 to 36 cm contain bioclast in high volume. Specifically, in the interval of 35 – 36 cm contains bioclasts up to 70%. However, in the interval of 126.5 – 128.5 cm. has low content of bioclasts. Roundness of ancient storm sediment ranges in very angular to sub-rounded.

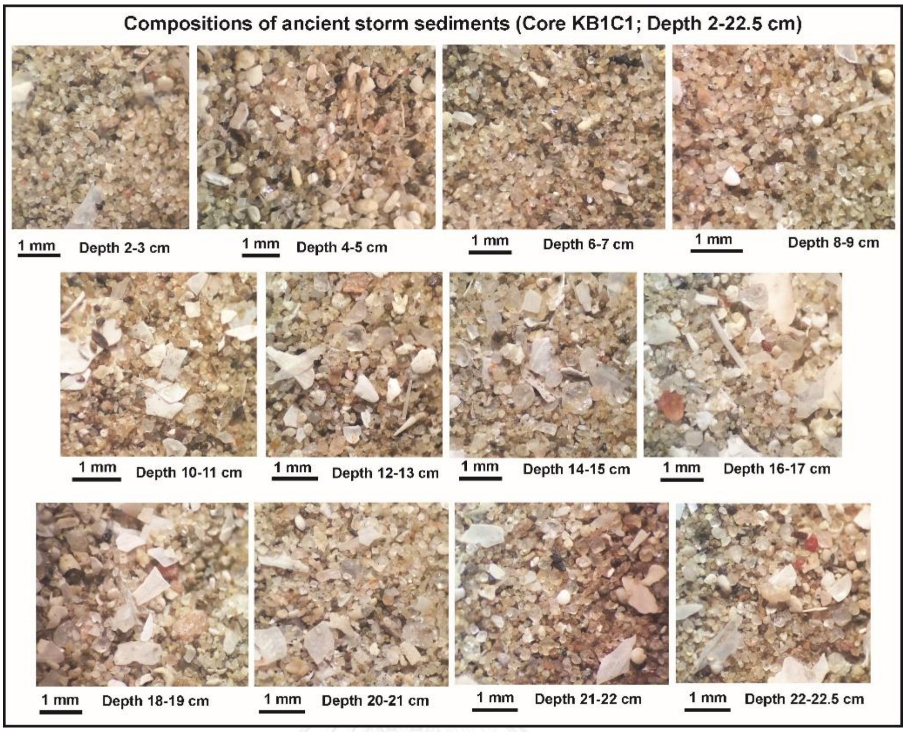

Figure 4.29 Compositions of ancient storm sediments from core KB1C1 at depth 2-22.5 cm.

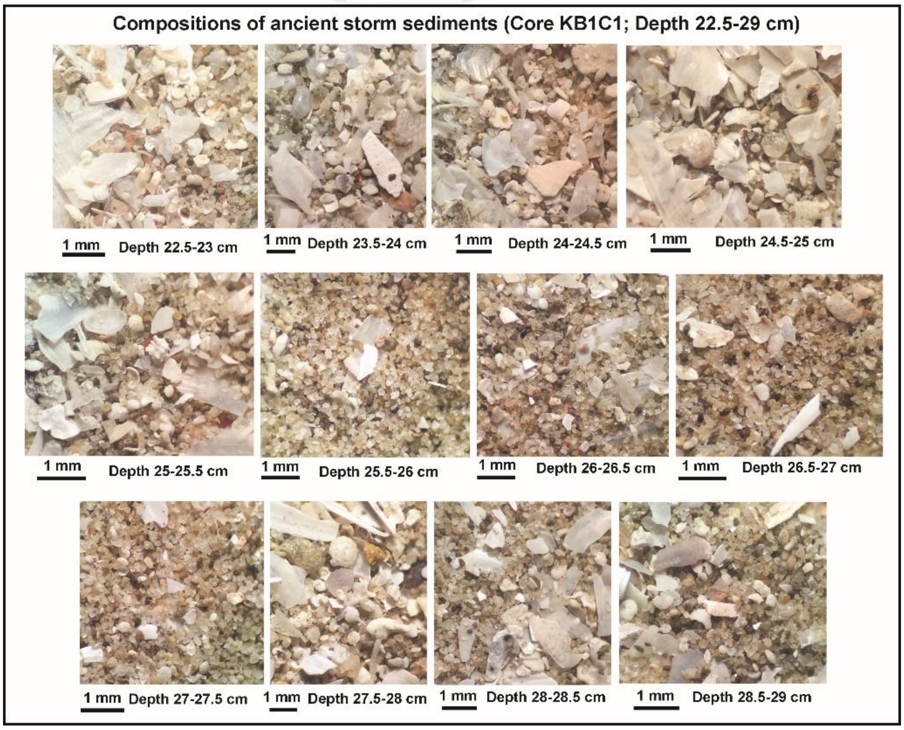

Figure 4.30 Compositions of ancient storm sediment from core KB1C1 at depth 22.5-29 cm.

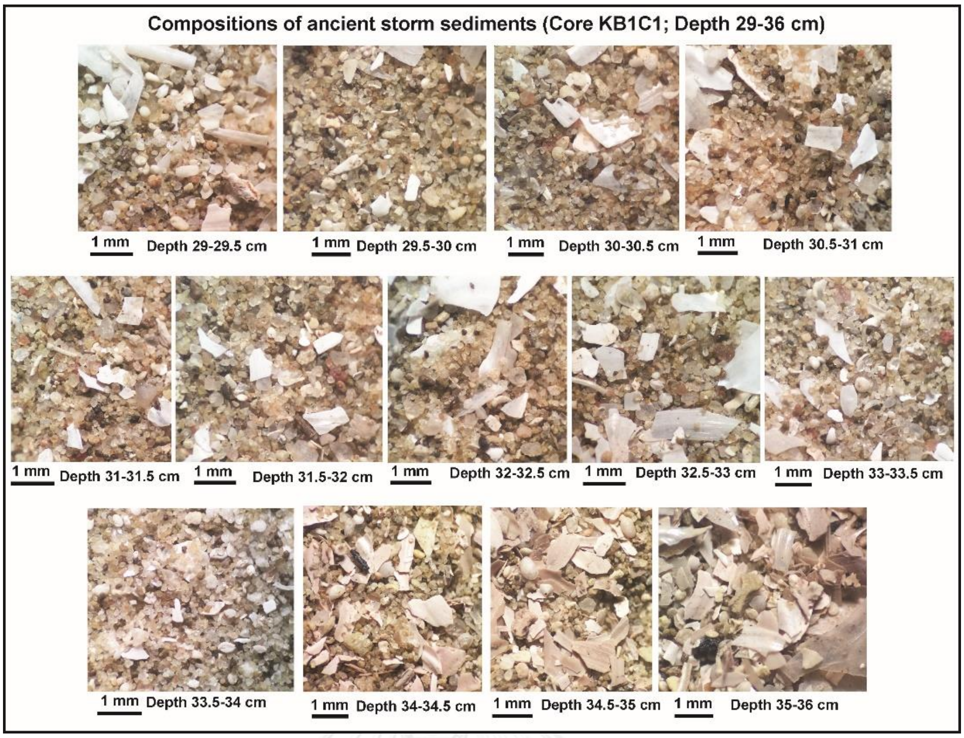

Figure 4.31 compositions of ancient storm sediment from core KB1C1 at depth 29-36 cm.

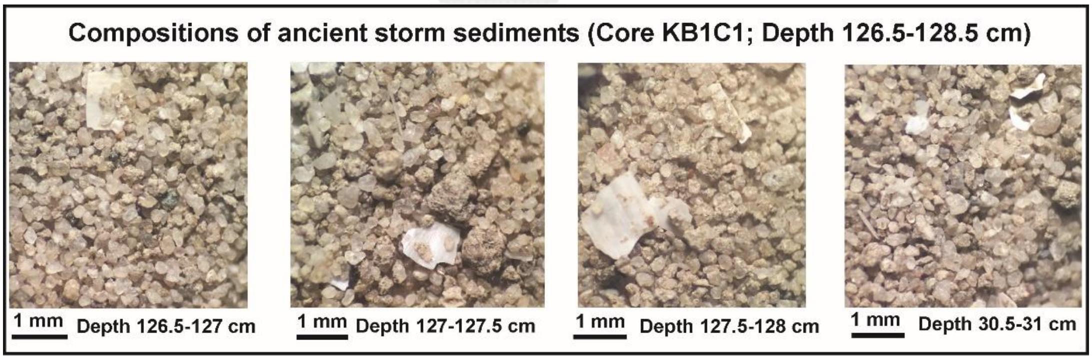

Figure 4.32 Compositions of ancient storm sediment from core KB1C1 at depth 126.5-128.5 cm.

Grain size characteristics

In this section, 136 samples of ancient storm sediments from transect 1 (KB1C1-KB1C4) were analyzed by laser granulometric method. 8 samples of non-storm sediments; however, were performed by sieve analysis. The compulsory reason of different analysis was mentioned in the Chapter 3.

Mean grain sizes of ancient storm sediment samples obtained from laser granulometric method were plotted in graph for recognizing the variation of ancient storm deposit.

