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Abstract

A 1500-year record of mangrove dynamics has been established from palaeoecological analyses on three cores from Salak Phet Bay, Koh Chang island in the eastern Gulf of Thailand. The occurrence of Rhizophora, accompanied by other mangrove species, suggested that Salak Phet Bay supported a mangrove community from at least 1500 cal yr BP. From 1500 cal yr BP the mangrove extent decreased indicating less inundation frequency, possibly in response to a sea-level fall until 1300 cal yr BP. Following this regression, sea-level rise resulted in an increased presence of mangrove taxa until 500 cal yr BP. The study documents that Salak Phet Bay was characterised by relatively low saline conditions based on the occurrence of the moist-loving species (Oncosperma) around 1500-500 cal yr BP. After 500 cal yr BP mangrove taxa gradually decreased and terrestrial herbaceous taxa, mainly grasses, increased suggesting that the frequency of marine inundation was reduced as sea level fell. Drier conditions were also recorded by an increase in terrestrial grasses and a decrease in Oncosperma after 500 cal yr BP. In the uppermost sediments the increased presence of Rhizophora is probably associated with recent global sea-level rise although changes in mangrove composition are possibly related to human activities within Koh Chang. The sedimentation rate and the mangrove migration at Koh Chang have kept pace over the past 1500 years but this may be challenged under predicted future rapid sea-level rise as accommodation space for mangroves to migrate inland is required to maintain viable mangrove forests.

Keywords	pollen analysis, palaeoecological analysis, the eastern Gulf of Thailand, sea-level change
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Cover letter

The manuscript is a Research Paper detailing late Holocene mangrove dynamics and palaeoenvironment recorded from an island of the eastern Gulf of Thailand using palaeoecological analyses. We presently know little about the vegetation history of this area and this research allows us to establish a better understanding of sea level changes, climate history and human activity on the ecosystem across this region.

Response to reviewer

Comments from the editors and reviewers:
Editor
Thank you for submitting your manuscript to Quaternary International. The reviewer noticed a few typo's. Please have an extra close look and submit the final version.

- We have looked through the manuscript and corrected typo errors.

Reviewer 2

I commend the authors on the efforts they have made to the manuscript. With the clarity on limitations on surveyed elevations and the revised figures and text I recommend that this paper be accepted for QI.

Mangrove dynamics and environmental changes on Koh Chang, Thailand during the last millennium

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Abstract

A 1500-year record of mangrove dynamics has been established from palaeoecological analyses on three cores from Salak Phet Bay, Koh Chang island in the eastern Gulf of Thailand. The occurrence of *Rhizophora*, accompanied by other mangrove species, suggested that Salak Phet Bay supported a mangrove community from at least 1500 cal yr BP. From 1500 cal yr BP the mangrove extent decreased indicating less inundation frequency, possibly in response to a sea-level fall until 1300 cal yr BP. Following this regression, sea-level rise resulted in an increased presence of mangrove taxa until 500 cal yr BP. The study documents that Salak Phet Bay was characterised by relatively low saline conditions based on the occurrence of the moist-loving species (*Oncosperma*) around 1500-500 cal yr BP. After 500 cal yr BP mangrove taxa gradually decreased and terrestrial herbaceous taxa, mainly grasses, increased suggesting that the frequency of marine inundation was reduced as sea level fell. Drier conditions were also recorded by an increase in terrestrial grasses and a decrease in *Oncosperma* after 500 cal yr BP. In the uppermost sediments the increased presence of *Rhizophora* is probably associated with recent global sea-level rise although changes in mangrove composition are possibly related to human activities within Koh Chang. The sedimentation rate and the mangrove migration at Koh

Chang have kept pace over the past 1500 years but this may be challenged under predicted future rapid sea-level rise as accommodation space for mangroves to migrate inland is required to maintain viable mangrove forests.

Keywords: pollen analysis, palaeoecological analysis, the eastern Gulf of Thailand, sea-level change

1. Introduction

Mangroves are assemblages of trees and shrubs that have developed physiological and morphological adaptations to the intertidal habitat. Mangroves are found between mean sea level and high water spring tide along subtropical to tropical coasts (Woodroffe & Grindrod, 1991; Ellison, 2008; Punwong et al., 2013a). Mangroves provide vital ecosystem services such as coastal protection, habitats for animals and plants, leading to high biodiversity, filtering of sediment and pollution and regulation of the global carbon budget (Spalding et al., 2010; Marchio et al., 2016). Mangrove species normally grow in bands parallel to the shoreline related to the influence of ecological and environmental factors such as salinity, tides, muddy sediments and anaerobic soils (Kathiresan and Bingham, 2001).

Mangrove ecosystems are highly sensitive to climate changes, including the amount of precipitation, sea-level changes and human disturbances (Gilman et al., 2008). Changes in regional rainfall pattern affect freshwater runoff which in turn influences salinity, leading to changes in the mangrove composition (Snedaker, 1995; Ellison, 2000; Gilman et al., 2008; Mikhailov and Isupova, 2008). Sea level change causes changes in tidal inundation frequency and magnitude, and is one of the most significant factors influencing mangrove composition and distribution. Mangroves respond to sea-level fluctuations by migrating landward or seaward with a rise or a fall in sea level, respectively; hence are considered a sensitive indicator of sea-level and tidal regime (Gilman et al., 2008; Walters et al., 2008). Mangroves can tolerate sea-level rises if the rate of mangrove sedimentation is equal to, or more than, the rate of sea-level rise. If the mangrove sedimentation rate is less than the rate of sea-level rise then the mangrove communities will experience die back. If sea level rises and the coastal zone lacks accommodation space for landward mangrove migration due to factors such as steep topography and/or recent coastal development, the mangrove ecosystem will die *in situ* (Gilman et al., 2008). Mangroves accumulate sediment on small islands more slowly than in riverine mangrove forests on the mainland as they are primarily influenced by tides with low freshwater sediment input (Twilley, 1992; Ellison, 2000). Therefore, mangroves on small islands are less likely to survive under sea-level rise (Ellison, 2000). Recently, studies evaluating the ability of mangroves to cope with sea-level rise, by establishing past mangrove sedimentation rates have been increasing (Ellison, 2000; González et al., 2010; Urrego, 2013; Ellison, 2015; Ellison and Strickland, 2013; Setyaningsih et al., 2019). An assessment of mangrove vulnerability to future sea level rise is crucial to mitigate and plan for the effects on these ecosystems.

Global sea-level has risen approximately 1-2 mm a^{-1} since the late 19th century (Church & White, 2011); this is a major threat to mangrove ecosystems (Ellison, 2015) and of great concern to populations who live within the low-lying coastal areas. Recent rapidly rising sea level across the Gulf of Thailand of between 0.7-12.7 mm a^{-1} during AD 1942-2004 (Trisirisatayawong et al., 2011; Sojisuporn et al., 2013) indicates that Thailand has experienced a higher rate of sea-level rise than the global average over the last few decades. Pollen of mangrove taxa, recovered from the sedimentary record has been increasingly used as an indicator of past ecosystem response to sea-level change across the tropics (Behling et al., 2001; Blasco et al., 1996; Versteegh et al, 2004; Ellison, 2008; Hait et al., 2009; Punwong et al., 2013a; b; 2018a). Sea level index points can be developed by establishing an indicative range for mangrove species through contemporary studies of the altitude of the upper and lower limits of the mangrove areas (Ellison, 2005; Horton et al., 2005). A study reconstructing sea-level from East Africa demonstrated that the relationship of ratios between the key mangrove taxa and their altitudes had the potential to refine the vertical errors of sea-level change (Punwong et al., 2018a). In addition, records retrieved from mangrove sediment can be used to detect other past natural events such as storm surge (González et al., 2010).

Most records of Holocene sea-level change along the Gulf of Thailand indicate that sea level reached its maximum with a highstand at about 2-4 m above the present mean sea level around 6000 cal yr BP (Sinsakul, 2000; Tanabe et al., 2003; Choowong et al., 2004; Horton et al., 2005). This mid-Holocene sea-level rise is in agreement with a study from the peninsular of Malaysia and Thailand indicating a highstand between 6800-5000 cal yr BP between 5 m (Tjia, 1996) and 1.7 m (Mallinson et al., 2014) above the present mean sea level. The mid-Holocene sea-level rise is recorded slightly earlier at around 7000 cal yr BP in Singapore (Hesp et al., 1998, Bird et al., 2007). Relative sea level is then recorded to have fluctuated in the Gulf of Thailand until it reached its present level around 1500 cal yr BP (Tjia, 1996; Sinsakul, 2000; Choowong et al., 2004; Horton et al., 2005; Mallinson et al., 2014). Only one study has been undertaken directly on mangroves located in the upper Gulf of Thailand (Punwong et al., 2018b). The results demonstrated that a higher than present sea level influenced the area from at least 1100 cal yr BP until 700 cal yr BP before a lower sea level occurred until around 200-100 cal yr BP. After around 100 cal yr BP, there was a signal of recent sea-level rise that corresponded to the instrumental sea-level study based on tide gauge data spanning the last 60 years (Trisirisatayawong et al., 2011).

To date, studies have neglected to investigate the mangrove vegetation and environmental history of the offshore islands within the Gulf of Thailand during the last millennium. In this study we report the first high-resolution record of mangrove dynamics and environmental history from Salak Phet Bay, Koh Chang island in the eastern area of the Gulf of Thailand. Palaeoecological methods and techniques including stratigraphical analysis, pollen analysis, loss on ignition and radiocarbon dating of mangrove sediments were used to investigate ecosystem and environmental change over the last 1500 years. Koh Chang has experienced extensive tourism development, associated activities (e.g. road building) and population growth (Kusanagi et al., 2003) that has potentially influenced coastal ecosystems over recent decades. The reconstruction of the coastal environmental history prior to human disturbances in this area will be compared to sea-level reconstruction available for the region to understand the capacity of mangroves in Koh Chang to adapt to current and future scenarios of climate change and provide insights into how mangroves respond to environmental changes; crucial information for the management of the coastal zone and conservation of mangrove areas.

1.1. Study site

Location

Salak Phet Bay is situated in the east of Koh Chang island, Trat Province, in the eastern region of the Gulf of Thailand (Figure 1). Koh Chang is the second largest island of Thailand and was designated as a National Park in 1982. It is influenced by a diurnal tide with a tidal range of 0.9 m as recorded at Mak island (20 km away) (Admiralty Tide Table, 2014). The study area is covered by a belt of dense mangroves varying from 600 m to 1200 m in width occurring in a south-eastern alignment. The area is characterised by shallow unconnected tidal creeks that have occasional freshwater input from terrestrial runoff, particularly during the rainy season.

