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Beach ridge evolution in response to the Holocene sea-level change from Surat Thani, Thai-Malay Peninsula

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ABSTRACT: Sets of beach ridge plains and sand spit at Laem Pho, Chaiya coast of Surat Thani, the Thai-Malay peninsula, the Gulf of Thailand show their evolution in response to a long-term sea-level change from the middle Holocene to the present. The most landward set of beach ridges defines the paleo-shoreline located at 4.5 km far inland with an elevation up to 4 m of ancient sea level above the present mean sea level. Interestingly, the orientation of beach ridges reflects that they were mainly formed by longshore current in southeast direction likely similar to beach ridges in the other coastal sectors of the western part of the Gulf. The major composition of beach ridge included quartz, whereas minor composition was feldspar. Roundness and sphericity of beach ridge sediments showed sub-rounded and sub-angular. Physical properties of beach sediment and the preservation of feldspar in beach sediment suggest the main source from granite exposure near this coastal plain. Major sediment pathway was possibly supplied from the Phum Rieng canal. Optically stimulated luminescence dating revealed the formation of beach ridge plain here starting from 7,171 ± 460 years BP. The sand spit has been formed at 440 years BP. These ages responded to the formation of beach ridge after sea level had reached the highstand in the middle Holocene.

KEYWORDS: beach ridge plain, sand spit, Holocene sea level curve, OSL dating, Chaiya coast, Thai-Malay Peninsula

INTRODUCTION

The Holocene sea level records have been reported from many parts of coastal regions in Southeast Asia. Along the Thai-Malay Peninsula, previous studies have been focused on various aspects that are mostly the relation of beach ridge evolution in response to the global sea-level change. Most of researchers agreed that the sea level in this peninsula was higher than 3 m from the present mean sea level (MSL) during the middle Holocene [1–6]. Not only finding the records of sea-level change, locating the Holocene shoreline as well as improving sea-level curve have also been done from the southern peninsular Thailand [7, 8].

Radiocarbon (C-14) dating of peat and organic materials found in mud deposits has been applied extensively to infer the history of sea-level change and to draw sea level curve. The first sea level curve of the Thai-Malay Peninsula was drawn [1] with reference data from the Malacca Strait suggesting that sea level has reached maximum at 5 m from the MSL. Later, 3 rebound phases of sea level fluctuations from the Thai-Malay Peninsula occurred between the middle to late Holocene [2]. The first curve in the Gulf of Thailand (GoT) was proposed [3] that the fluctuation of sea level above and below the present MSL occurred twice during the middle Holocene to about 2,000 years ago. Shell fragments included in beach ridge deposit from the western and the eastern GoT were dated [4] and provided the progradation during the marine regression occurring in 4,000 to 2,000 years BP. Accelerator Mass Spectrometry (AMS) dating of oyster and coral from rock shelter at the Andaman coast has given the age of 5,700 years BP at 2.6 m higher than the present MSL [9]. At both sides of the Thai-Malay Peninsula, the oldest age of oyster attached to limestone wall ranges from 6,513–6,390 years BP at an elevation of 2.5 ± 0.1 m above the present MSL [10, 11]. All results of radiocarbon dating showed a similar trend of sea level regression after 6,500 years BP.

Optically stimulated luminescence (OSL) dating has been applied to infer the age of beach ridge sediments from the east and the west of the Thai-Malay peninsula [6, 12] as well as the Andaman Sea [13]. The paleo-shoreline during the mid-Holocene highstand was located 7–8 km inland from the present shoreline [5]. At Chumphon coastal plain, the orientation of beach ridges at the innermost part shows the longshore current drove beach sediment to deposit from the north to the south [6]. The formation of sand spit 15 km far inland from the Chanthaburi coast occurred from the early to middle Holocene through about 1,000 years BP [12]. The age of beach ridge plain from Sam Roi Yot National Park at Prachuap Khiri Khan also corresponded with the progradation after the mid-Holocene [10]. Results of OSL dating of beach ridges from GoT and the Andaman Sea revealed the similar pattern of the beach ridge plain evolution in response with marine regression (with the highest elevation of ridge about 5 m above MSL) extensively developed after 6,000 years BP.