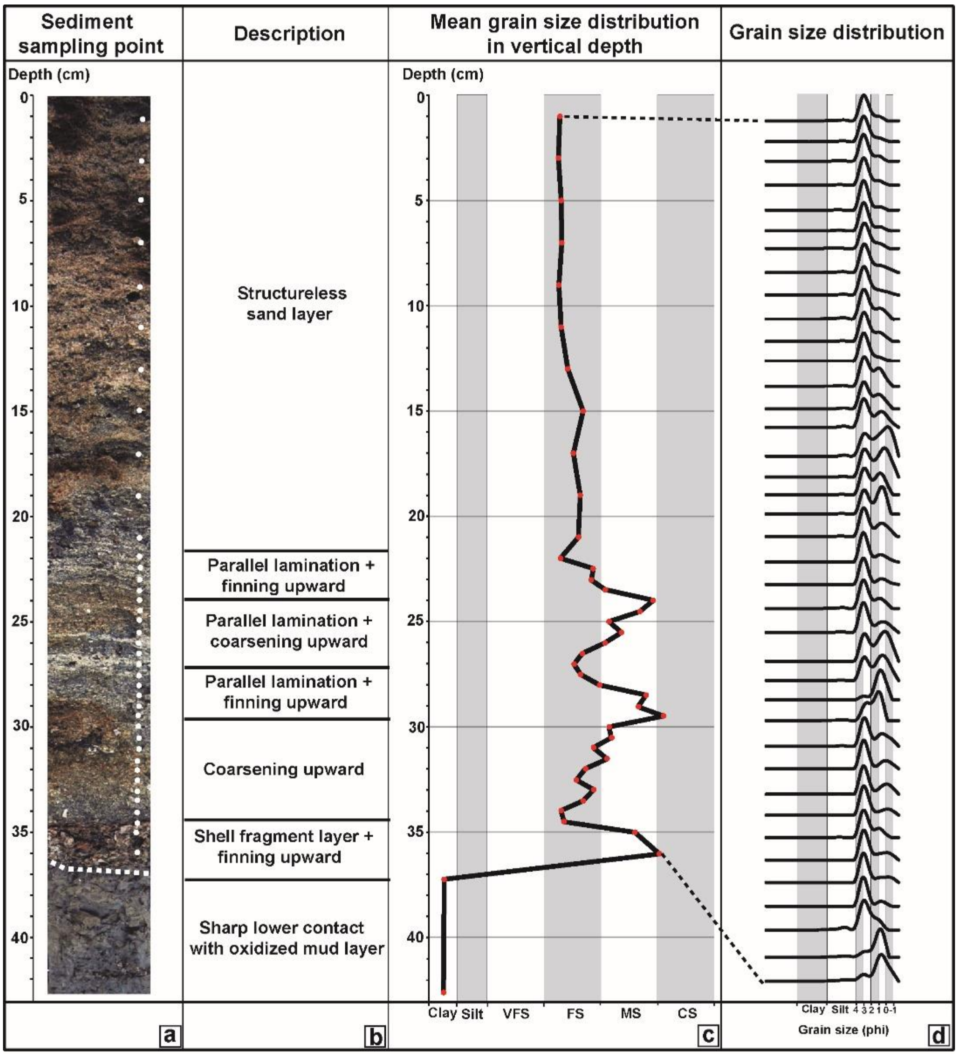

Figure 4.33 a) stratigraphy of core KB1C1 at depth 0 – 43 cm; b) description; c) mean grain size distribution in vertical depth and d) grain size distribution.

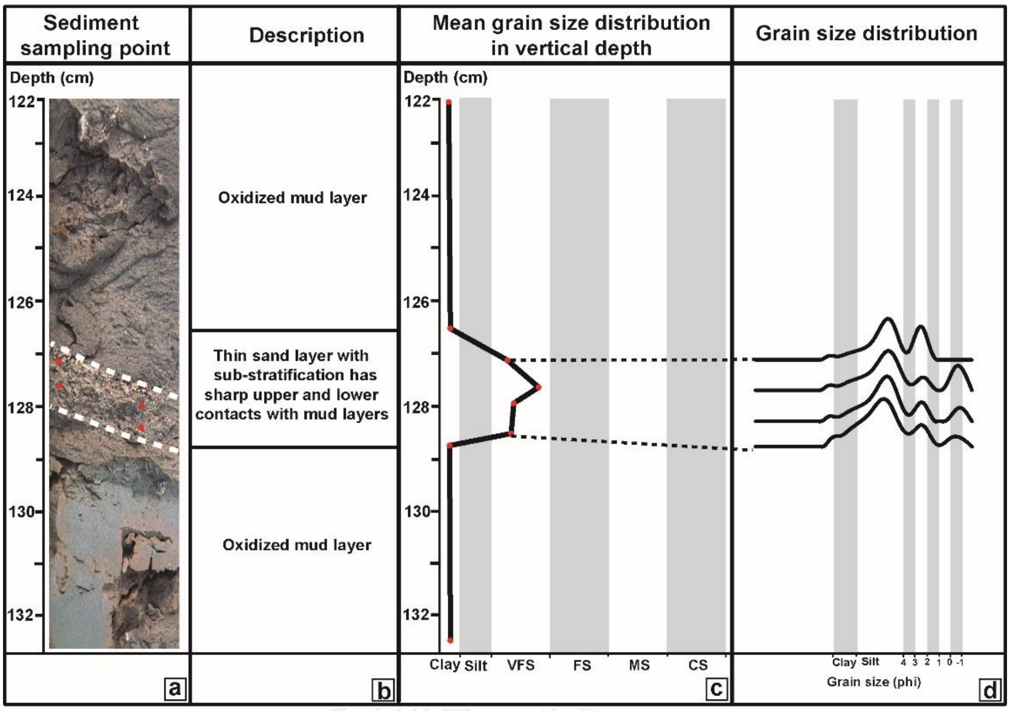

Figure 4.34 a) stratigraphy of core KB1C1 at depth 122 – 132 cm; b) description; c) mean grain size distribution in vertical depth and d) grain size distribution.

Mean grain size distribution in vertical depth of core KB1C1 reveals the variation of sand grain size inside the structure of parallel lamination that comprised the sequences of two normal grading and two reverse grading at depth 22 – 36 cm, varying fine to coarse sand. Mean grain sizes in range 0 – 20 cm contain fine sand and there is no change in mean grain size distribution. The unchanging and changing mean grain sizes are likely meant the stages of storm surge waves that transported an amount of eroded sediments mixing with many sources inland in the first stage. And then, since an amount of eroded sediments from many sources were transported inland, contributing to the decrease of sediment supply and become unchanging in mean grain size. At the depth of 127 – 128.5 cm, mean grain sizes are very fine sand. The characteristics of grain size distribution in core KB1C1 mostly contain both unimodal and bimodal distribution.

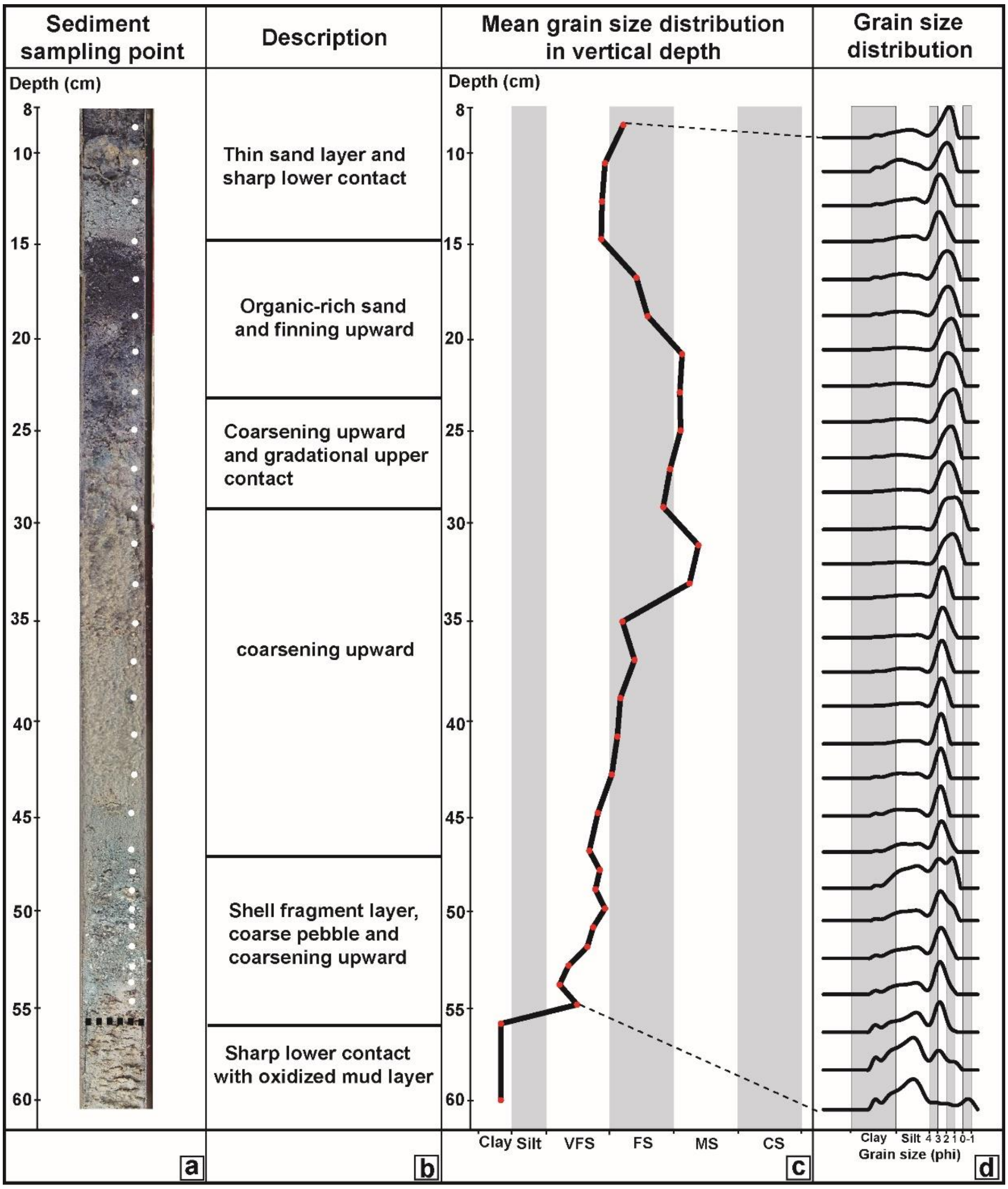

Figure 4.35 a) stratigraphy of core KB1C2 at depth 0 – 60 cm; b) description; c) mean grain size distribution in vertical depth and d) grain size distribution.