Geology and Geomorphology

Koh Chang island is composed of Permo-Triassic volcanic rock forming an igneous mountain range with cliffs and steep slopes (Songtham, 2011; Pumijumnong & Payomrat, 2013). The elevation of Koh Chang ranges between mean sea level and 743 metres (Kusanagi et al., 2003; Pumijumnong & Payomrat, 2013) and the mountains of Koh Chang are formed of fine-grained volcanic rock, light-brown or red in colour (Schmidt, 1902). The plains along the east coast of the island are rich in sandy clay and the west coast consists of beach sand (Pumijumnong & Payomrat, 2013).

Climate and vegetation

The climate of Koh Chang is characterised by two seasons: a summer season from November to April, and a rainy season from May to October. The climate is influenced by northeast and southwest Asian monsoons; the northeast monsoon brings dry air during the summer season and damp air during the rainy season accounting for 90% of the average annual rainfall of ~4900 mm (1982-2011) (Pumijumnong & Payomrat, 2013; Sirianansakul & Pumijumnong, 2014). The average maximum, minimum, and mean temperatures are 31.8 °C, 23.6 °C, and 27.4 °C, respectively (Thai Meteorological Department, 2010). The vegetation on Koh Chang consists of around 1000 species (Pengkhlai et al., 2007) mainly classed as tropical rainforest taxa (Pumijumnong & Payomrat, 2013). On the east coast of Koh Chang, where Salak Phet is located, the area is covered by beach and mangrove forest. The dominant trees are *Terminalia catappa* L., *Melaleuca cajuputi* Powell, *Syzygium grande* (Wight) Walp., *S. gratum* (Wight) S. N. Mitra and *Pandanus odoratissimus* L.f. Typical mangrove taxa include *Rhizophora mucronata* Lam., *R. apiculata* Blume, *Ceriops decandra* Ding Hou, *C. tagal* (Perr.) C. B. Rob., *Bruguiera gymnorrhiza* (L.) Lam., *B. parviflora* (Roxb.) Griff., *Avicennia alba* Blume, *Xylocarpus granatum* J.Koenig, *X. moluccensis* (Lam.) M.Roem. and *Hibiscus tiliaceus* L. (Chamchumroon & Puff, 2003).

(Insert Figure 1)

2. Materials and methods

2.1. Fieldwork and sampling

Three sediment cores, SLP-S (12°00'00.7"N102°22'47.4"E), SLP-M (12°00'04.0"N 102°22'43.8"E) and SLP-L (12°00'09.1"N 102°22'38.1"E) were extracted along a transect oriented from landward to seaward through the mangrove in Salak Phet Bay (Figure 1B). The SLP-S core site was located in the seaward area, SLP-M core site in the middle of the mangrove area about 150 m from SLP-S and SLP-L core site was located in the landward area of the mangrove ecosystem approximately 240 m away from SLP-M. A 50 cm long, 5 cm diameter Russian corer was used to extract the cores samples from overlapping boreholes. Sediment samples were inserted in the sectioned PVC pipes, wrapped in aluminum foil and plastic sheeting and then labelled and packaged. A vegetation survey of 10 m^2 plots around the coring sites and along the transect from the landward to seaward in the mangrove area of Salak Phet was also undertaken.

2.2. Palaeoecological analysis

The three sediment cores, SLP-S, SLP-M and SLP-L were described in the laboratory following Tröels-Smith's classification (1955). They were subsampled at 10 cm along the whole length of each core for pollen, charcoal and loss on ignition (LOI) analyses. Pollen and spores were extracted using the acetolysis method (Erdtman, 1969; Faegri and lversen, 1989) and heavy liquid separation with sodiumpolytunstate solution (Hunt, 1985). Exotic *Lycopodium* spores (batch 3862: 9666 ± 212 grains per tablet) were used to determine the pollen concentration following Bonny (1972) and Smol et al. (2001). Sample residues were stored in silicone oil. Pollen and spores were identified by comparison with pollen from extant specimens and modern pollen references (Thanikaimoni, 1987; Chumchim, 2010; Hutangkura, 2012). *Bruguiera gymnorhiza* and *Ceriops tegal* were grouped together as *Bruguiera/Ceriops* type because they could not be distinguished by light microscopy (Chappell & Grindrod, 1985). The pollen content of some samples was very sparse and therefore insufficient to achieve a count of 300 grains. To determine the optimal grain count, the number of pollen taxa in five samples from each site were counted and recorded for every 20 grains. After 80 grains the number of new taxa did not increase. At least 150 pollen grains were counted for each level after establishing that this number was sufficient to identify any new taxa. Pollen taxa were grouped into ecological categories to aid interpretation: mangroves, back mangroves, terrestrial herbaceous, non-mangrove arboreal and unknown. Mangroves and back mangroves were grouped according to Watson's (1928) and Santisuk's (1983) inundation classes. Pteridophyte spores were excluded from pollen sum. Pollen data were zoned using a stratigraphically constrained cluster analysis, CONISS (Grimm, 1991). Pollen-slide charcoal analysis was undertaken to reconstruct fire history using microscopic charcoal. However, the charcoal fragments were extremely sparse and insufficient to be analysed. Loss on ignition (LOI) at 550°C and 950°C followed Heiri et al. (2001) was used to determine the organic carbon and carbonate content. The palaeoecological data were plotted as diagrams using TILIA2 and TILIA*Graph (Grimm, 1991).

2.3. Chronology

Eight organic samples from the basal sections of the cores and where biostratigraphic changes were noted were prepared for the acid-base-acid (ABA) pre-treatment method following Brock et al. (2010). The samples were radiocarbon dated by Acceleration Mass Spectrophotometry (AMS) at DirectAMS Radiocarbon Dating Service, USA to establish a chronology within which to place the environmental changes. The dates were calibrated using the northern hemisphere calibration of the Intcal13 curve (Reimer et al., 2013) using OxCal v4.10 (Bronk-Ramsey, 2009).

3. Results

3.1. Vegetation survey and mangrove zonation in the Salak Phet area

The mangrove ecosystem of Salak Phet was surveyed to show the ecological distribution and dominant mangrove species along a 400 m transect from landward to seaward (Figure 2). There were 12 mangrove species: *Acrostichum aureum, Avicennia officinalis, Bruguiera gymnorrhiza, Ceriops tagal, Lumnitzera littorea, Nypa fruticans, Phoenix paludosa, Rhizophora apiculata, Rhizophora mucronata, Sonneratia alba, Suaeda maritima* and *Xylocarpus granatum* (Figure 3). The SLP-S location was dominated by *Rhizophora mucronata* (80%) and *Bruguiera gymnorrhiza* (20%) trees. The SLP-M site was characterised by *Ceriops tagal* (70%), *Rhizophora mucronata* and *R. apiculata* (20%) and *Lumnitzera littorea* (10%) trees. The SLP-L location was dominated by *Lumnitzera littorea* (65%) and *Bruguiera gymnorrhiza* (35%) trees. At present, the SLP-L and the SLP-M locations are covered by mangroves and back mangrove taxa, while the SLP-S site is characterised mainly by seaward mangrove species. The zonation of the modern vegetation composition is related to the distance of each coring site from the sea. A zonation of the mangrove ecosystem in Salak Phet Bay has been developed based upon a combination of Watson's (1928) and Santisuk's (1983) inundation classes. There were six mangrove species and seven back mangrove species (Figure 3) in Salak Phet Bay.

(Insert Figure 2)

(Insert Figure 3)

3.2. Stratigraphy and loss on ignition

Each site was cored until the sediment became impenetrable when coarse sand was reached. The basal unit of the three cores consisted of dominant sub-rounded poorly sorted sand with varying concentrations of silt. Marine shells identified as *Parvicardium* sp., *Cyclocardia* sp., *Placamen* sp., *Anomalocardia squamosal*, *Placuna* sp. (oyster) shells and shell fragments were present at the bottom layer of SLP-S and SLP-M cores (Figure 3). Peat was found at the top of the SLP-M core. Organic material, including root fragments, increased towards the upper unit of all cores with bark fragments also being present. The boundaries between stratigraphic units in all three cores are transitional. The detailed stratigraphic descriptions including grain-size, sorting, roundness, composition of the three cores are shown in Figures 3 and 4.

The organic and carbonate content throughout the three cores varied between 2% to 40% and 0.8% to 6 %, respectively (Figures 5-7). The organic content of the three cores increased from the base to the top of the core related to the peat and root fragments in the upper units of the cores. The organic content of SLP-L ranged from 3.88% to 31.42% and sharply decreased from 10.61% to 6.53% between 80 and 70 cm related to the absence of root fragments. The SLP-M core has a very low organic content (2.28-6.06%) at the base with increased content (7.5-36.84%) in the overlying peat unit. The organic content of the SLP-S core ranged from 2.78% to 40.18 %. The organic content of SLP-S represented the highest percentages (40.18%) at 60 cm corresponding to the occurrence of bark and root fragments.

The carbonate content of all the cores decreased from the lower to the upper units except in the SLP-M core. The carbonate analyses recorded low percentages throughout the SLP-L core (0.88-1.91%). The carbonate content of SLP-M ranged from 1.29% to 6.57%. Samples at depths from 40 to 0 cm have the highest carbonate content (3.10-6.57%) compared to the lower sections (1.28-3.55%). The carbonate content of SLP-S ranged from 0.85% to 3.91%. The percentage of carbonate content (1.35-3.61%) in the lower unit of SLP-S was higher than the other cores, corresponding to the occurrence of shells and shell fragments.

(Insert Figure 4)

(Insert Figure 5)

(Insert Figure 6)

(Insert Figure 7)

3.3. Chronological results and sedimentation rates

Eight radiocarbon dates were obtained from the three cores; two from SLP-S and SLP-M and four from SLP-L (Table 1). The radiocarbon dates obtained from small bark and wood fragments indicate that the sediment deposits accumulated continuously, with a robust chronology that is in sequence although the results from the SLP-L represent a younger date at the base of sequence (118 cm) that is possibly due to sediment reworking. Although acid-based-acid pre-treatment was undertaken to prevent percolation of humic acids through leaching into the mangrove sequences (Hammond et al., 1991), the reversed date may be due to contamination through root penetration introducing younger material at lower depths. In addition, the sediment above the dates of 864 ± 68 cal yr BP at 25 cm in the SLP-L show a possible hiatus, although there was no evidence of erosion identifiable from the continuous stratigraphy or the pollen assemblage. Therefore, seven radiocarbon dates (excluding the date from 118 cm of SLP-L) are used to provide a chronological framework to interpret the palaeoecological data. As no indicators of disturbance had been found in the sequence, it is assumed that a constant rate of deposition occurred in these sediment sequences. Linear regression was therefore used to construct the age-depth model (Figure 8). The overall sedimentation rates of SLP-S, SLP-M and SLP-L are 1.4 mm a^{-1}, 1.1 mm a^{-1} and 0.6 mm a^{-1}, respectively.