In this paper, we applied OSL dating to infer the

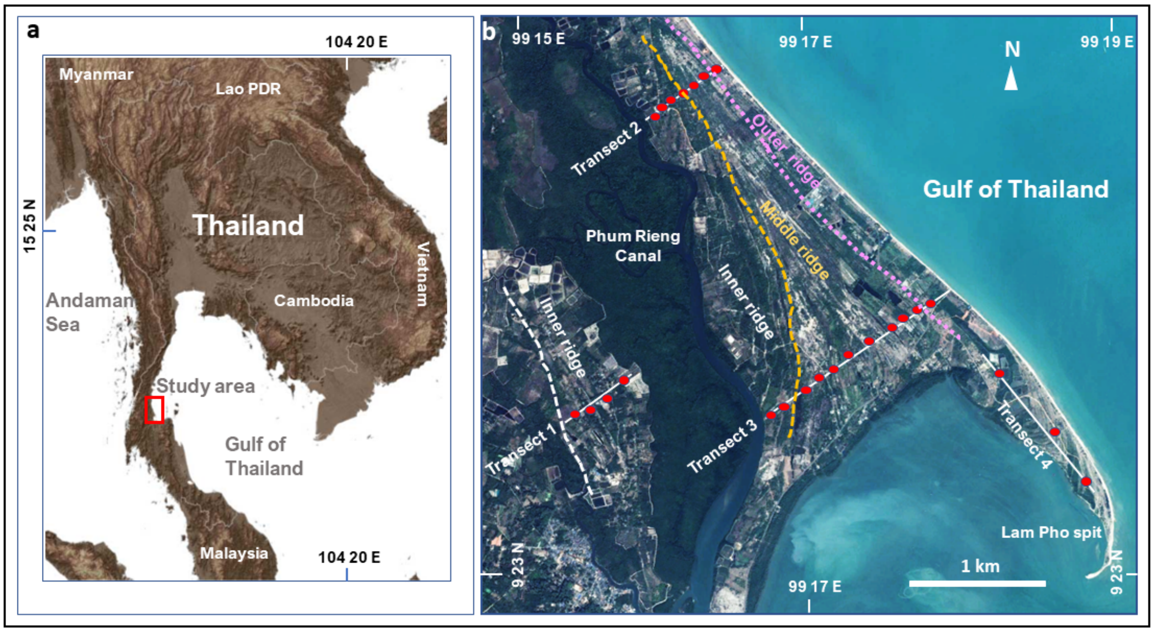

Fig. 1 (a) Digital Elevation Model (DEM) showing the location of the study area (red square box). (b) The morphology of Chaiya beach ridge plain including the inner, the middle, and the outer ridges. Locations of transect lines and OSL dating pits are shown. The Phum Rieng canal is located between the inner ridges. Lam Pho sand spit is developing in southeastward direction.

age of beach ridge from part of the Thai-Malay peninsula at Chaiya coastal plain, Surat Thani (Fig. 1a). This coastal plain owns its completion in coastal morphology that likely preserves the continue record of marine transgression and regression during the Holocene. Therefore, we hypothesized that, apart from the history of sea-level change, the age and orientation of beach ridge plains here may suggest the direction of longshore currents in the GoT throughout the Holocene.

The maximum level of beach ridge at Chaiya coastal plain is up to 4.5 m above the present MSL. The inner set of beach ridge plain is recognized at 4.5 km inland from the present shoreline. A large tidal channel (locally named Phum Rieng canal) divides the inner ridges into 2 parts (Fig. 1b). The middle set of beach ridge is bounded by a large tidal channel in the west and small intermittent tidal channel being developed in a swale in the east. The outer beach ridges including recent sand spit are located in the east (also see Fig. S1).