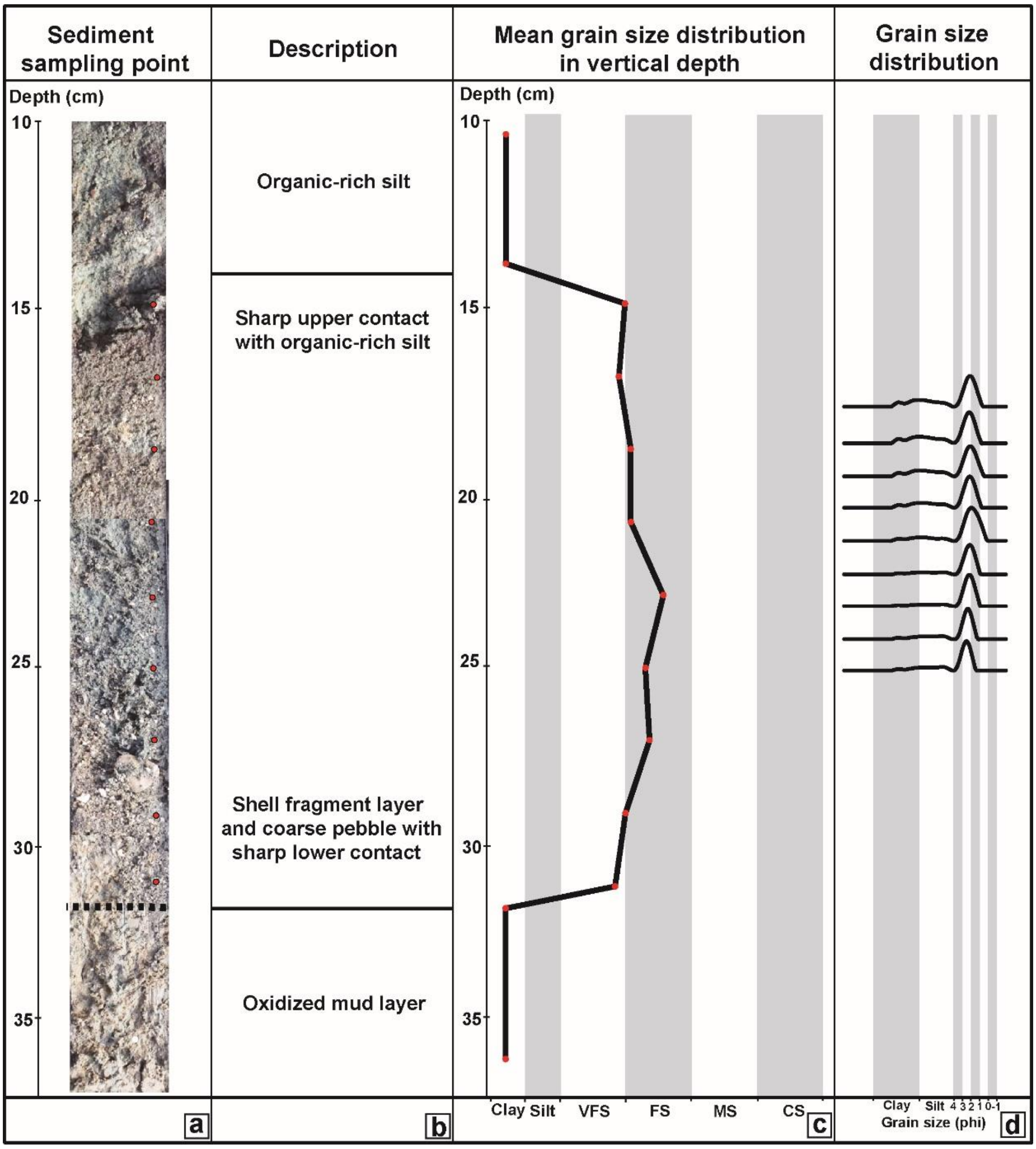

Figure 4.36 a) stratigraphy of core KB1C3 at depth 10 – 35 cm; b) description; c) mean grain size distribution in vertical depth and d) grain size distribution.

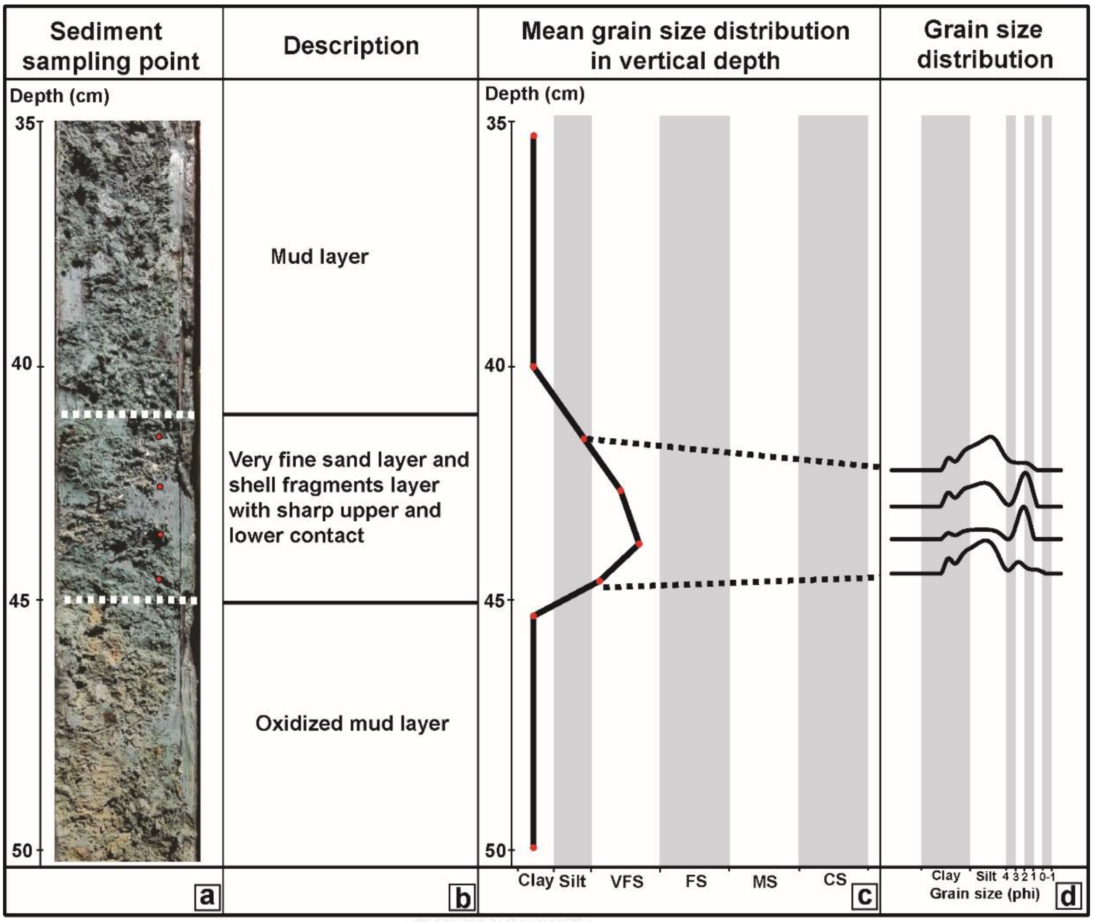

Figure 4.37 a) stratigraphy of core KB1C4 at depth 35 – 50 cm; b) description; c) mean grain size distribution in vertical depth and d) grain size distribution.

4.4 fossil and microfossil classifications

Seven mollusks, twenty-four foraminifers and two ostracods were identified under dissecting microscope. These marine faunas can use as the excellent indicator of washover sediment source and the depth of storm wave base; for example, the existence of bivalve that its habitat living at shoreface zone at depth 5 m, but was found at the deposits within a sand layer in muddy environment such as swale, marsh, indicative of the abnormal processes such high energy flow (storm surge). Non – broken valves were secluded for classifying only (Figure 4.38).

Similarly, the ancient storm sediments in this study found bivalvia and gastropoda fossils which theirs habitats are commonly found at the shallow water zone such as mangrove, intertidal are *Nuculana (Thestyleda) soyoae*, *Circe scripta*, *Psammotreta (Tellinimactra) edentula*. Sea floor at depth of 2 – 54 m. is *Carditellona pulchella*. And, in the sublittoral and upper bathyal zone is *Nassarius siquijorensis*.