Organic material within mangrove sediments can be both allochthonous and autochthonous brought into the system by tides and freshwater input (Ellison and Stickland, 2010). However, previous studies using wood fragments from mangrove sediment for dating (González et al., 2010; Woodroffe et al., 2015a) have proved that dating small wood fragments may yield more reliable ages compared to bulk sediments or rootlets that may be affected by younger mangrove material or old carbon reworking (Woodroffe et al., 2015a). However, other approaches such as using organic concentrates (Woodroffe et al., 2015b) or pollen concentrates (Vandergoes & Prior, 2003) have been used to eliminate the allochthonous and reversal factors.

(Insert Figure 8)

Table 1 Radiocarbon dates from Salak Phet mangrove areas including calibrated ages using the northern hemisphere calibration of the Intcal13 curve (Reimer et al., 2013) in the programme OxCal v4.10 (Bronk-Ramsey, 2009).

Core	Depth (cm)	Code	Type of samples	Fraction of modern pMC	^{14}C yr BP	cal yr BP
SLP-S	95	D-AMS 026633	Bark	88.28±0.26	1001 ± 24	884 ± 81
SLP-S	163	D-AMS 025455	Wood fragments	87.50±0.26	1073 ± 24	993 ± 62
SLP-M	75	D-AMS 026634	Bark	93.83±0.27	512 ± 23	529 ± 21
SLP-M	149	D-AMS 022267	Wood fragments	83.91±0.33	1409 ± 32	1324 ± 40
SLP-L	25	D-AMS 026635	Bark	88.70±0.28	963 ± 25	864 ± 68
SLP-L	85	D-AMS 026636	Bark	83.51±0.26	1448 ± 25	1342 ± 41
SLP-L	100	D-AMS 028366	Bark	82.40±0.28	1555 ± 27	1457 ± 69
SLP-L	118	D-AMS 025456	Wood fragments	86.38±0.26	1176 ± 24	1093 ± 87

3.4. Pollen analysis

Pollen analyses on the three cores of Salak Phet Bay were undertaken and the data classified into four groups based on the ecological categories (Table 2). Pollen diagrams were zoned based on similar floristic composition using a stratigraphically constrained cluster analysis.

Table 2 Mangrove pollen present in the sediment cores based on ecological categories.

Group	Species / Core	SLP-L	SLP-M	SLP-S
Mangroves	*Avicennia*	x	x	x
	Bruguiera/Ceriops	x	x	x
	Rhizophora	x	x	x
	Sonneratia		x	x
Back mangroves	*Acanthus*			x
	Acrostichum		x	x
	Chenopodiaceae cf. *Suaeda*		x	x
	Lumnitzera	x	x	x
	Oncosperma	x		x

Terrestrial herbaceous	Asteraceae			x
	Cyperaceae	x		x
	Poaceae	x	x	x
	Polygalaceae	x		
Non-mangrove arboreal	Arecaceae	x	x	x
	Casuarina		x	
	Croton		x	
	Dipterocarpaceae			x
	Elaeocarpus			x
	Euphorbiaceae	x	x	x
	Fagaceae	x	x	x
	Largerstomia		x	
	Myrtaceae	x	x	x
	Pinus		x	x
	Sapindaceae			
	Tiliaceae	x		x

Pollen zone descriptions of SLP-S core

The pollen diagram of SLP-S core was divided into two zones; SLP-S-1 (165-95 cm) and SLP-S-2 (95-0 cm) as shown in Figure 5.

SLP-S-1 *(165-95 cm: ~1000-880 cal yr BP)*

Mangrove taxa have the highest representation (74-59%) followed by back mangrove (8-27%), non-mangrove arboreal (9-23%), terrestrial herbaceous (0-3%) and unknown pollen (0-3%) respectively. Mangrove taxa are characterised by *Rhizophora* (38-58%), *Bruguiera/Ceriops* (4-16%), *Avicennia* (1-5%) and *Sonneratia* sp. (0-1%). *Oncosperma* (6-19%) has the greatest abundance among back mangrove taxa with a peak of 19% at the base of the core followed by *Lumnitzera* (1-9%), *Acrostichum* (1-5%) and *Acanthus* (0-3%). Non-mangrove arboreal taxa are present in this zone with Arecaceae, Dipterocapaceae, *Elaeocarpus*, Euphorbiaceae, Fagaceae, Myrtaceae, *Pinus* and Tiliaceae. Terrestrial herbaceous pollen are rare with only Asteraceae, Cyperaceae and Poaceae present. Pollen concentration fluctuates from 3576 to 10,675 grains cm^{-3}.

SLP-S-2 (*95-0 cm: ~880 cal yr BP to present*)

Mangrove taxa are the primary group (65.3-90.5%) in this zone characterised by *Rhizophora, Avicennia* and *Bruguiera/Ceriops*. Back mangrove is characterised by the rapid decrease of *Oncosperma* from the bottom to the top of this zone with percentages of 1-5%

while *Lumnitzerta* (1-7%)*, Acrostichum* (0-4%), and *Acanthus* (0-1%) decrease gradually. Non-mangrove arboreal taxa mainly Fagaceae (0-4%) and Myrtaceae (0-4%) also decrease to low percentages. Terrestrial herbaceous taxa show an increase of Poaceae (up to 4%) with few Asteraceae and Cyperaceae. Pollen concentrations are higher than the previous zone (3975-37,619 grains cm^{-3}).

Pollen zone descriptions of SLP-M core

The pollen diagram of SLP-M core was divided into three zones; SLP-M-1 (150-135 cm), SLP-M-2 (135-15 cm) and SLP-M-3 (15-0 cm) as shown in Figure 6.

SLP-M-1 *(150-135 cm: ~1300-1200 cal yr BP)*

There is a high representation of mangrove taxa (55-68%) especially *Rhizophora* pollen (54-50%) followed by *Bruguiera/Ceriops* pollen (3-6%) and *Avicennia* pollen (1-7%). Pollen and spores of back mangroves are present (12-17%), characterised by *Oncosperma* (16-9%), which has the greatest abundance among back mangrove taxa with a peak of 16% at the base of the core, *Lumnitzera* (1-3%) and *Acanthus* (0-1%). Non-mangrove arboreal taxa are present at the bottom of the zone (24-11%) including *Pinus* (1-3%), Fagaceae (3-8%), Arecaceae (3-5%), Myrtaceae (0-2%) and *Largerstomia* (0-2%). Pollen concentrations are low (7,527-12,142 grains cm^{-3}).

SLP-M-2 *(135-75cm: ~1200-530 cal yr BP)*

Mangrove taxa (79-92%) increase in this zone and are characterised by *Rhizophora* (61-70%) *Bruguiera/Ceriops* (5-22 %) followed by *Avicennia* (1-9 %) and *Sonneratia* sp. (0-1%) while pollen and spores of back mangroves decrease from the bottom of the zone (3-11%) and increase towards the top. Terrestrial herbaceous taxa increase to 0-7% with Poaceae pollen (0-6%). Pollen from non-mangrove arboreal taxa are present (1-10%) dominated by Arecaceae (0-7%). Pollen concentration fluctuates between 13,590 to 90,619 grains cm^{-3}.

SLP-M-3 *(75-0 cm: ~530 cal yr BP to present)*

This zone contains the greatest abundance of mangrove pollen (84-97%) with *Rhizophora* (50-67%) followed by *Bruguiera/Ceriops* (10-41%) and *Avicennia* (0-5%) while back mangrove taxa (0-6%) are characterised by *Lumnitzera* (0-6%) and *Oncosperma* (0-4%). Non-mangrove arboreal taxa consist of Fagaceae pollen at 3%. Terrestrial herbaceous taxa (0-7%) gradually decrease. Pollen concentration ranges from 9,601 to 90,619 grains cm^{-3}.

Pollen zone descriptions of SLP-L core

The pollen diagram of SLP-L core was divided into three zones; SLP-L-1 (120-85cm), SLP-L-2 (85-25 cm) and SLP-L-3 (25-0 cm) (Figure 7).

SLP-L-1 *(120-85 cm: Prior to ~ 1460-1340 cal yr BP)*

Mangrove taxa (68-85%) namely *Rhizophora* (54-69%), *Bruguiera/Ceriops* (36-52%), and *Avicennia* (2-11%) have the highest representation in this zone. Back mangrove taxa (5-8%) are characterised by *Lumnitzera* (1-8%) and *Oncosperma* (0-7%). Non-mangrove arboreal taxa (6-12%) mainly contain Fagaceae (4-6%) and Tiliaceae (0-3%). Terrestrial herbaceous taxa (0-9%) in particular *Polygala* (0-6%) increase towards the top of the zone and Poaceae (0-3%) is present. Pollen concentrations are relatively high (15,597-55,676 grains cm^{-3}) with peaks at 100-90 cm.

SLP-L-2 *(85-25 cm: ~1340-860 cal yr BP)*

Mangrove taxa remain dominant in this zone characterised by *Rhizophora* (63-78%), *Bruguiera/Ceriops* (7-11%), and *Avicennia* (1-4%). *Avicennia* and *Bruguiera/Ceriops* and increase towards the top of this zone. Back mangrove taxa show an increase of *Lumnitzera* (4-12%) with a marked decline of *Oncosperma* (0-4%). Non-mangrove arboreal taxa (1-6%) characterised by Fagaceae (1-4%), Myrtaceae (0-1%) and Tiliaceae (0-2%) decrease at the beginning of this zone but increase at the top. Arecaceae, Euphorbiaceae are rarely found < 1%. Poaceae (0-7%) is present throughout the zone and increase to the top while Cyperaceae (<1%) is present only at 30 cm. The pollen concentration values are low at 10,214-54,650 grains cm^{-3}.

SLP-L-3 (0-25 cm*: ~860 cal yr BP to present*)

Mangrove taxa (69-84%) including *Rhizophora* (53-68%), *Bruguiera/Ceriops* (14-15%) and *Avicennia* (0-1%) increase at the beginning and then decline at the top of the zone. Back mangroves taxa (13-16%) increase from the bottom to the top dominated by *Lumnitzera* (11-15%). *Oncosperma* (<0.7%) sharply decreases. Percentages of terrestrial herbaceous taxa (1-12%) dramatically increase with Poaceae at 1-12%. Non-mangrove arboreal taxa decrease to 1%. The pollen concentration is 21,328-36,433 grains cm^{-3}.