MATERIALS AND METHODS

Google Earth images taken in 2016 (Quick Bird satellite) with the best resolution at 0.6 m were used to interpret the geomorphological landforms in the study area (Fig. 1b).Then, the geomorphological map was created for marking lines of topographic survey perpendicular to the shoreline and locating sediment sampling points especially from beach ridges along the trend of progradation. For the field work, the topographic survey was conducted by using a total station SOKKIA SET 630R (Sokkia, Japan) for identifying the different characteristic of landforms and the elevations of beach ridges above the present mean sea level (Fig. S1), and then topographic profile was made. Sediment sampling was collected for grain size analysis and age determination by OSL dating. After digging the excavation pit on selected ridges at $50 \times 50 \times 50$ cm^3, the sediments were collected at 40 cm depth in plastic bags and plastic tubes with end caps to avoid sunlight for the best accuracy analysis by OSL dating. After that, hand auger was used to drill beach sediments for analyzing the compositions and stratigraphical correlation. Bioclast was collected from nearshore sediments for systematic faunal classification.

Beach sediments from fifteen sites were collected by hand auger for grain size analysis and statistical calculation by moment method. Parameters including mean grain size, standard deviation (sorting), skewness, and kurtosis were calculated based on Blott and Pye [14]. Sediment compositions, roundness, and sphericity were analyzed under binocular stereomicroscope [15].

Two parameters are used for OSL age calculation: the annual dose calculation (AD) and the equivalent dose determination (ED). About 25 sediments were collected in plastic bags for annual dose analysis and plastic tubes with end caps for equivalent dose analysis [16]. Sediment samples for OSL method were preserved to avoid the sunlight. Sediment samples with bioclast were collected for fossil identification and systematic fauna classification under binocular stereomicroscope.

RESULTS AND DISCUSSION

Orientation of beach ridges inferred the longshore current

After the satellite image interpretation, the geomorphological characteristics in the study area were categorized into 3 units including old sandy beach, young sandy beach, and old lagoon. Old sandy beaches consist of beach ridge plains and the active sand spit, which are the dominant landforms of this area. The orientations of beach ridge plains are mostly parallel to the shoreline from the north to the south. However, beach ridges have special characteristics which can be categorized into 5 series. Series 1 is located at inner most part of this area. Series 2, 3, and 4 located in the middle part of the area were separated from Series 1 by Phum Rieng canal. Then, they have formed a gigantic beach ridge plain. The last series is located next to the shoreline representing the recent beach. The innermost beach ridges located approximately 4.5 km inland are used to infer the paleo-shoreline in this area. On the other hand, sand spit in this area shows the southwestward orientation reflecting that the present longshore current is controlled by the reflection from the nearest islands.

Physical properties of beach ridge sediments

In this area, the average values of grain size parameters were summed up into four parameters including mean grain size, standard deviation (sorting), skewness, and kurtosis (Fig. 2). The mean grain size of series 1, 3, 4, and 5 is medium sand, while series 2 is dominated by coarse sand. The standard deviation of series 1 is poorly sorted, and series 2 to 5 is moderately sorted. The skewness of series 1 and 3 is fine-skewed. Series 2 is very fine-skewed. Series 4 is coarse-skewed, and series 5 is near-symmetrical. The kurtosis of series 1, 2, 3, and 5 is extremely leptokurtic; series 4 is very leptokurtic.

Factors controlling the mean grain size values of beach sediments are the different sources of sediments, mode of transportation, and the environment of deposition [17]. The grain sizes of sediments can be used to indicate the distance of transportation and the energy of transportation [17–19]. The mean grain sizes of sediments from old beach ridges and recent beach in this area are mostly identified as medium to coarse sand indicating that the sources of sediments are not far from this area. Besides, the energy of transportation is in moderately high energy condition. Sediments in swales (old lagoon) were found as sandy loam and sandy clay, representing the low energy environment. Nevertheless, not only the distance, but also the duration of transportation are the controlling factors of beach sediment grain sizes.

The standard deviation (sorting) is a parameter used in this work to evaluate the uniformity of grain size distribution of sediments upon the size of source rock, the distance of transportation, the range of weathering, and the energy difference of the depositing medium [18, 20]. While the good sorting refers to smooth, stable currents [20], sorting in this area is mostly poorly to moderately sorted, indicating low to high energy current.