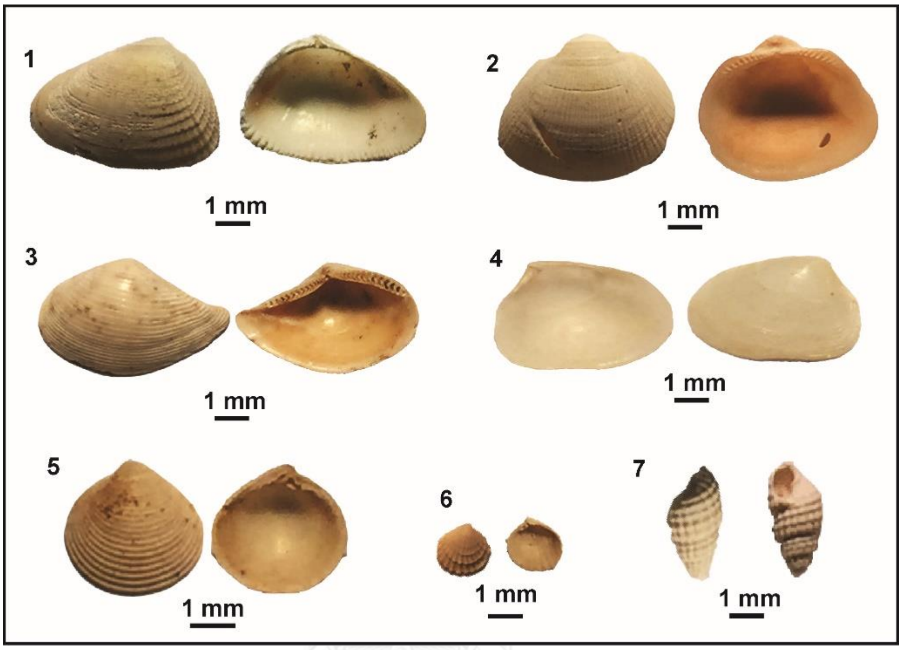

Figure 4.38 Bivalvia and Gastropoda fossils found from ancient storm sediments; 1) *Mactra sp*; 2) *Striarca lacteal* (Linnaeus, 1858); 3) *Nuculana (Thestyleda) soyoae*; 4); *Psammotreta (Tellinimactra) edentula*, 5) *Circe scripta* (Linnaeus, 1758); 6) *Carditellona pulchella* (Lynge, 1909) and 7) *Nassarius siquijorensis* (Adams, 1852).

Microfossils found form ancient storm sediments are commonly foraminifers and ostracod, calcareous benthonic species include species of *Ammonia*, *Elphidium*, *Quinqueloculina*, *Spriroloculina*. They live in sand surface of shallow marine such as delta, estuary, low-inter tidal at depth varying 0 – 100 m. Moreover, the presence of some species in ancient storm sediments (*Asterorotalia pulchella*, *Cellanthus craticulathus*, *Elphidium sp.*, *Psudorotalia sp*. and *Quinqueloculina sp.*) is consistent with the study of Jumnongthai (1983) that found a number of these genera from the Gulf of Thailand between depths of 29 – 34 m. Therefore, this can indicate the depth of storm wave base for these sand layers.

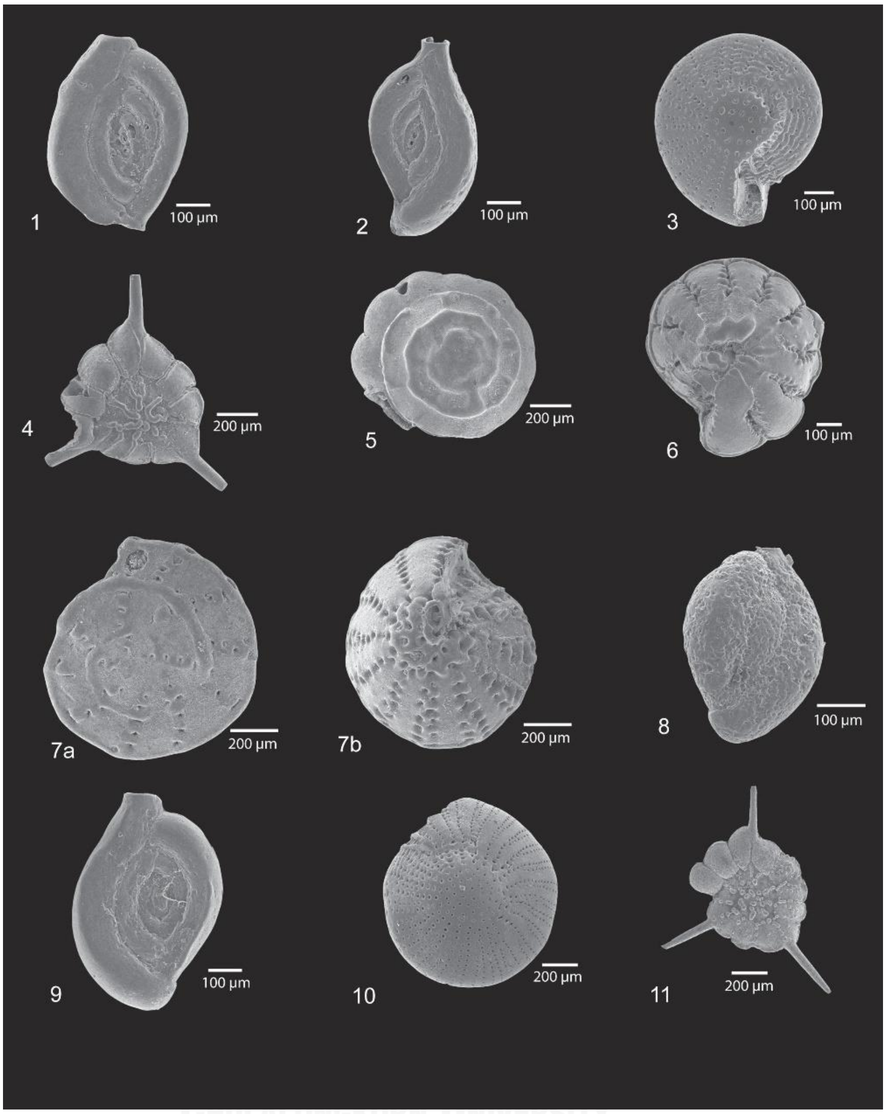

Figure 4.39 Plate 1 1) *Spiroloculina lucida*; 2) *Spiroluculina manifesta*; 3) *Elphidium advenum*; 4) *Asterorotalia pullchella*; 5) *Eponides sp.*; 6) *Psudolotalia sp.*; 7) *Ammonium baccarii*; 8) *Psudomassilinq sp.*; 9) *Spiroluculina clara*; 10) *Elphidium crispum* and 11) *Asterorotalia trispinosa*.

Figure 4.40 Plate 2 1) *Asterorotalia sp.*; 2) *Psudolotalia sp.*; 3) *Biloculina inormata*; 4) *Dendritina striata*; 5) *Cellathus craticulatus*; 6) *Siphonaperta sp.*; 7) *Quinqueloculinna parkeri*; 8) *Poroeponides lateralis*; 9) *Peneroplis pertusus*; 10) *Quinqueloculina seminulum*; 11) *Spiroloculina lucida*; 12) *Quinqueloculina gualtieriana* and 13) *Quinqueloculina gualtieriana*.

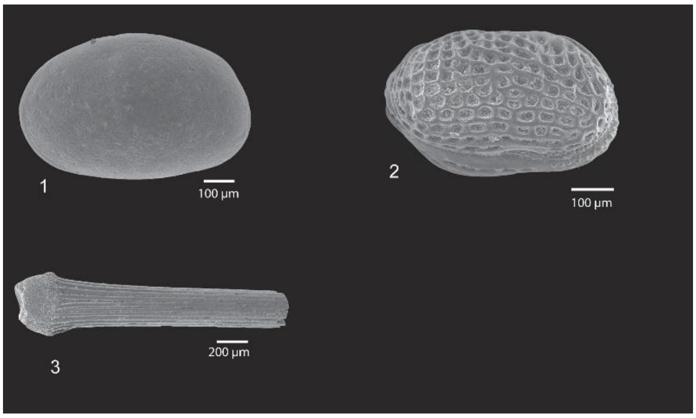

Figure 4.41 Plate 3 1) *Propontocypris bengalensis* ; 2) *Keijella neali* and 3) *Antalis vulgaris* (da Costa, 1778).

4.5 Age determination

Knowing the ages of study area is the important data particularly the occurrence time of beach ridges for controlling the time of ancient storm activity. The results of the ten dated samples are listed in the tables 4.1.and 4.2.

Name	U (ppm)	Th (ppm)	K (%)	W (%)	AD (Gy/ka)	ED (Gy)	Age (yr)
L1D1	0.76±0.008	2.04±0.009	0.37±0.002	2.48	0.614±0.012	0.718±0.014	1,160±30
L1D2	0.53±0.008	1.92±0.009	0.31±0.002	1.37	0.517±0.013	1.083±0.03	2,090±70
L2D3	0.69±0.008	2.26±0.009	0.36±0.002	2.44	0.605±0.012	0.744±0.024	1,220±40
L1D4	0.68±0.008	1.87±0.009	0.26±0.002	2.26	0.497±0.012	1.51±0.28	3,034±106
L1D5	0.49±0.008	1.53±0.009	0.32±0.002	1.81	0.481±0.013	1.758±0.049	3,650±140
L2D6	0.66±0.008	2.28±0.009	0.32±0.002	1.76	0.573±0.012	1.832±0.042	3,190±100

Table 4.1 Results of OSL dating analysis from sandy beach ridges.