4. Interpretation and Discussion

The mangrove ecosystem and coastal environment in Salak Phet was reconstructed using a combination of palaeoecological indicators consisting of stratigraphical analysis, pollen analysis, loss on ignition and radiocarbon dating. In addition, the data from the contemporary mangrove zonation of six mangrove species and seven back mangrove species in Salak Phet Bay was used to aid the interpretation of ecosystem and environmental change through the fossil record as follows. *Rhizophora mucronata* and *Sonneratia alba* are pioneer species found at the seaward edges where *S. alba* is inundated by medium to all high tides and *R. mucronata* is inundated by normal to all high tides (Santisuk, 1983; Tomlinson, 1986). *S. alba* is mostly found in soft mud and sand in seafront locations and is intolerant of long periods of exposure to freshwater (Taylor et al., 2003; Giesen et al., 2007). *Rhizophora* species are seaward inhabiting species with *R. mucronata* dominating in wet, muddy soils and form large homogeneous stands on upper river banks and creeks (Chapman, 1976; Taylor et al., 2003). In addition to these two species, *Rhizophora apiculata* inhabits soft and muddy soils (Giesen et al., 2007) that are inundated by spring to medium high tides. *Bruguiera gymnorrhiza* and *Ceriops tagal* are upper intertidal species; *B. gymnorrhiza* being found between *R. mucronata* and *C. tagal* (Taylor et al., 2003) in areas inundated by abnormal to normal high tides (Santisuk, 1983). *C. tagal* appears in the upper intertidal and dry areas inundated by spring to normal high tides; it prefers clay substrates (Giesen et al., 2007) and has a weaker root system that is unable to withstand strong waves (Taylor et al., 2003). *Avicennia officinalis* is also inundated by abnormal tides to normal high tides, it grows on the landward margins of true mangrove or along tidal river banks characterised by sandy clay sediments (Pumijumnong, 2014; Giesen et al., 2007). The back mangroves are characterised by *Nypa fruticans* and *Xylocarpus granatum* in an area inundated by abnormal tides to normal high tides. *Nypa fruticans* usually forms pure stands but sometimes grows with other species such as *Lumnitzera racemosa* (Kusmana, 2014). *Xylocarpus granatum* occurs along landward fringes of mangrove and brackish water environments where freshwater has more influence, and the environment is less saline (Taylor et al., 2003; Giesen et al., 2007). *Acrostichum aureum* is also inundated by abnormal tides to spring high tides. It occurs in brackish creeks and rivers and prefers soils with a wide range of salinity (Medina et al., 1990; Giesen et al., 2007). *L. racemosa* is characteristic of the landward fringe of many mangrove communities with high salinity, sandy substrate and also inundated by abnormal tides to spring high tides (Gallin et al., 1989; Giesen et al., 2007). There are two back mangrove species that are found in this area that are inundated by only abnormal tides; *Phoenix paludosa* and *Suaeda maritima. P. paludosa* is usually found in the landward margin of mangroves and also in the area bordering the estuarine water and land (Rao, 1972). This species is associated with dry areas and grows on dry, clay and brackish to saline soils (Giesen et al., 2007).

The three cores (SLP-S, SLP-M and SLP-L) record a cross-core similarity in stratigraphy containing a lower unit of increased sorted sand that becomes increasingly organic with root and bark fragments up-core. The dominance of sub-rounded poorly sorted sand in all cores (Figure 4) possibly indicated that the sediments were deposited fairly close to the source area of igneous mountains that cover most of Koh Chang (Pumijumnong & Payomrat, 2013). It is also possible that storm events may have deposited the poorly sorted sand. However, there was no evidence of erosion or the presence of a sharp stratigraphical boundary that would support this hypothesis. In addition, a study on storm deposits along the coastal area of the Gulf of Thailand revealed that washover deposits from storm are well-sorted medium to very fine-grained sand with heavy minerals (Phantuwongraj & Choowong, 2012) none of which were identified at Salek Phet Bay.

The mangrove pollen through the sediment sequence was used to reconstruct coastal ecosystem dynamics, sea-level changes and recent human impacts by examining the dominant mangrove pollen in each core as a proxy. *Rhizophora* was found to be dominant in all of the cores extracted and was used to indicate a lower intertidal area inundated by all high to spring tides. *Rhizophora* pollen are recognised as being dispersed from local sources, therefore representing their source plants very well but being over-represented as they are a wind-pollinated species (Muller, 1959; Somboon, 1990; Van Campo & Bengo, 2004; Punwong et al., 2013a; 2013b). Studies on mangrove pollen representation (Behling et al., 2001; Ellison, 2005; Ellison & Strickland, 2013) showed that proportions of more than 50% of modern surface mangrove pollen including *Rhizophora* and other mangrove species such as *Bruguiera* and *Avicennia* indicate a mangrove environment. The vegetation survey undertaken at each of the coring sites corresponded to the pollen found in the uppermost levels of 10 cm of the cores.

***Circa* 1500-500 cal yr BP**

Following a mid-Holocene highstand, a marine regression occurred in the Gulf of Thailand and other Southeast Asia regions commencing at around 6000 cal yr BP (Tjia, 1996;

Sinsakul, 2000; Tanabe et al., 2003; Horton et al., 2005; Mallinson et al., 2014). The Salak Phet Bay record presented here started around 1500 cal yr BP with a high representation of *Rhizophora*, accompanied by other mangrove species; *Avicennia, Bruguiera*/*Ceriops* and *Sonneratia* sp. at the beginning of SLP-L-1 zone indicating that Salak Phet Bay had been covered by mangrove forest by around 1500 cal yr BP. The sub-rounded poorly sorted sand layer at the bottom of all cores, combined with the pollen evidence suggests that Salak Phet Bay was a shallow marine environment during a regressive phase in the late Holocene. Salak Phet Bay then developed into an intertidal environment as the area became suitable for mangrove to establish by 1500 cal yr BP when the coastline was located farther seaward compared to the present-day. The decrease in *Rhizophora* from the bottom to the top of SLP-L-1 and the increase in non-mangrove arboreal in the zones SLP-M-1 and SLP-L-1 indicated mangrove started to migrate seaward. This ecosystem shift was possibly due to on-going sea-level fall in response to less tidal inundation allowing terrestrial conditions to exist until around 1300 cal yr BP. The sand content increases upwards in the SLP-M-1 and SLP-L-1 cores coincident with decreased *Rhizophora* pollen, supporting the interpretation that at around 1500 BP sea level was falling. There is also a high representation (up to 20%) of *Oncosperma* in the SLP-L-1 and SLP-M-1 zones indicating freshwater input in Salak Phet Bay: the contemporary distribution of *Oncosperma* is in the landward fringes of brackish water swamps (Giesen et al., 2007). The predominance of *Oncosperma* in SLP-M-1 and SLP-L-1 corresponds with an appearance of Myrtaceae taxa which grows in moist habitats (Schmidt, 1902). Therefore, during the period 1500-1300 cal yr BP, it is likely that Salak Phet Bay supported a higher intertidal environment with more freshwater input than the present day.

Mangroves characterised by *Rhizophora* started increasing through SLP-L-2 and SLP-M-2 from around 1300 cal yr BP. SLP-L-2 contains a similar age determination (1300-900 cal yr BP) to zone SLP-M-2 (slightly after 1340-500 cal yr BP) and SLP-S-1 (1000-900 cal yr BP). The increasing presence of *Rhizophora*, with an occurrence of *Oncosperma* and more silt content in SLP-M-2 and SLP-L-2 zones suggests that the Salak Phet Bay probably experienced a greater inundation frequency due to a sea-level rise occurring from around 1300-900 cal yr BP resulting in mangroves migrating landward. The appearance of marine shells as *Parvicardium* spp., *Cyclocardia* spp., *Placamen* spp., *Anomalocardia squamosal*, *Placuna* spp. and shell fragments in SLP-S-1 and SLP-M-2 also suggest a sea-level rise. In addition, the present-day ecological habitat of *A. squamosa* (Roopnarine et al., 2008) found in the SLP-S core suggests that the seaward area of Salak Phet Bay was an intertidal to shallow subtidal environment during this period. No shell residues were found in SLP-L possibly due to its location at a greater distance from the sea compared to the other two sites. The increase of *Rhizophora* with a decrease in upper intertidal species, *Bruguiera/Ceriops* (Santisuk, 1983) at the top of zone SLP-M-2, and between the depths of 100 to 50 cm in SLP-S-2, represents a cross-core similarity dated to around 500 cal yr BP and further suggests that sea level continued rise until around 500 years ago. This interpretation is supported by the dominance of silty sand particles in the zones; SLP-M-2 and SLP-S-2. Evidence from the three cores suggests that after 1300 years, mangroves extended in Salak Phet Bay as sea level rose in this region, consistent with the Holocene sea-level curve of the east of Malay-Thai Peninsula that shows a trend of sea-level rise after 1300 cal yr BP (Tjia, 1996). Rising sea level is also recorded in the south of the Gulf of Thailand until around 500 cal yr BP before falling to the present level (Horton et al., 2005). However, these results contradict the studies undertaken on the Setiu coast, northeast of Malaysia, Malay–Thai Peninsula that indicate an episode of sea-level fall around 1400 to 300 cal yr BP (Mallinson et al., 2014) and on the western coast of the Gulf of Thailand where beach ridges recorded a sea-level fall to the present level after 1600 cal yr BP (Nimnate et al., 2015).

It should also be noted that from around 1500-500 cal yr BP, Salak Phet Bay was influenced by freshwater as evidenced by the presence of *Oncosperma*, together with Myrtaceae, in all three cores. The occurrence of these two taxa together with fern spores is indicative of wet conditions that appears to correlate with a similar period recorded in the northeast of Thailand; combined these studies indicate an increased summer monsoon between 1150 and 980 cal yr BP (Chawchai et al., 2015). More widely, several tree ring studies have also indicated greater magnitude monsoons in the Southeast Asia region around 900-850 cal yr BP (Buckley et al., 2010; 2014). Other studies in the western upper Gulf of Thailand suggest wet conditions associated with stronger monsoon over Southeast Asia a little later between 800-700 cal yr BP (Punwong et al., 2018b) and between 700-650 cal yr BP (Buckley et al., 2010; 2014; Lieberman & Buckley, 2012). After around 700 cal yr BP, *Oncosperma* sharply decreased at Salak Phet Bay concomitant with an increase in Poaceae pollen together with a decrease in Myrtaceae, that may suggest less freshwater input in the bay from around 700 cal yr BP. This coincides with drier conditions recorded in northeastern Thailand between 650-500 cal yr BP (Chawchai et al., 2015).