Skewness and kurtosis are indexes of the significant action of transporting agent comparing sediments from similar environment but different sources [19, 21]. Skewness is the important index for measuring the asymmetry of grain size distribution [22], and the variation of kurtosis values represents the fluctuation and flowing characteristic energy of the environment while sediments are deposited [23, 24]. In this area, more than 80 percent of sediments showed the fine-skewed values, whereas the 20 percent belonged to coarse-skewed. Coarse-skewed refers to negative skewness, and coarse grain size indicates high energy and winnowing action (removal of fine grain size). Fine-skewed refers to positive skewness, and fine grain size indicates low energy (calm) environment [25, 26]. This area indicates fine- to coarse-skewed which represents calm to storm environment. The kurtosis values of this area are extremely leptokurtic which has the mid-portions better than those sorted at the tails, indicating the high energy environment. However, grain size distribution was considered by mineral compositions, texture of grains, roundness, and sphericity. The landform in this area is dominated by beach ridge plains that mostly comprise sand sediments. The major and minor sediment compositions are quartz and feldspar, respectively (Fig. 3). The bioclasts and sub-angular texture of sediments in series 5 indicate the short-time of transportation and local source of sediments near the site. Sandy loam and sandy clay were found in swale of sand spit representing the low energy area.

Age of beach ridges

About 25 sediment samples from beach ridges were analyzed by OSL dating. However, in this study, beach ridges were categorized into 5 series based on the orientation of beach ridges. Only 4 series of beach ridges were taken for age determination because series 5 (recent beach) is inferred as a part of the present shoreline (Figs. 4 and 5 and Table 1).

OSL dating from beach ridge of series 1 revealed the range of ages from $6{,}270 \pm 430$ to 950 ± 30 years BP. Series 2 and 3 which are located in the middle