Name	U (ppm)	Th (ppm)	K (%)	W (%)	AD (Gy/ka)	ED (Gy)	Age (yr)
KB1	0.73±0.008	3.38±0.008	0.77±0.002	6.89	0.970±0.012	1.186±0.035	1,220±30
KB2	0.71±0.008	0.45±0.008	0.84±0.002	29.74	0.738±0.012	1.550±0.1	2,100±140
KB3	1.01±0.007	4.74±0.008	0.93±0.002	23.40	0.993±0.011	2.51±0.234	2,520±230
KB4	1.10±0.007	5.52±0.008	1.09±0.002	25.82	1.106±0.011	2.931±0.386	2,650±350

Table 4.2 Results of OSL dating analysis from vertical depth.

According to the results of Optically Stimulated Luminescence (OSL) data, the age of the first sandy beach ridge between foreshore and backshore are 2,090±70 and 1,160±30 years before present. The ages of the second sandy beach ridge between foreshore and backshore are 3,650±140 and 3,034±106 years before present. Theoretically, OSL ages of the first beach ridge must be younger than the second beach ridges. The swale should form during 3,034±106 to 2,090±70 years ago. Then, the first beach ridge formed during 2,090±70 to 1,160±30 years ago. The sequences of seaward progradation occurred as a result of the gradual decrease of sea level in the past.

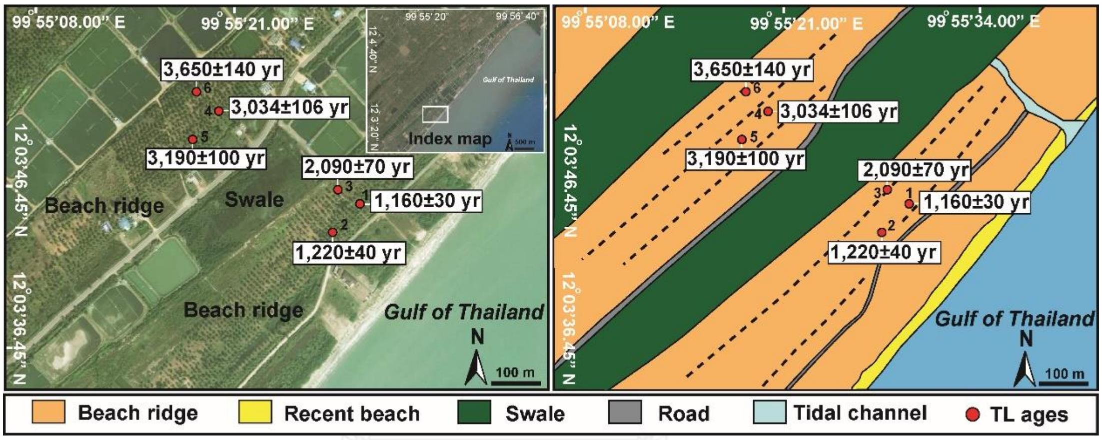

Figure 4.42 High resolution satellite image (left) and geomorphologic map (right) showing the results of OSL ages. Dashed lines indicate ridge and swale and yr indicates years ago.

Moreover, at the natural trench, four OSL ages at the distal part of the first beach ridge in vertical depths indicate the time of beach ridge deposits from top to bottom (1,220±30, 2,100±140, 2,530±230 and 2,650±350 years ago respectively. There are two ancient storm layers during 2,100±140 and 2,530±230. The age – depth results are beneficial to control the time of ancient storm deposit. Two ancient storm layers obtained from core KB1C1 were collected from the bottom of natural trench here which the oldest OSL age is 2,650±350 years ago. Theoretically, in the deeper part of the deposition must be older than 2,650±350 years ago. William et al., (2016) reported geologic records of Holocene typhoon strikes on the Gulf of Thailand which studied at

Kui Buri area close to the area of this study around 2.2 km. AMS radiocarbon dating result from a wood fragment at depth of 144 cm in the same swale is 6,977 years ago. Therefore, multiple sand layers found in the deeper part of core KB1C2; therefore, should be older than 6,977 years ago.

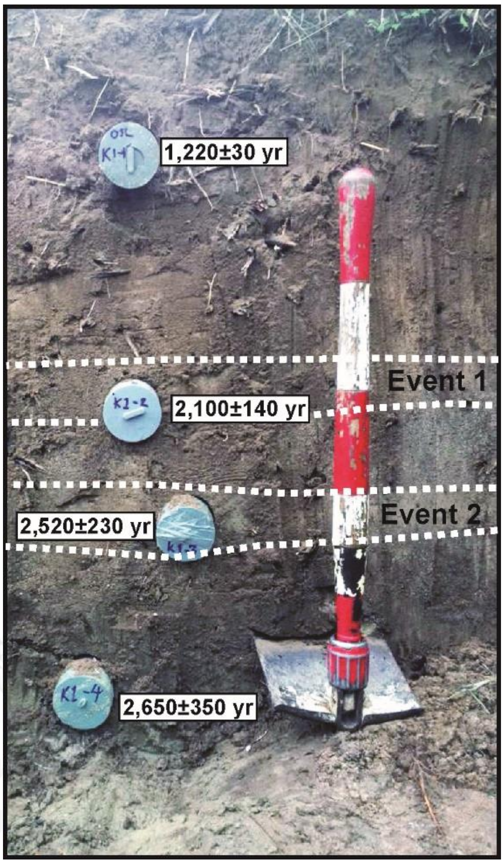

Figure 4.43 Picture showing the results of OSL ages at the natural trench of the first beach ridge.

Hence, the interpretation of the time of ancient storm deposits based on the results of Optically Stimulated Luminescence (OSL) ages and the radiocarbon age of William et al., (2016) indicates ancient storm deposits found from the swale of Kui Buri area during the mid-Holocene to late-Holocene period (6,977 to 1,220±30 years ago).

CHAPTER 5

DISCUSSIONS

5.1 The origin of sand layer

The appearances of sand layers found at Kui Buri area in swale environment that forming behind beach ridge and locating around 260 m inland from the present shoreline indicate the anomalous sedimentation possibly by unusual process. Usually, swale environment contains fine-grained sediments such as mud and/or silt, but the presences of the anomalous sand layers indicated the high energy event (storm and tsunami). The sand layers found from swale contained sharp lower and upper contacts with mud layers that indicate abrupt change of normal swale deposits from mud to sand sediments and return to mud or silt sedimentation as reported by Donnelly (2001a); Donnelly et al. (2001b); Donnelly and Webb (2004a); Liu and Fearn (1993); Goff et al. (2004); Liu (2007); Liu et al. (2008); Phantuwongraj (2012); William (2013) and William et al. (2016). Furthermore, the presence of mud rip-up clast and coarse pebbles within sand layers found from coring study indicates high energy flow that eroded swale surface during transportation and then deposited together with sand at the time of deposition.

The fluvial flood origin can be ruled out for sand deposits. Although the swale site located close to Kui Buri River and some periods in the past, swale may connect with this river, however the existences of marine fossils (bivalve and gastropod), microfossils (foraminifera and ostracod) and shell fragments within sand layers were confirmed that these sand sediments mixing with fauna were not transported by fluvial processes. Calcareous foraminifers including species of *Ammonia*, *Elphidium* and *Quinqueloculina* are rarely found in swale of the study area, which are subjected to consistently low salinity, periodic desiccation and seasonal freshwater flooding from rainfall (Williams, 2013). Therefore, it is unlikely that these genera can live in this harsh environment.

Moreover, slope wash or mass wasting processes can also be ruled out because the existence of marine fossils. Here, the sand layers deposited by tsunami are considerably impossible because there is no record concerning tsunami deposits along the Gulf of Thailand. In Thailand's history, only the Andaman coast have been experienced such a pre-historic tsunami waves (Jankaew, 2008). However, some researchers have pointed out the possibility of future tsunami that may possibly generate from the South-China Sea where subduction is located. For example, Ruangrassamee (2009) demonstrated the model concerning the effect of tsunamis generated in the Manila Trench. Manila Trench is far from the Gulf of Thailand approximately 2,500 km and tsunami will be attenuated by the diffraction of waves around the coast of Vietnam. After the assumed earthquake of magnitude 9.0 occurred, maximum wave amplitude that direct toward to the Gulf of Thailand could be only about 0.65 m wave height. Therefore, sand layers found from swale at Kui Buri were considered to have formed by extreme coastal storm deposits (tropical storm and typhoon). Although strong wave generate by NE monsoonal wind can transport sediment from nearshore, however this strong wave has not enough energy that transported sediment from nearshore and deposited onto swale site due to the distance from the present shoreline to swale and the elevation of topography.

Other evidences that supports wave that was generated by extreme coastal storm include sedimentary structures within laminated sand layers mixing with shell fragments. Reverse and normal gradings found within sand layer of core KB1C1 are one significant characteristic of washover deposit as reported by Schwartz (1975); Deery, 1977; Leatherman and Williams (1983); Sedwick and Davis (2003), Turtle et al. (2004); Morton et al. (2007), Phantuwongraj et al. (2008); Spiske and Jaffe (2009) and Phantuwongraj (2012).This sedimentary structure can be used to indicate the frequency of storm surge wave number that carried sediment and deposited onto swale (Williams et al., 2016).

Base on stratigraphical and sedimentological data, the deposits of sand layers were characterized by wedge shape profile that thinner and finer inland. Wedge shape sand into mud indicates the overflow of wave across beach ridge such as overwash process by extreme coastal storm.