Circa 500 cal yr BP to present

After 500 cal yr BP *Rhizophora* gradually decreased from the bottom to the top of SLP-M-3 zone. This corresponds to the decrease in *Rhizophora* in the uppermost part of SLP-S-2 zone (50-0 cm) at around 500 cal yr BP to present. SLP-L-3 zone (dated from 900 cal yr BP to present) probably represents a recent sediment accumulation with increasing amounts of *Bruguiera/Ceriops*. The decrease in *Rhizophora*, and the increase in *Bruguiera/Ceriops*, are related to increased terrestrial herbaceous taxa, mainly Poaceae in all the cores suggesting that the frequency of marine inundation was further reduced as sea level fell after 500 cal yr BP allowing terrestrial vegetation to develop in Salak Phet Bay. This sea-level fall is also indicated by a higher pollen percentage of Poaceae and *Lumnitzera* and back mangrove taxa, in SLP-L-3. This interpretation is regionally supported by studies from the upper Gulf of Thailand that indicate an ongoing marine regression during the last 1000 years (Somboon & Thiramongkol, 1992; Tanabe et al., 2003), particularly after 700 cal yr BP (Punwong et al., 2018b). A study from the south of the Gulf of Thailand also suggests a lower sea level after around 500 cal yr BP (Horton et al., 2005). However, mangrove pollen in particular *Rhizophora*, show a slightly increased presence at the top of the SLP-S and SLP-M possibly reflecting recent sea-level rise. These tentative signals of mangrove response to historical sea-level rises correlate with a mangrove study from the upper Gulf of Thailand indicating sea-level rise in the last century (Punwong et al., 2018b) and a relative sea-level rise of ~ 0.7-1.2 mm a^{-1} recorded in the eastern Gulf of Thailand during the last 60 years (Trisirisatayawong et al., 2011). Koh Chang was recorded as a temporary shelter for ships from China trading with the Ayutthaya Kingdom at ~650-250 cal yr BP (AD 1300s to 1700s) during the monsoon seasons. Although there was an established fishing village in Salak Phet in the 1920s (Rochanarat, 2007), anthropogenic activity is commonly recorded during the last 50 years from mangrove locations in Thailand (Pumijumnong, 2014) and tourism development in Koh Chang started in the early 2000s (UNEP, 2008). Although Koh Chang was designated as National Park in 1982, the old coastal communities were not included in the preserved areas (Pumijumnong & Payomrat, 2013). Associated with this settlement and tourism development is the increased use of mangroves providing materials for building (Taylor, 1982) and this could account for the recent changes in some of those taxa in Salak Phet Bay.

An increase in terrestrial grasses and a decrease in *Oncosperma* after 500 cal yr BP may relate to a reduction in precipitation over Southeast Asia including Vietnam and Thailand during 500-130 cal yr BP (Lieberman & Buckley, 2012) before an increase in rainfall was documented in the northwest of Thailand and Southeast Asia after around 100 cal yr BP (Cook et al., 2010; Lieberman & Buckley, 2012). In addition, *Oncosperma* spp. is commonly used as a resource for house construction (Dransfield et al., 2004) and jetties (Bandaranayake, 1998) and this may have been another contributory factor responsible for the recent disappearance of this taxon.

The pollen records from Salak Phet Bay record the responses of mangrove to sea-level change, suggesting that mangroves in the eastern Gulf of Thailand adapted to changes in sea-level that occurred in the last 1500 years. As future sea-level rise may be the one of the most important factors threating the changing distribution of mangroves, insights into past mangrove dynamics should be used more systematically to evaluate the ability of mangrove to cope with climate change particularly sea-level rise. Given the current maximum rate of sea-level rise in the eastern Gulf of Thailand of 1.2 mm a^{-1}, mangroves in Salak Phet Bay with average sedimentation rates of 0.6-1.4 mm a^{-1} (Figure 8) could persist under the current scenario of sea-level rise. However, the estimated overall sedimentation rates for the past 1500 years are not sufficient to keep pace with the future projections of sea level rise in the Gulf of Thailand of 0.28-0.65 m by 2100 (~3-7 mm a^{-1}) (Sojisuporn et al., 2013). It is predicted that the coastal zone of the Gulf of Thailand will be under by seawater by 2070 (Lovelock et al., 2015). The results of this study therefore suggest that the capacity to accumulate sediments in Salak Phet Bay will not be enough to maintain future mangrove ecosystems. Moreover, mangroves on small islands like Salak Phet Bay, where freshwater discharge is low, are more vulnerable to collapse under the projected sea-level rise as the sediment accumulation depends solely on tides and accommodation space for mangrove migration (Ellison, 2000). It is recommended therefore that management plans consider these factors in planning for the future, otherwise mangrove communities will disappear due to a combination of enhances sea-level rise and coastal erosion.

5. Conclusions

The palaeoecological records from Salak Phet Bay, Koh Chang are the first reconstruction of mangrove ecosystem dynamics from the eastern coast of Thailand for the last 1500 years. Mangrove ecosystems have been established in Salak Phet Bay from at least 1500 cal yr BP suggesting this bay was located in a low intertidal environment. Mangroves subsequently decreased in extent indicating less frequent marine inundations, possibly due to a lower sea level until 1300 cal yr BP. Sea-level rise was recorded from 1300-500 cal yr BP indicated by increasing mangrove taxa, particularly *Rhizophora* and the appearance of marine shells as Salak Phet Bay experienced greater inundation frequency from 1300-500 cal yr BP.

Salak Phet Bay was also influenced by freshwater input as evidenced by the presence of *Oncosperma* that is coeval with an increased summer monsoon in the Southeast Asia region.

After 500 cal yr BP mangroves gradually decreased and terrestrial herbaceous taxa increased, suggesting that the frequency of marine inundation was further reduced as sea level fell. Drier conditions were also recorded indicated by an increase in terrestrial grasses and a decrease in *Oncosperma* after 500 cal yr BP. A subsequent increase in *Rhizophora* pollen may reflect a recent sea-level rise, although changes in plant composition may relate to recent human activities within Koh Chang. The average rate of sedimentation in Salak Phet Bay suggested that although mangroves of Koh Chang kept pace with the past 1500 years and current rates of sea-level change, they may not be capable of surviving under future predicted sea-level rise scenarios.

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Figure captions

Figure 1 Location map of Koh Chang (A) Koh Chang with mangrove areas boxed (B) Map of mangrove areas and coring sites in Salak Phet Bay.

Figure 2 Study site and mangrove area of Salak Phet Bay from seaward (A) to landward (F).

Figure 3 A cross section showing the ecological distribution and dominant mangrove species from landward to seaward in the Salak Phet mangrove area and coring sites including the stratigraphic details of SLP-S, SLP-M and SLP-L cores.

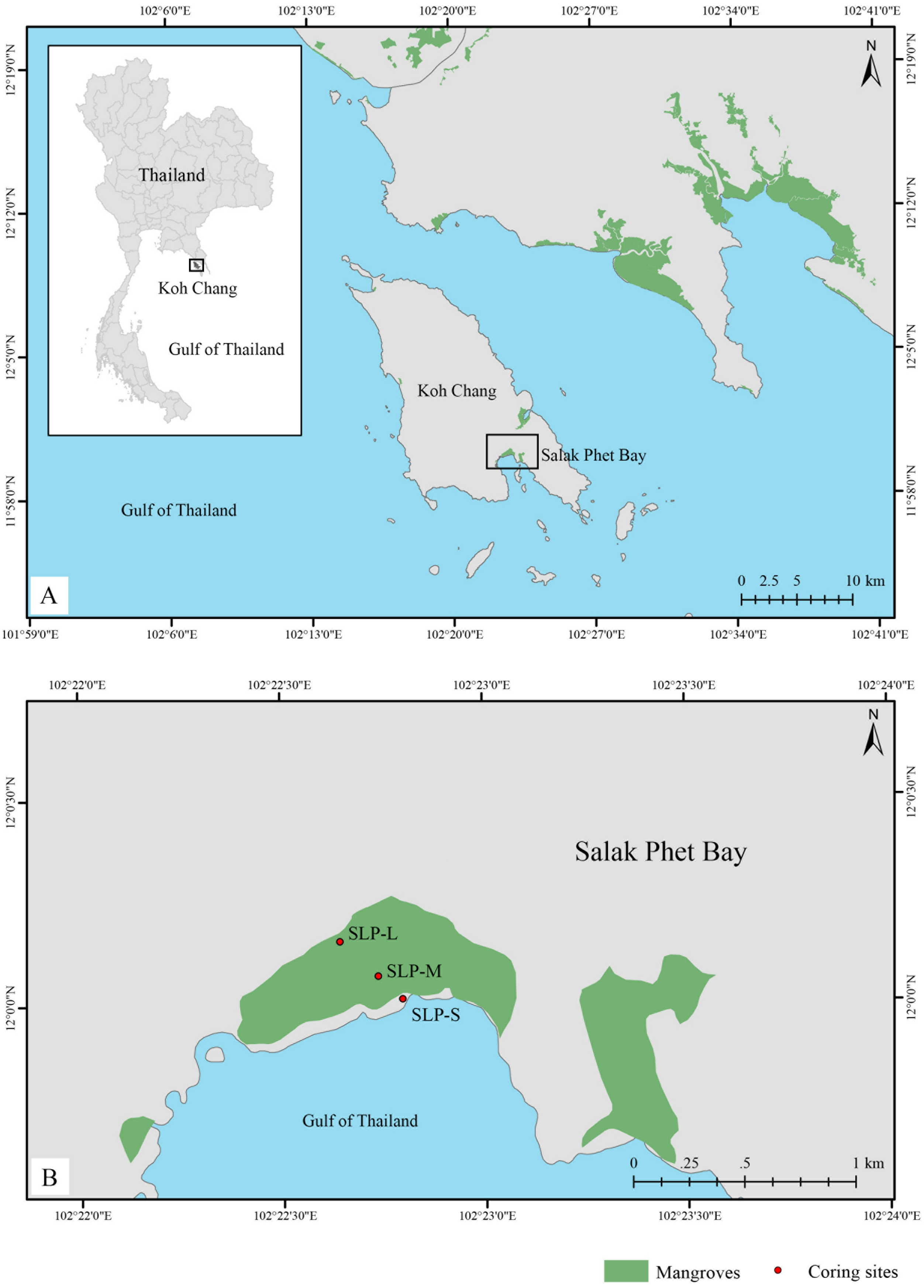
Figure 4 Images of sediment composition in SLP-S, SLP-M and SLP-L cores

Figure 5 Pollen diagram of SLP-S core showing percentage pollen frequency and loss on ignition analyses.

Figure 6 Pollen diagram of SLP-M core showing percentage pollen frequency and loss on ignition analyses.

Figure 7 Pollen diagram of SLP-L core showing percentage pollen frequency and loss on ignition analyses.