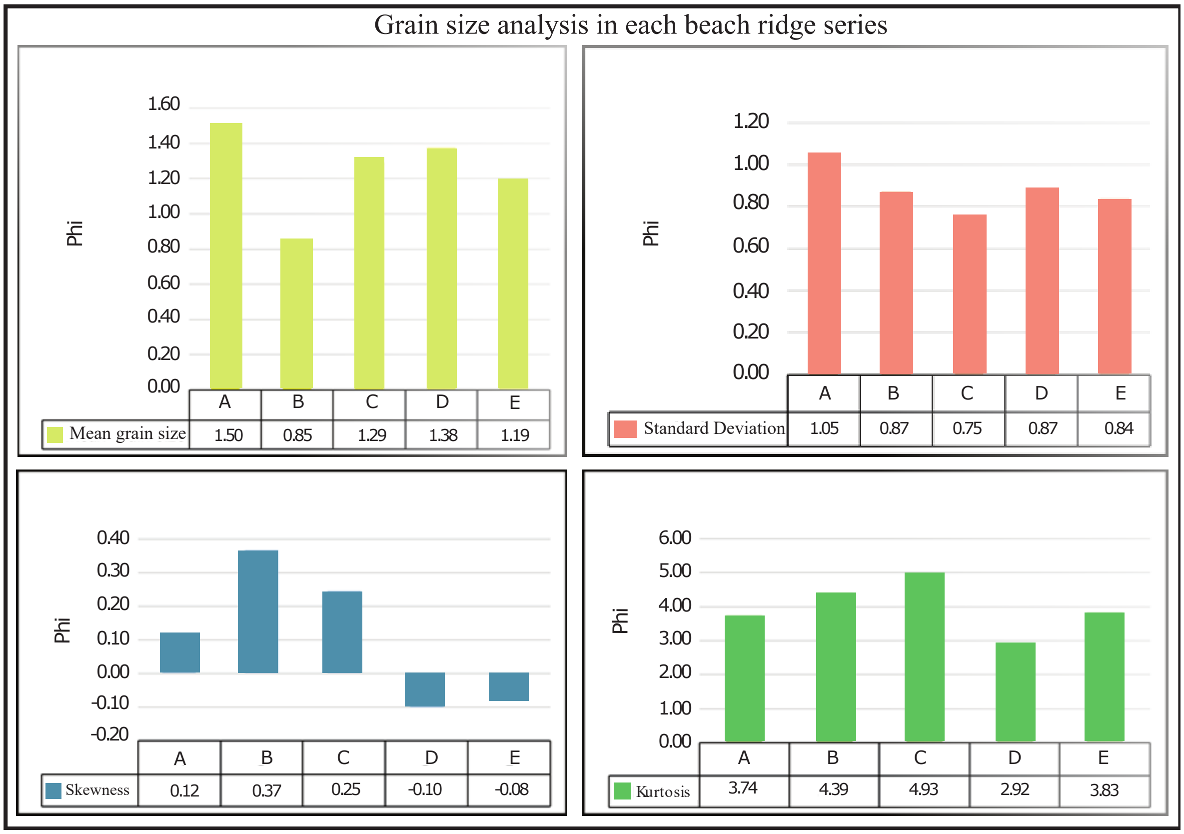

Fig. 2 Bar charts showing grain size analysis from 5 series of beach ridges (see text for explanation).

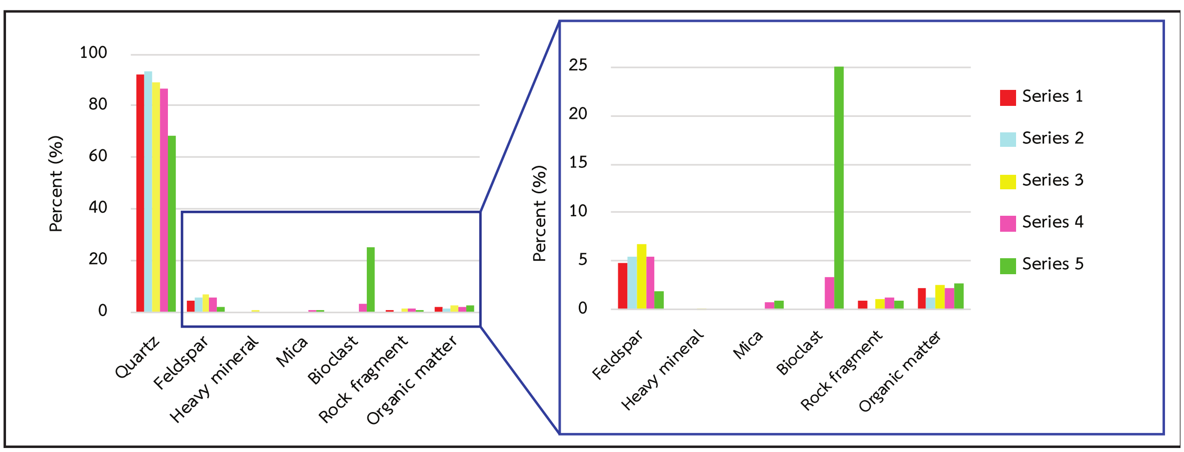

Fig. 3 Histogram showing sediment composition from 5 series of beach ridges. Bioclasts are dominated in series 5 (the modern beach).

part were separated from series 1 by Phum Rieng canal. They have age ranging from 7,170 ± 460 to 2,510 ± 150 years BP and from 5,830 ± 370 to 1,570 ± 60 years BP, respectively. However, the discontinuity of the ages of series 2 and 3 in the middle part of the beach ridge plains may have been influenced by typhoon strike to the GoT [27]. Williams et al [27] reported 11 typhoon strikes during 1,952 to 7,575 years BP at the Cha-am beach and 8 typhoon strikes during 4,075 to 7,740 years BP at Kui Buri beach, and there were 2–5 strikes greater than typhoon strike between 3,900 and 7,800 years BP. The other assumption of the discontinuity of ages is that the progradation of the middle beach ridges in southwestward and seaward