According to paleontological data, the habitats of marine fossils and microfossils found within sand layer can be used to represent storm wave base. Bivalvia fossils (*Carditellona pulchella*) live around sea floor at depth 2 – 54 m were found in sand layers and also foraminifers of calcareous benthonic species in high concentration including *Asterorotalia pulchella*, *Cellanthus craticulathus*, *Elphidium sp.*, *Psudorotalia sp*. and *Quinqueloculina sp.* living at sand surface of shallow marine i.e. delta, estuary, intertidal were recognized. Jumnonngthai (1983) found these genera at depth between 29 – 34 m from sea surface on the Gulf of Thailand. It suggests that wind speed that can generate storm wave base at depth of these fossil habitats must be very strong. Therefore, only typhoon or tropical storm with wind speed more than hundreds km/hr (119 km/hr) are of possible wind-generate wave for generating such a depth wave base.

5.2 Site sensitivity

Site sensitivity or the ability of a site to preserve a geological record of a tropical cyclone or typhoon in the form of a sand layer is discussed here. According to William (2013), "...The two main conditions required are that the storm surge must be of sufficient height to overtop the coastal barrier and that onshore wind speed must be sufficient high to generate waves capable of transporting enough sand into the site to form a preserved layer. Generally, higher magnitude major hurricanes (Categories 3-5) have higher wind speed and higher surge heights and so more likely to deposit sand beds at a site. However, This can be complicated by another factors – *proximity to landfall* –wherein a nearby landfalling minor hurricane (Categories 1 - 2) could generate the same surge height and wind speed as a more distantly landfalling major hurricane. Another complication concerns the position of a site in the right – or left – front quadrant of the landfalling hurricane. Because of the cyclonic circulation of northern hemisphere storms, the highest onshore winds are experienced in the right front quadrant; in the left front quadrant, off shore wind are experienced which are not conductive to onshore sediment transport (Liu, 2004; Elsner et al., 2008)."

The occurrence of storm events along the Gulf of Thailand, typhoon or tropical storm was commonly generated from South-China Sea and the Pacific Ocean and moved from the east to the west direction. Therefore, the high possibility of location where the coastal area can be experienced in the right front quadrant directly is the southern peninsular Thailand. However, other factors control the ability of a site to preserve sand layer must be taken into account. They include storm characteristics, geographic position relative to storm path, timing of storm events, duration of wave exposure, wind stress, degree of flow confinement, antecedent topography and geological framework, sediment textures, vegetative cover, and type and density of coastal development (Morton, 2002).

5.3 Grain size analysis

Base on the results of sedimentological analysis, grain size distributions of ancient storm sediments show both unimodal and bimodal distribution. It contains coarse to very fine sand, while grain size distribution of non – storm sediments commonly displays as unimodal distribution with medium to fine sand and well sorted. The differences of both ancient and non – storm sediments were distinguished apparently by using the plotting chart comparing various parameters such mean grain size, standard deviation, skewness and kurtosis (Figure 5.1). Bimodality of ancient storm sediments indicates the difference in source of sediments before and during storm event. Eroded sediments from original surface such as beach can represent one mode of deposition, but if the sediments were transported from somewhere else apart from beach, the mode of deposition can likely be bimodal (Figure 5.2).

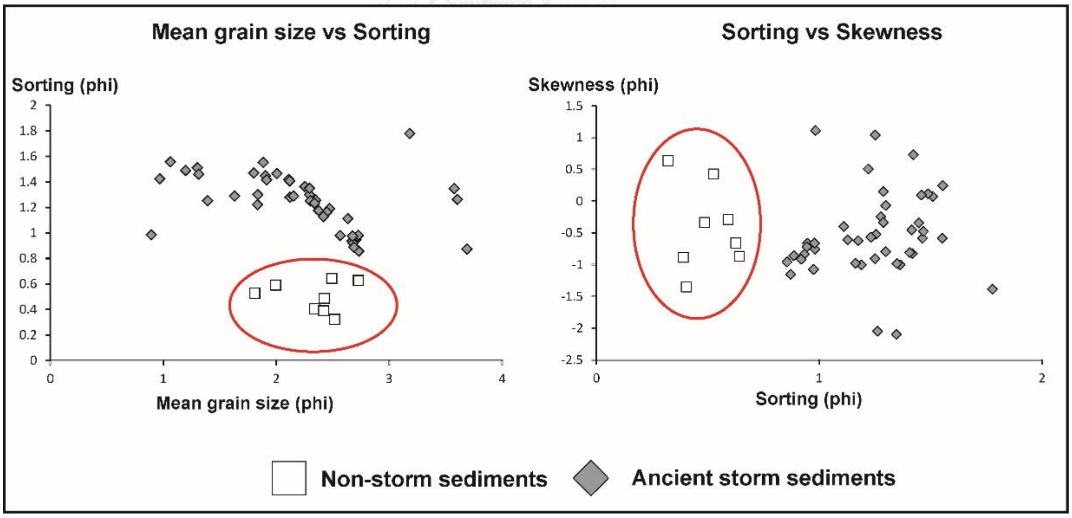

Figure 5.1 picture showing comparison of grain size parameters between ancient storm and non-storm sediments.

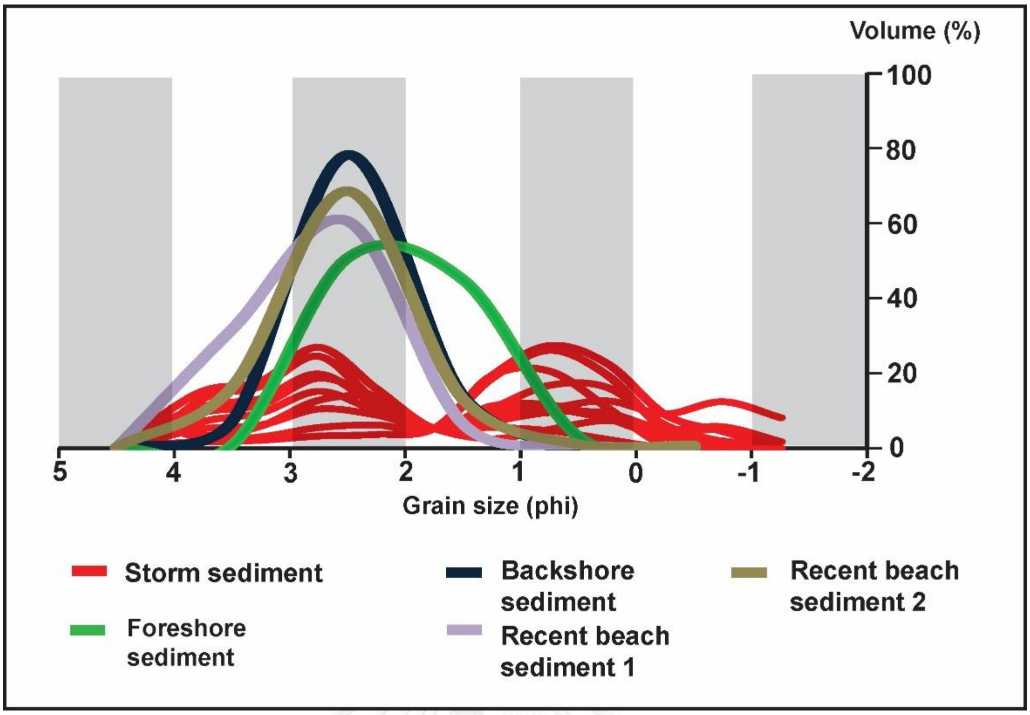

Figure 5.2 picture showing the comparison of grain size distribution between ancient storm and non-storm sediments.

5.4 The age of sand deposits

Prachuap Khiri Khan area has been experienced storm surge from Typhoon Linda in November 1997. However, at Kui Buri area, there is no geological record of sand sheet layer generated from Typhoon Linda. The results of Optically Stimulated Luminescence (OSL) dating from two beach ridges in the study area can be used as age control and helped to explain the evolution of beach ridge plain in this area. The ages of the second beach ridge (inner beach ridge) between backshore and foreshore range between 3,650±140 to 3,034±106 years ago. And the ages of the first beach ridge between backshore and foreshore are between 2,090±70 to 1,160±30 years ago. It is meant that swale between these two beach ridges was formed during 3,034±106 to 2,090±70 years ago.