Figure 8 Age-depth relationship plots for SLP-S, SLP-M and SLP-L cores.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102°13'0"E
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102°27'0"E
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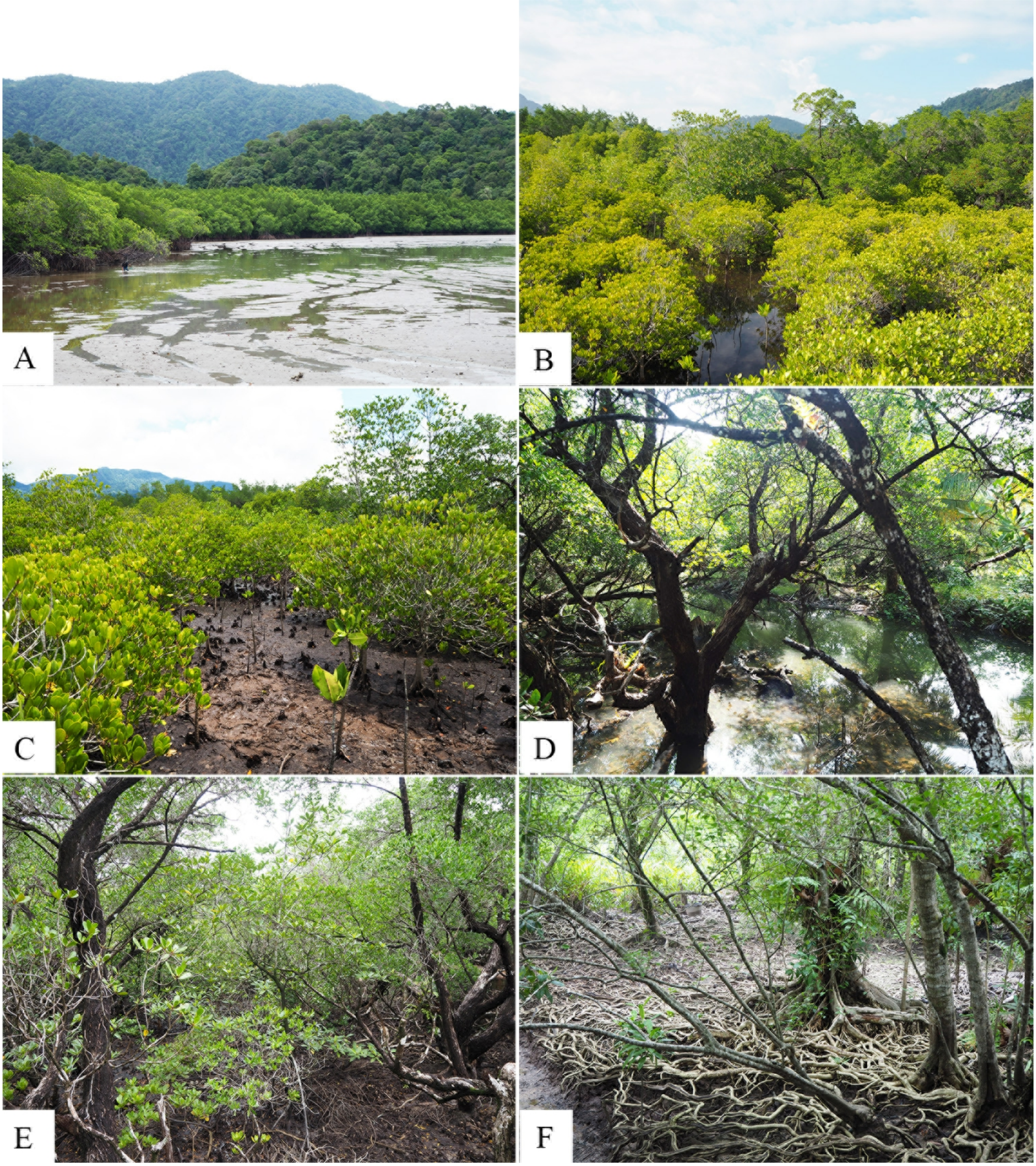
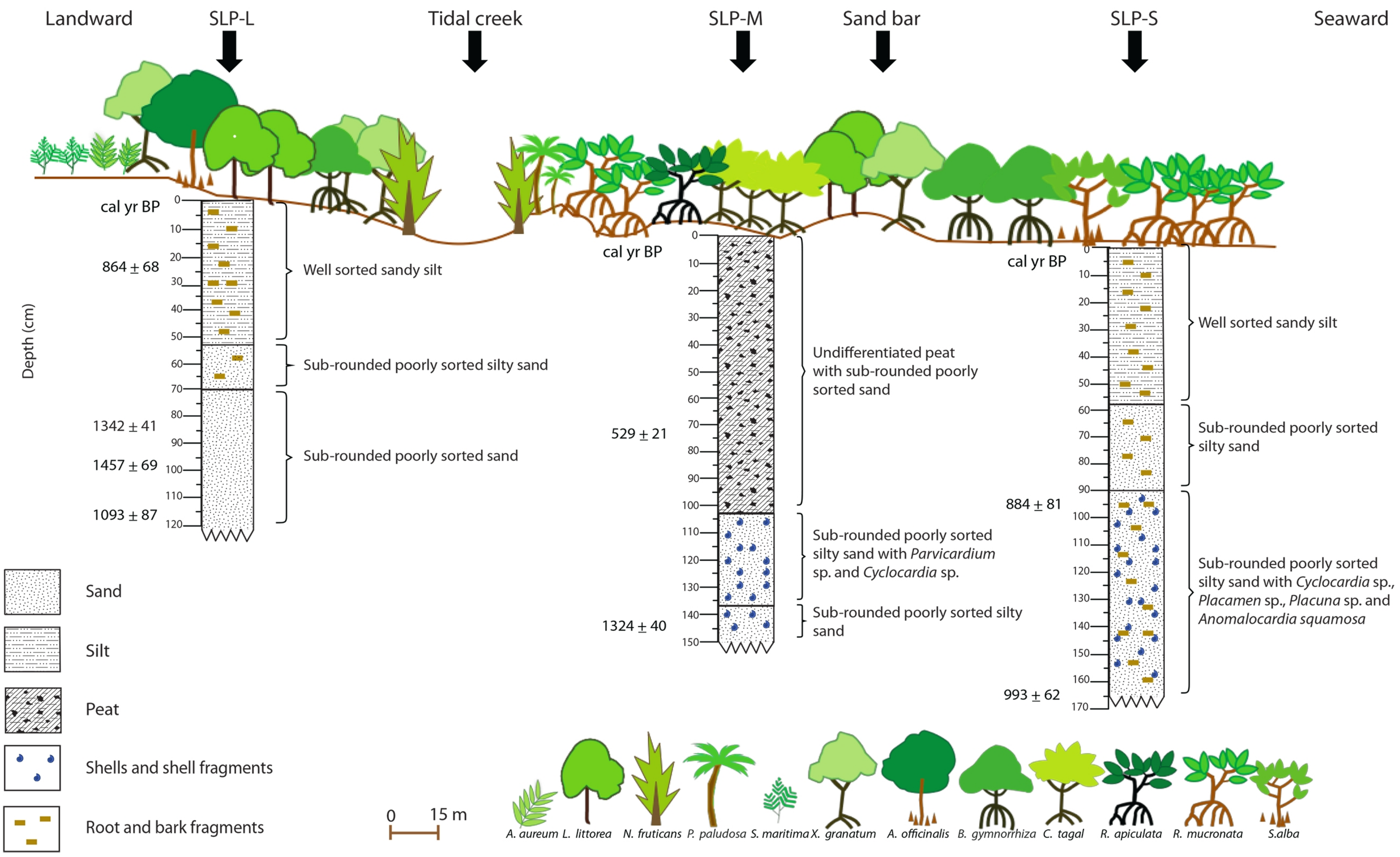
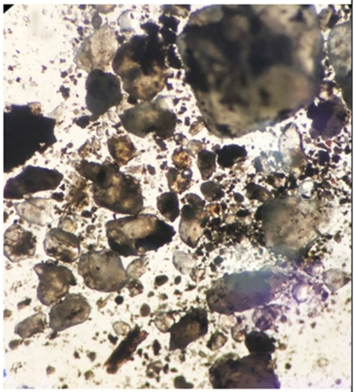
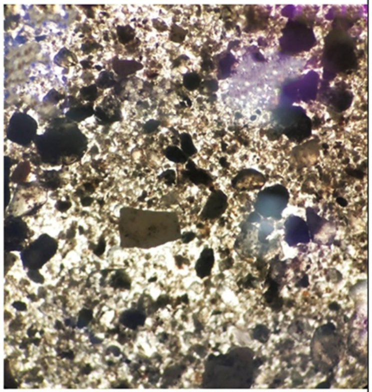
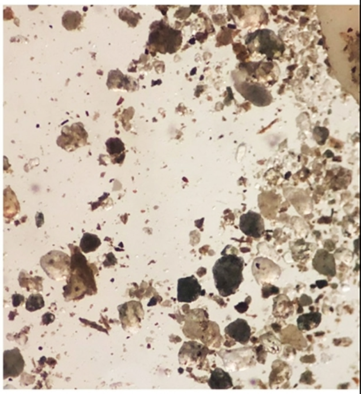
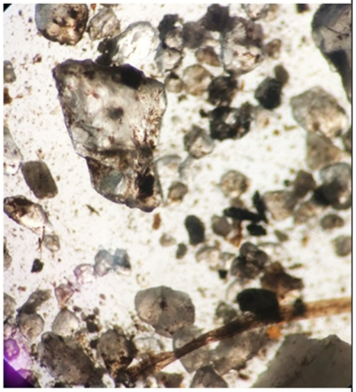
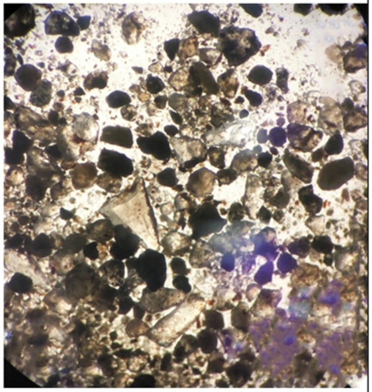
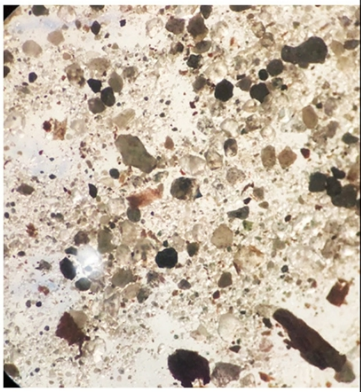
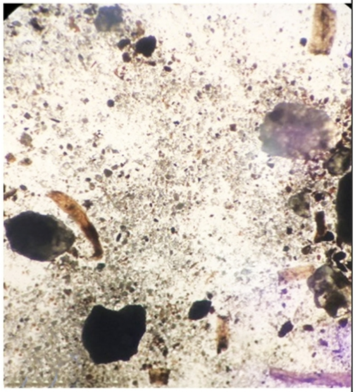
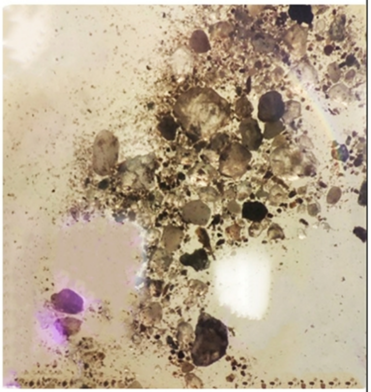
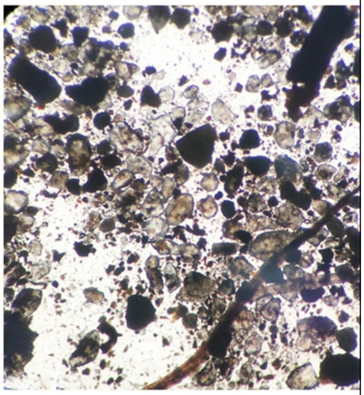
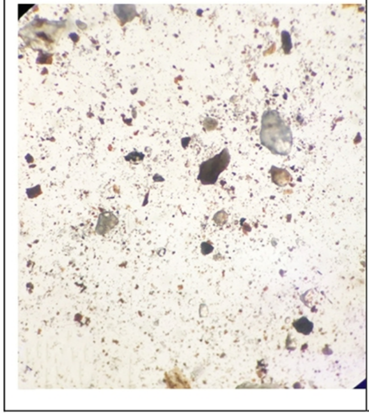
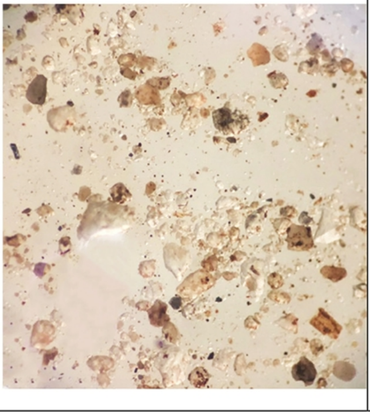
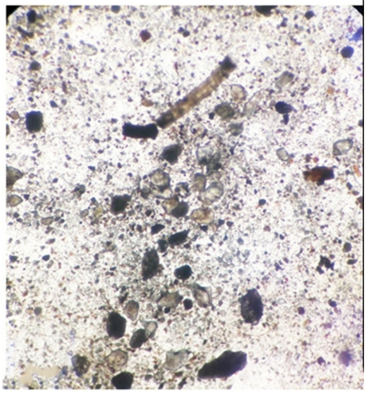
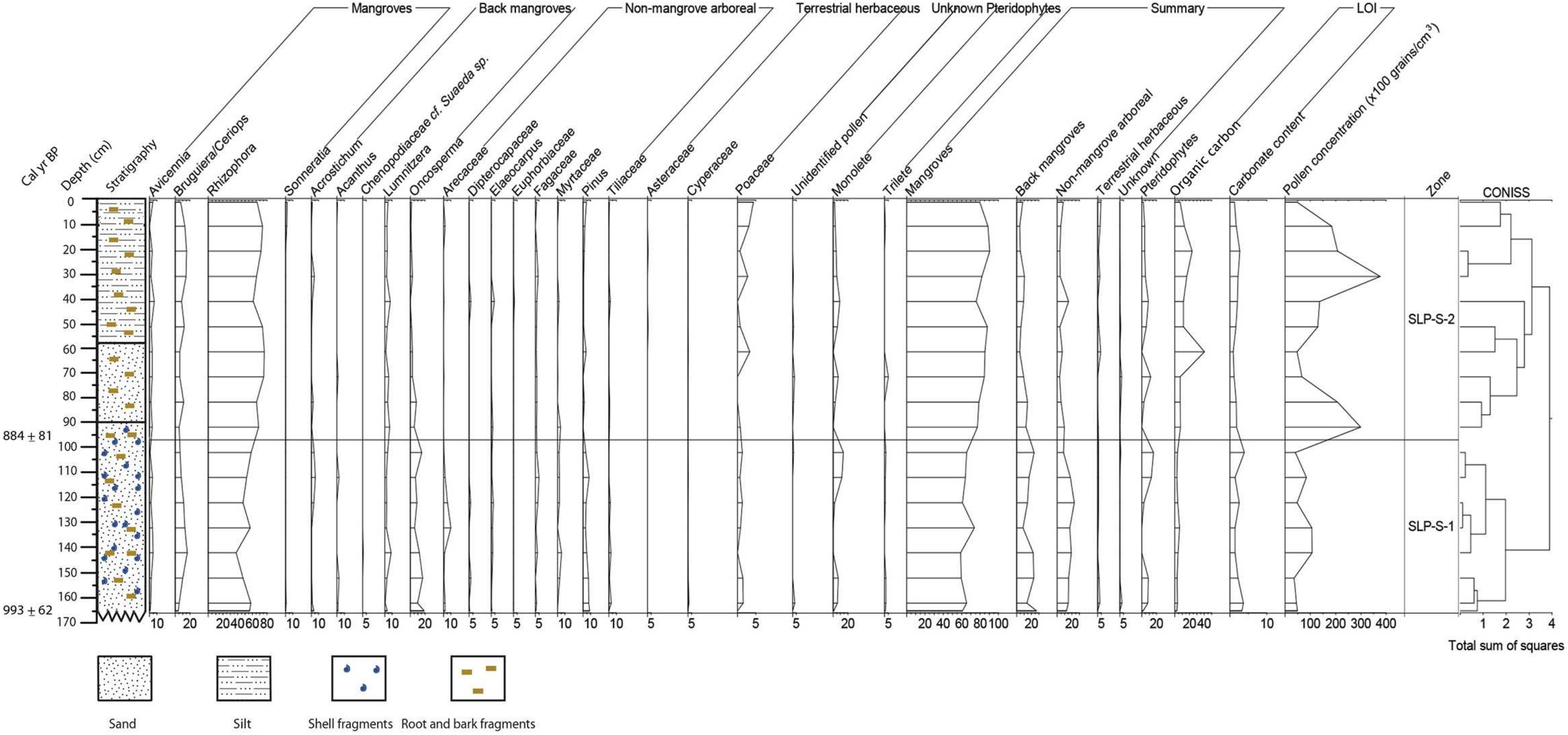
102°41'0"E
12°19'0"N
12°12'0"N
12°5'0"N
11°58'0"N
101°59'0"E
N
Thailand
Koh Chang
Gulf of Thailand
Koh Chang
Salak Phet Bay
Gulf of Thailand
0 2.5 5 10 km
A
102°22'0"E
102°22'30"E
102°23'0"E
102°23'30"E
102°24'0"E
12°0'30"N
12°0'0"N
N
Salak Phet Bay
SLP-L
SLP-M
SLP-S
Gulf of Thailand
0 .25 .5 1 km
B
Mangroves
Coring sites