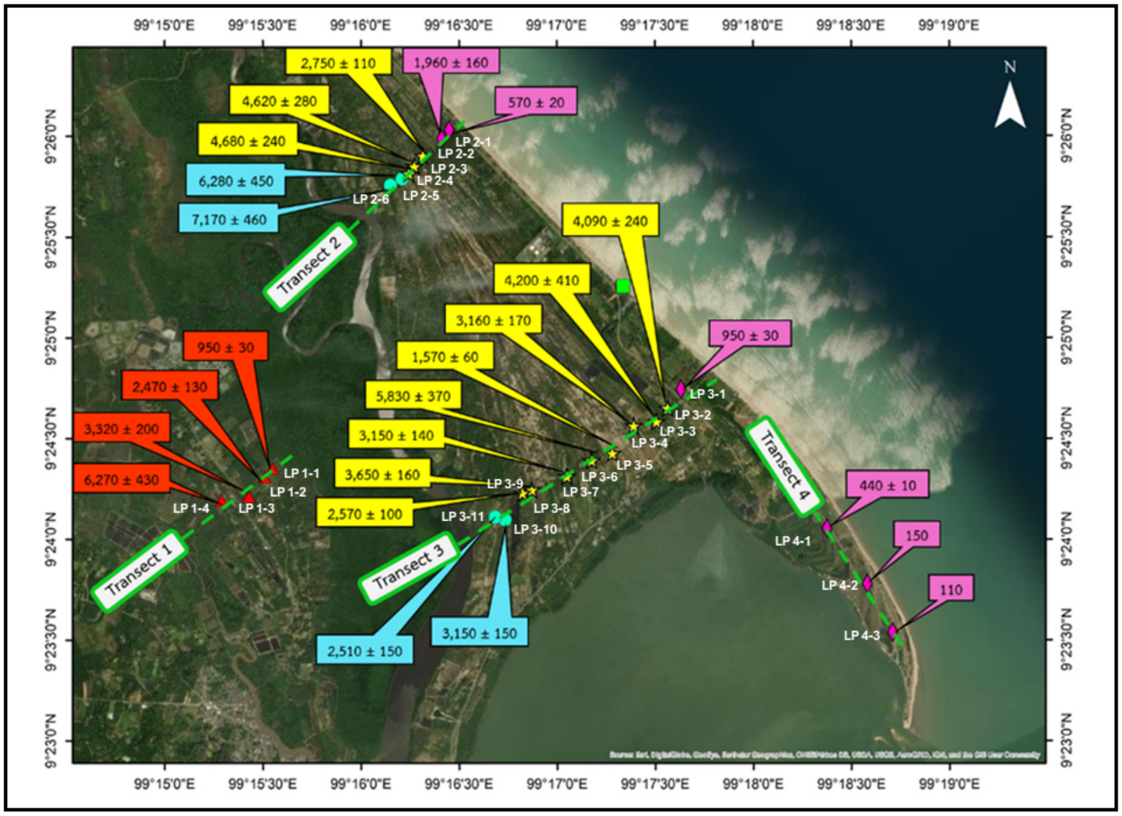

Fig. 4 OSL ages from each sampling location. Different colors show the difference of beach ridge series 1 to 5 (see text and Table 1 for more explanation).

directions may have reworked beach sediment and redeposited along the longshore current.

Series 4 consists of beach ridges and sand spit located near the recent beach area. The age of beach ridges in series 4 is ranging from 1,960 ± 160 to 110 ± 4 years BP and represents the modern process of sediment progradation from the present longshore current.

Holocene sea-level curve

After the last glacial period in the late Pleistocene, the ice mass melted continuously causing sea-level rise and transgression worldwide [4]. In Southeast Asia, especially the GoT, the previous study showed that the sea level dropped more than 50 m resulting in the submerge in part of the Sunda shelf [28]. However, there was a progradation of coastal area after sea-level retreated back into the sea after the middle Holocene [7].