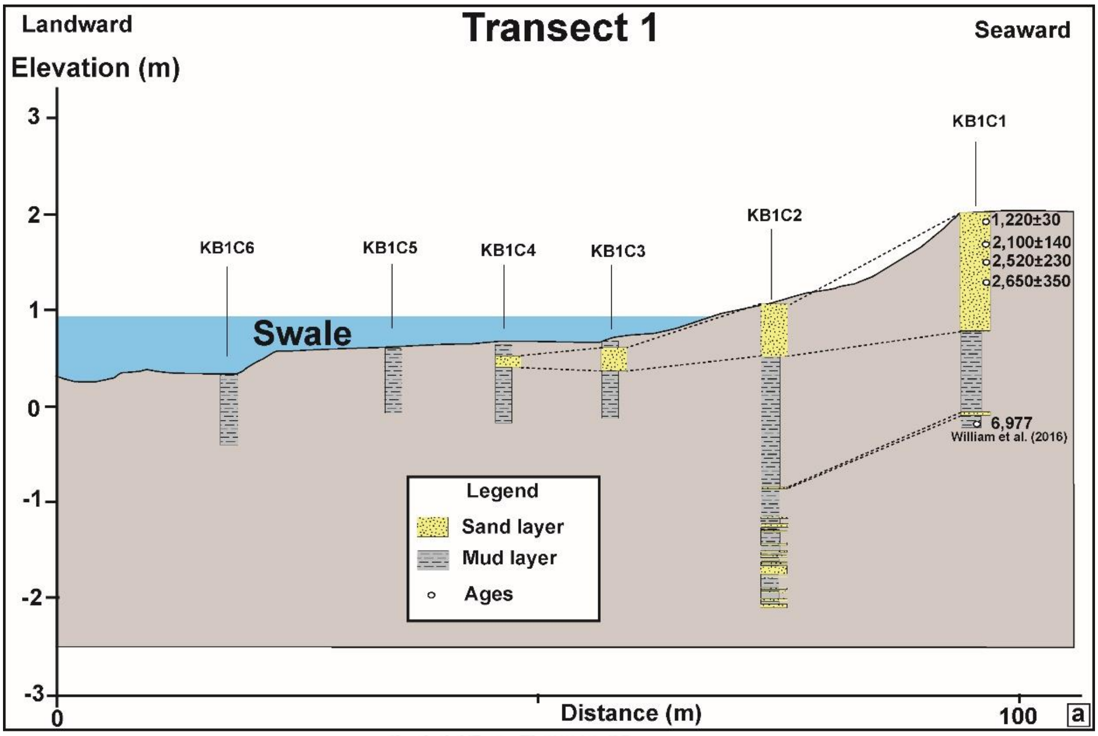

Figure 5.3 picture showing correlation of ages in core KB1C1.

However, four Optically Stimulated Luminescence (OSL) ages in vertical depth of the first beach ridge at depth 20, 50, 65 and 85 cm are 1,220±30, 2,100±140, 2,520±230 and 2,650±350 years ago, respectively. These ages are very beneficial because core KB1C1 were collected under depth of 85 cm and two sand layers of ancient storm deposits at depth 0 – 36 cm and 127- 128.5 cm were found. It is certified that 2 events of ancient storm deposits must be older than 2,650±350 years ago. Core KB1C1 has 140 cm long; however, there is no age that controls the ancient storm deposits in the deeper part of core KB1C1.

The results of AMS radiocarbon age at depth 141 cm from a wood fragment of Williams et al. (2016) were inferred to this area because Core SRY4 was obtained at Kui Buri area in the same swale. The AMS radiocarbon age reported by Williams at al. (2016) is 6,977 years ago. Therefore, the position of deposit from core KB1C1 at depth 141 cm can be correlated with the AMS radiocarbon age of Williams et al., (2016). The period during 2,650±350 to 6,977 years ago indicated two paleo records of extreme coastal storms. At depth 200 – 300 cm of core KB1C2 contains multiple sand layers (up to 27 layers). These multiple sand layers within muddy environment may have formed by several unusual coastal storm events. These extreme coastal storm events must be older than 6,977 years ago based on AMS radiocarbon ages and range depth of finding ancient storm layers. Although, there might be the large uncertainties in age range, but a number of high frequency of extreme coastal storm strikes over 6,977 years ago is clearly distinctive. Two or three extreme coastal storm strikes base on sand layers in KB1C2 and KB2C1 are recorded in the period 2,650±350 to 6,977 years ago; on the other hand, as many as 24 extreme coastal storm strikes based on sand layers from KB1C2 or as few as 9 extreme coastal storm strikes based on sand layer from KB2C1 are recorded after 6,977 years ago. At a minimum, there are approximately five times as many extreme coastal storm strikes based on 9 sand layers from KB2C1 prior to 6,977 years ago. At a minimum, there are approximately 12 times as many extreme coastal storm strikes based on 24 sand layers from KB2C1 prior to 6,977 years ago. According to Williams et al. (2016), possible reason for this uneven frequency of extreme coastal storm strikes is heightened site sensitivity in the mid – Holocene, increasing the opportunities of a nearby typhoon strikes being recorded by washover sand layer. Another possibility is that a change in climatic conditions in the mid – Holocene increased the frequency and/or intensity of extreme coastal storm making landfall in the Gulf of Thailand. Higher intensity extreme coastal storms are more likely to cause overwash of coastal barriers and form a relatively thick, laterally extensive and preserved washover deposits (Williams et al. 2016).

It is possible that in the past this site was lagoon based on OSL age of two beach ridges in comparison with the mid Holocene highstand peak of sea level curves of Choowong et al. (2004). Lagoon has high preservation potential of sand layers generated from extreme coastal storm strikes. Later, in the late – Holocene, the possible of sea level falling likely reduce preservation potential in the area.

Approximately 3.5 m dropping in the sea level created the characteristics of high topography of prograded beach ridge plain and increased the distances from coastline.

CHAPTER 6

CONCLUSION

The sedimentary structures of ancient storm deposits found at a swale between the two beach ridges from Kui Buri, Prachuab Khiri Khan Province contained parallel lamination, mud rip-up clast, sharp upper and lower contact, sub-horizontal stratification, normal grading and reverse grading. Shell fragment layer also was observed strikingly. Coring study of three transects reveals that one sand sheet contain sharp upper and lower contacts with oxidized mud layer. In the upper part of cores displays wedge shape profiles that the deposit of sediments thinner and finer inland indicates landward direction. Multiple sand layers with shell fragments contained sharp upper and lower contacts with mud layers in the deeper part of core KB1C2, KB2C1 and KB3C1 were found up to 27, 12 and 16 layers respectively. The similar characteristic of sand layers in the deeper part of core KB1C2, KB2C1 and KB3C1 is dark grey color and all sand layers found form coring study contains shell fragments and microfossil (foraminifera). This firmly indicates the origin of sand that was transport from marine source. The distance of ancient storm deposits from the present shoreline is around 350 m.

Base on the interpretation of satellite image and aerial photos, geomorphologic features of study area can be mainly divided into 6 units including beach, beach ridge, swale, tidal channel, alluvial plain and mountain. The study area associated with the mid-Holocene marine transgression.

Three topographic profiles of study area reveal that on the right side of swale (the location of transect 1) is lower than the left side of swale (the location of transect 3). This is consistent with multiple sand layers at the deeper part of core KB1C2 which were found more in numbers than that found in core KB2C1 and KB3C1. Swale elevation may control the potential preservation of ancient storm sediments. The average maximum and minimum of tidal range from tide gauge station (Ko Lak station) are 2.13 and 1.04 m.

The compositions of ancient storm sediments mostly compose of quartz, bioclasts in high concentration and heavy mineral. Roundness and sphericity of ancient storm sediments contains angular to sub-rounded and low sphericity, while non – storm sediments show sub – angular to rounded and high sphericity. Furthermore, recent beach sediment contains foraminifera and ostracod. Bivalvia and gastropoda fossils were commonly found in ancient storm sediments including *Mactra sp*., *Striarca lacteal*, *Nuculana (Thestyleda) soyoae*, *Psammotreta (Tellinimactra) edentula, Circe scripta*, *Carditellona pulchella* and *Nassarius siquijorensis* that inhabit at shallow water zone such as mangrove, intertidal, sea floor and sublittoral and upper bathyal zone. 24 foraminifers also were found in ancient storm sediment, especially calcareous benthonic species in high concentration include species of *Ammonia*, *Elphidium*, *Quinqueloculina*, *Spriroloculina* that live in sand surface of shallow water zone such as delta, estuary, low-inter tidal at depth varying 0 – 100 m. Moreover, two ostracods found in the ancient storm sediment are *Propontocypris bengalensis* and *Keijella neali*.

Sedimentological analysis by laser granulometric method indicated the variation of mean grain size distribution of ancient storm sediments in vertical depth from coarse to very fine sand with poorly sorted to well sorted, fine skewed to very coarse skewed and leptokurtic to extremely leptokurtic. Non – storm sediment (recent beach, foreshore, backshore) were analyzed by sieve analysis, composed of medium and fine sand with moderately well sorted to well sorted, very fine skewed to very coarse skewed and extremely leptokurtic. Ancient storm sediments can be distinguished from non – storm sediments by using the plotting chart comparing mean grain size versus sorting, mean grain size versus skewness, mean grain size versus kurtosis, sorting versus skewness, sorting versus kurtosis and skewness versus kurtosis.

Mostly ancient storm sediments exhibited bimodal distribution while non – storm sediments display unimodal distribution. The comparison of grain size distribution between ancient storm sediments and non – storm sediments indicate the sediment sources that were transported from recent beach, foreshore and backshore.

Base on Optically Stimulated Luminescence (OSL) ages of sandy beach ridges, the occurrence of the second beach ridge between foreshore and backshore are 3,034±106 and 3,650±140 years ago. The ages of swale ranges 3,034±106 to 2,090±70 years ago and the age of the first beach ridge between foreshore and backshore are 2,090±70 and 1,160±30 years ago that resulted from gradual decrease of sea level in the past. According to the study of William et al. (2016), AMS dating result from wood fragment in the deeper part of core SRY4 at depth 141 cm indicated 6,977 years ago. The ages of ancient storm deposits may be during the mid-Holocene to late-Holocene period (1,220±30 to 6,977 years ago).

REFERENCES

Center, J.T.W. 2014. JTWC tropical cyclone best track data site Trans.). In (Ed.),^(Eds.), (ed., Vol. pp.). (Reprinted from.

Choowong, M., Ugai, H., Charoentitirat, T., Charusiri, P., Daorerk, V., Songmuang, R. and Ladachart, R. 2004. Holocene Biostratigraphical Record in Coastal Deposit from Sam Roi Yod National Park, Prachuap Khiri Khan, Western Thailand. The Natural History Journal of Chulalongkorn University. 4(2): 1-18.