A
B
C
D
E
F


Landward
SLP-L
Tidal creek
SLP-M
Sand bar
SLP-S
Seaward
Depth (cm)
cal yr BP
864 ± 68
1342 ± 41
1457 ± 69
1093 ± 87
0
10
20
30
40
50
60
70
80
90
100
110
120
Well sorted sandy silt
Sub-rounded poorly sorted silty sand
Sub-rounded poorly sorted sand
cal yr BP
529 ± 21
1324 ± 40
130
140
150
Undifferentiated peat with sub-rounded poorly sorted sand
Sub-rounded poorly sorted silty sand with *Parvicardium* sp. and *Cyclocardia* sp.
Sub-rounded poorly sorted silty sand
cal yr BP
884 ± 81
993 ± 62
160
170
Well sorted sandy silt
Sub-rounded poorly sorted silty sand
Sub-rounded poorly sorted silty sand with *Cyclocardia* sp., *Placamen* sp., *Placuna* sp. and *Anomalocardia squamosa*
Sand
Silt
Peat
Shells and shell fragments
Root and bark fragments
0 15 m
A. aureum
L. littorea
N. fruticans
P. paludosa
S. maritima
X. granatum
A. officinalis
B. gymnorrhiza
C. tagal
R. apiculata
R. mucronata
S.alba

SLP-L	**SLP-M**	**SLP-S**
120-90 cm 	150-137 cm 	165-100 cm 
90-70 cm 	137-103 cm 	100-90 cm 
53-70 cm 	103-80 cm 	90-57 cm 
53-0 cm 	80-0 cm 	57-0 cm 


Mangroves
Back mangroves
Non-mangrove arboreal
Terrestrial herbaceous
Unknown
Pteridophytes
Summary
LOI
Cal yr BP
Depth (cm)
Stratigraphy
Avicennia
Bruguiera/Ceriops
Rhizophora
Sonneratia
Acrostichum
Acanthus
Chenopodiaceae cf. Suaeda sp.
Lumnitzera
Oncosperma
Arecaceae
Dipterocapaceae
Elaeocarpus
Euphorbiaceae
Fagaceae
Myrtaceae
Pinus
Tiliaceae
Asteraceae
Cyperaceae
Poaceae
Unidentified pollen
Monolete
Trilete
Mangroves
Back mangroves
Non-mangrove arboreal
Terrestrial herbaceous
Unknown
Pteridophytes
Organic carbon
Carbonate content
Pollen concentration (x100 grains/cm³)
Zone
CONISS
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
884 ± 81
993 ± 62
SLP-S-2
SLP-S-1
10
20
20406080
10
10
10
5
10
20
10
5
5
5
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5
5
20
5
20 40 60 80100
20
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5
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2040
10
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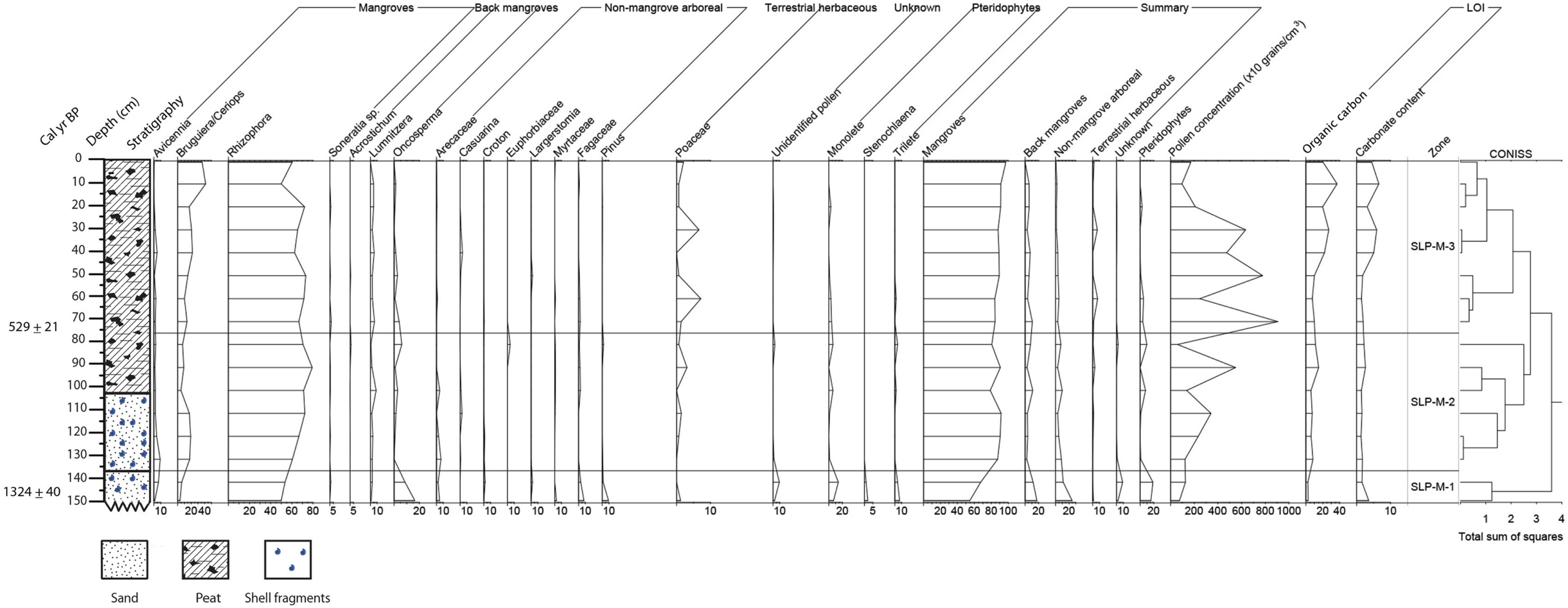
1
2
3
4
Total sum of squares
Sand
Silt
Shell fragments
Root and bark fragments