Davis Jr, R.A., Andronaco, M. and Gibeaut, J.C. 1989. Formation and development of a tidal inlet from a washover fan, west-central Florida coast, U.S.A. Sedimentary Geology. 65: 87-94.

Donnelly, J.P. 2005. Evidence of Past Intense Tropical Cyclones from Backbarrier Salt Pond Sediment: A Case Study from Isla de Culebrita Puerto Rico, USA. Journal of Coastal Research. 201-210.

Donnelly, J.P., et al. 2001a. 700 yr sedimentary record of intense hurricane landfalls in southern New England. Geological Society of America Bulletin 113: 714-727.

Donnelly, J.P., Bryant, S.S., Butler, J., Dowling, J., Fan, L., Hausmann, N., Newby, P., Shuman, B., Stern, J., Westover, K. and Webb III, T. 2001a. 700 yr sedimentary record of intense hurricane landfalls in southern New England. Geological Society of America Bulletin. 113; no.6: 714-727.

Donnelly, J.P., Butler, J., Roll, S., Wengren, M. and Web III, T. 2004. A back barrier overwash record of intense storms from Brigantine, New Jersey. Marine Geology. 210: 107-121.

Donnelly, J.P., Roll, S., Wengren, M., Butler, J., Lederer, R., and Webb, T. 2001b. Sedimentary evidence of intense hurricane strikes from New Jersey. Geology 29: 615-618.

Donnelly, J.P., Roll, S., Wengren, M., Butler, J., Lederer, R. and Webb III, T. 2001b. Sedimentary evidence of intense hurricane strikes from New Jersey. Geology. 29; no. 7: 615-618.

Donnelly, J.P., and Webb Iii, T. 2004. Backbarrier sedimentary records of intense hurricane landfalls in the northeastern United States. Hurricanes and Typhoons: Past, Present, and Future 58-95.

Elashry, M.T.a.W., H.R. 1968. Photo interpretation of shoreline changes between Capes Hatteras and Fear, North Carolina. Marine Geology. 6: 347-379.

Fritz, W.J.a.M., J.N. 1988. Basics of physical stratigraphy and sedimentology. U.S.A: John Wiley and Sons.

Goto, T., Satake, K., Sugai, T., Ishibe, T., Harada, T. and Murotani, S. 2015. Historical tsunami and storm deposits during the last five centuries on the Sanriku coast, Japan. Marine Geology. 367: 105-117.

Jankaew, K., Atwater, B.F., Sawai, Y., Choowong, M., Charoentitirat, T., Matin, M.E. and Prendergast, A. 2008. Medieval forewarning of the 2004 Indian Ocean tsunami in Thailand. Nature. 455: 1228-1231.

Jumnongthai, J. 1983. Recent smaller foraminifera from the Gulf of Thailand. Geol. Soc. Thailand 1: 39-53.

Lane, P., Donnelly, J.P., Woodruff, J.D. and Hawkes, A.D. 2011. A decadally-resolved paleohurricane record archived in the late Holocene sediments of a Florida sinkhole. Marine Geology. 287: 14-30.

Leatherman, S.P., and Williams, A.T. 1983. Vertical sedimentation units in a barrier island washover fan. Earth Surface Processes and Landforms. 8: 141-150.

Liu, K.-B. 2004. Paleotempestology: geographic solutions to hurricane hazard assessment and risk prediction. In WorldMinds: Geographical Perspectives on 100 Problems, pp. 443-448. Springer.

Liu, K.-b. 2007. Paleotempestology. Encyclopedia of Quaternary Science. Elsevier, Oxford 1978-1986.

Liu, K.-b., and Fearn, M.L. 1993. Lake-sediment record of late Holocene hurricane activities from coastal Alabama. Geology 21: 793-796.

Liu, K.-b., and Fearn, M.L. 2000a. Holocene history of catastrophic hurricane landfalls along the Gulf of Mexico coast reconstructed from coastal lake and marsh sediments. Current Stresses and Potential Vulnerabilities: Implications of Global Change for the Gulf Coast Region of the United States. Franklin Press. 223pp.

Liu, K.-b., and Fearn, M.L. 2000b. Reconstruction of prehistoric landfall frequencies of catastrophic hurricanes in northwestern Florida from lake sediment records. Quaternary Research 54: 238-245.

Morton, R.A. 2002. Factors Controlling Storm Impacts on Coastal Barriers and Beachs - A preliminary Basis for Near Real-Time Forecasting. Journal of Coastal Research. 18, No 3: 486-501.

Morton, R.A., and Sallenger, A.H., Jr. 2003. Morphological Impacts of Extreme Storms on Sandy Beaches and Barriers. Journal of Coastal Research. 19: 569-573.

Morton, R.A.a.P., J.G. 1985. Beach and vegetation-line changes at Galveston Island, Texas. erosion, deposition, and recovery from Hurricane Alicia. Trans.). In Geology, G.C.U.B.o.E. (Ed.),^(Eds.), (ed., Vol. pp.). The University of Texas at Austin.

. (Reprinted from.

Nanayama, F., et al. 2000. Sedimentary differences between the 1993 Hokkaido-nansei-oki tsunami and the 1959 Miyakojima typhoon at Taisei, southwestern Hokkaido, northern Japan. Sedimentary Geology. 135: 255-264.

Nott, J.a.H., M. 2001. High frequency of 'super-cyclone' along the Great Barrier Reef over the past 5,000 years. Nature. 413: 508-511.

Pailoplee, S. 2004. Thermoluminescence dating of Quaternary sediments using total blech and regenerationn method. Master's Thesis, Department of Geology, Faculty of Science Chulalongkorn University.

Phantuwongraj, S. 2010. Geological evidence of sea-level change: a preliminary investigation at Panag Tak area, Chumphon province, Thailand. 日本地質学会学術大会講演要旨 2010: 369-369.

Phantuwongraj, S., and Choowong, M.. 2012. Tsunamis versus storm deposits from Thailand. Natural Hazards. 63: 31-50.

Phantuwongraj, S., Choowong, M., and Chutakositkanon, V. 2008. Possible storm deposits from Surat Thani and Nakhon Si Thammarat provinces, the southern peninsular Thailand. Proc Inter Sym on Geo Res and Envi of Asian Terranes. Bangkok, Thailand 395-399.

Phantuwongraj, S., Choowong, M., Nanayama, F., Hisada, K., Charusiri, P., Chutakositkanon, V., Pailoplee, S. and Chabangbon, A. 2013. Coastal geomorphic conditions and styles of storm surge washover deposits from Southern Thailand geomorphology. 192: 43-58.

Pierce, J.W. 1970. Tidal inlets and washover fans. Journal of Geology. 78: 230-234.

Powers, M.C. 1953. A new roundness scale for sedimentary particle. Journal of Sedimentary . 23: 117-119.

Ruangrassamee, A.a.S., N. 2009. Effect of Tsunamis generated in the Manila Trench on the Gulf of Thailand. Journal of Asian Earth Sciences. 36: 56-66.

Sawai, Y., Jankaew, K., Martin, M.E., Prendergast, A., Choowong, M. and Charoentitirat, T. 2009a. Diatom assemblages in tsunami deposits associated with the 2004 Indian Ocean tsunami at Phra Thong Island, Thailand. Marine Micropaleontology. 73: 70-79.

Sawai, Y., Kamataki, T., Shishikura, M., Nasu, H., Okamura, Y., Satake, K., Thomson, K., Matsumota, D., Fujii, Y., Komatsubara, J. and Aung, T.T. 2009b. Aperiodic recurrence of geologically recorded tsunamis during the past 5500 years in eastern Hokkaido, Japan. J. Geophys. Res 114.

Schwartz, R.K. 1975. Nature and genesis of some storm washover deposits.

Tuttle, M.P., Ruffman, A., Anderson, T., and Jeter, H. 2004. Distinguishing tsunami from storm deposits in eastern North America: the 1929 Grand Banks tsunami versus the 1991 Halloween storm. Seismological Research Letters 75: 117-131.

Williams, H., Choowong, M., Phantuwongraj, S., Surakietchai, P., Thongkhao, T., Kongsen, S and Simon, E. 2016. Geologic Records of Holocene Typhoon Strikes on the Gulf of Thailand Coast. Marine Geology.

Williams, H.F.L. 2010. Storm surge deposition by Hurricane Ike on the McFaddin National Wildlife Refuge, Texas: implications for paleotempestology studies. The Journal of Foraminiferal Research 40: 210-219.

Williams, H.F.L. 2013. 600-year sedimentary archive of hurricane strikes in a prograding beach ridge plain, southwestern Louisiana. Marine Geology 336: 170-183.

Yu, F., Switzer, A.D., Annie Lau, A.Y., Esther Yeung, H.Y., Chik, S.W., Chiu, H.C., Huang, Z. and Pile, J. 2013. A comparison of the post-storm recovery of two study sandy beaches on Hong Kong Island, southern China. Quaternary International. 304: 163-175.

APPENDIX

VITA

Stapana Kongsen was born in Chonburi, Thailand on 3rd of May, 1991. After finishing high school from Singsamut school at Chonburi in 2008, he studied on Geography at Faculty of Geoinformatics, Burapha University and got Bachelor's Degree of Science in 2012. After that, he became interested in Geology until he decided to study in master degree and researched on ancient storm deposits at Department of Geology, Faculty of Science, Chulalongkorn University in 2013. By 2016, he got Master's Degree of Science.