Mangroves
Back mangroves
Non-mangrove arboreal
Terrestrial herbaceous
Unknown
Pteridophytes
Summary
LOI
Cal yr BP
Depth (cm)
Stratigraphy
Avicennia
Bruguiera/Ceriops
Rhizophora
Soneratia sp.
Acrostichum
Lumnitzera
Oncosperma
Arecaceae
Casuarina
Croton
Euphorbiaceae
Largerstomia
Myrtaceae
Fagaceae
Pinus
Poaceae
Unidentified pollen
Monolete
Stenochlaena
Trilete
Mangroves
Back mangroves
Non-mangrove arboreal
Terrestrial herbaceous
Unknown
Pteridophytes
Pollen concentration (x10 grains/cm^3)
Organic carbon
Carbonate content
Zone
CONISS
529 ± 21
1324 ± 40
0
10
20
30
40
50
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120
130
140
150
SLP-M-3
SLP-M-2
SLP-M-1
10
2040
20 40 60 80
5
5
10
20
10
10
10
10
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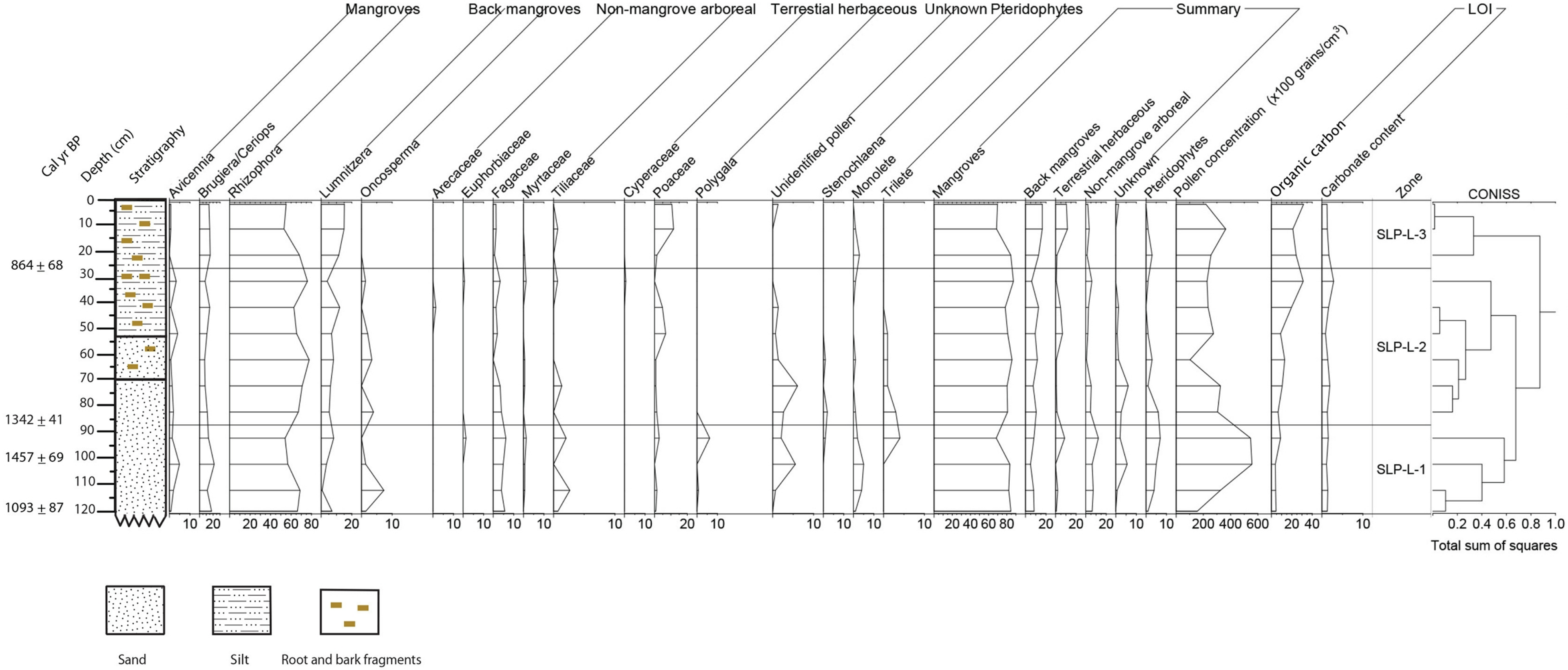
10
10
10
20
5
10
20 40 60 80 100
20
20
10
10
20
200 400 600 800 1000
20 40
10
1 2 3 4
Total sum of squares
Sand
Peat
Shell fragments


Mangroves
Back mangroves
Non-mangrove arboreal
Terrestial herbaceous
Unknown
Pteridophytes
Summary
LOI
Cal yr BP
Depth (cm)
Stratigraphy
Avicennia
Brugiera/Ceriops
Rhizophora
Lumnitzera
Oncosperma
Arecaceae
Euphorbiaceae
Fagaceae
Myrtaceae
Tiliaceae
Cyperaceae
Poaceae
Polygala
Unidentified pollen
Stenochlaena
Monolete
Trilete
Mangroves
Back mangroves
Terrestrial herbaceous
Non-mangrove arboreal
Unknown
Pteridophytes
Pollen concentration (x100 grains/cm^3)
Organic carbon
Carbonate content
Zone
CONISS
864 ± 68
1342 ± 41
1457 ± 69
1093 ± 87
0
10
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80
90
100
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120
SLP-L-3
SLP-L-2
SLP-L-1
10 20
20 40 60 80
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20 40 60 80
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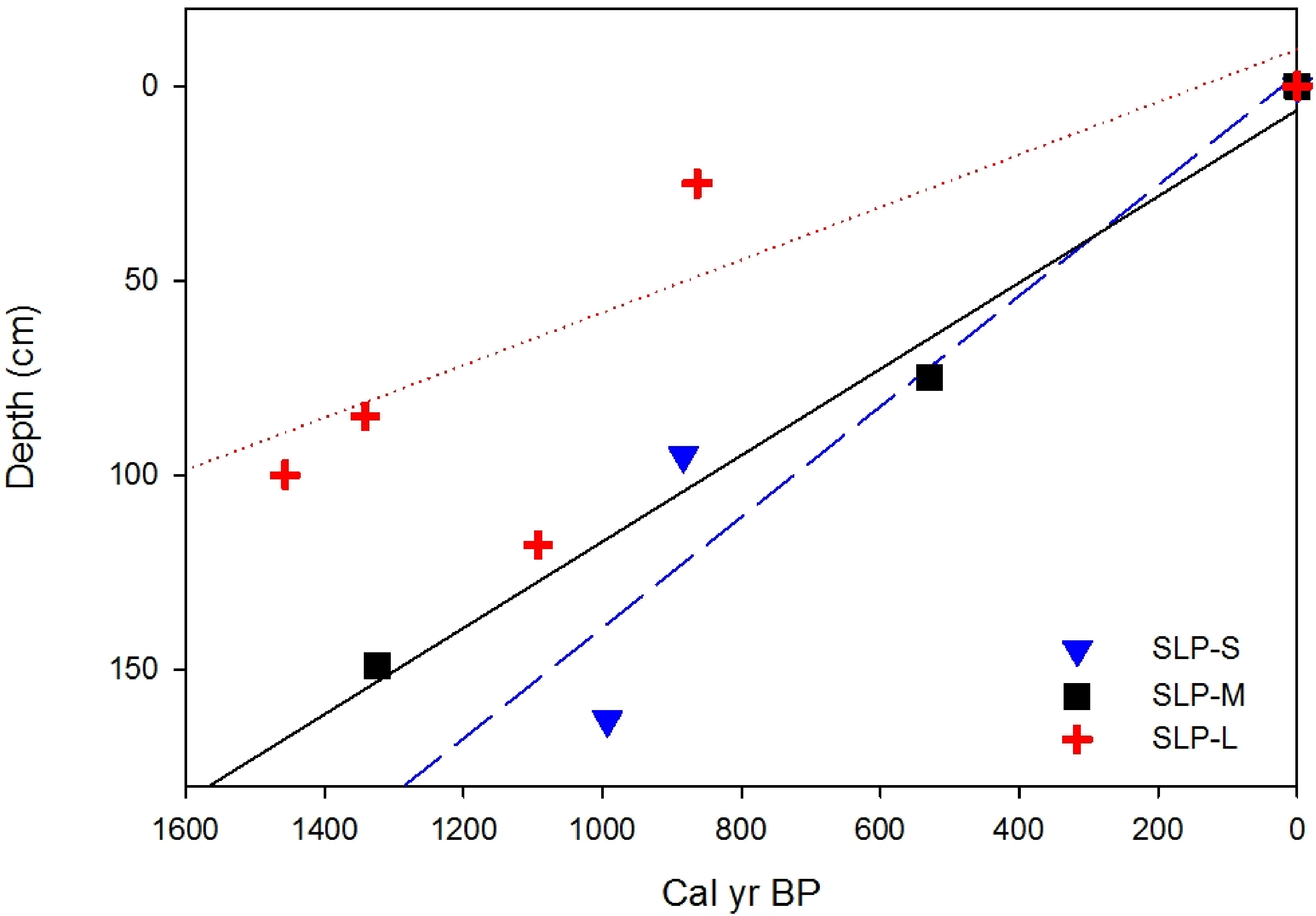
10
200 400 600
20 40
10
0.2 0.4 0.6 0.8 1.0
Total sum of squares
Sand
Silt
Root and bark fragments


0
50
100
150
Depth (cm)
1600
1400
1200
1000
800
600
400
200
0
Cal yr BP
▼ SLP-S
■ SLP-M
✚ SLP-L

Quaternary International

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We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the Editorial process. He/She is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Sincerely,

On behalf of all authors

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