The first sea-level curve in Southeast Asia was constructed from the Malacca Strait. The maximum level of sea-level rose up to 5 m in the middle Holocene [1]. The first sea-level curve of Thailand was proposed by Sinsakul et al [3], presenting 2 highstands of sea-level fluctuation with 5 m at 6,000 years BP and 3 m at 4,000 years BP. There was a rebound phase of marine transgression at 4,700 years BP corresponding to the previous study along the Thai-Malay peninsula [2] that presented 3 rebound phases of highstand in middle Holocene to late Holocene at 6,000, 4,000, and 2,700 years BP. Later, the study by Hesp et al [29] was against results from Geyh et al [1], Sinsakul et al [3], and Tjia [2] by reporting a rapid marine transgression rising up 3 m at 6,500 years BP and falling to the present sea level at 2,000–1,000 years BP. Choowong et al [4] presented a revised sea-level curve envelope of the GoT, corresponding well with the study at the Thai-Malay peninsula by Horton et al [5]. The curves show the upward trend of Holocene sea-level rise to the middle Holocene highstand at average 5 mm/year and fall at 1.1 mm/year to the present sea-level [4]. In addition, Nimnate et al [6] reported from Pak Nam Chumphon of the GoT that the highest sea-level transgression was approximately 4–5 m around 7,600 years BP (Fig. 6a). At Laem Pho, the elevation of the oldest ridge was measured at 4 m from about 7,170 ± 460 years BP. This age can be inferred as the highest marine transgression in this area. After that, the progradation of sea level was in seaward direction and slightly dropped to the present MSL (Fig. 6b).

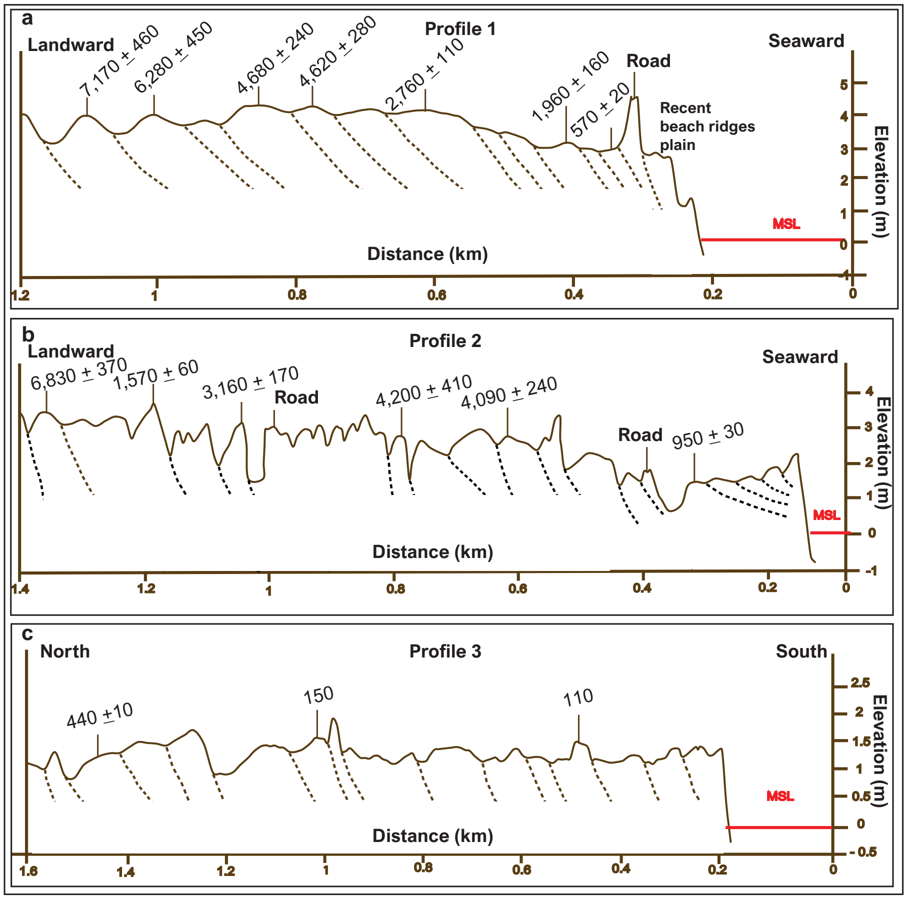

Fig. 5 Three topographic profiles with age of beach ridge plains. (a) Profile 1 (transect 2 in Fig. 4), (b) Profile 2 (transect 3 in Fig. 4). (c) Profile 3 (transect 4 in Fig. 4) along the sand spit in the southern part of study area.

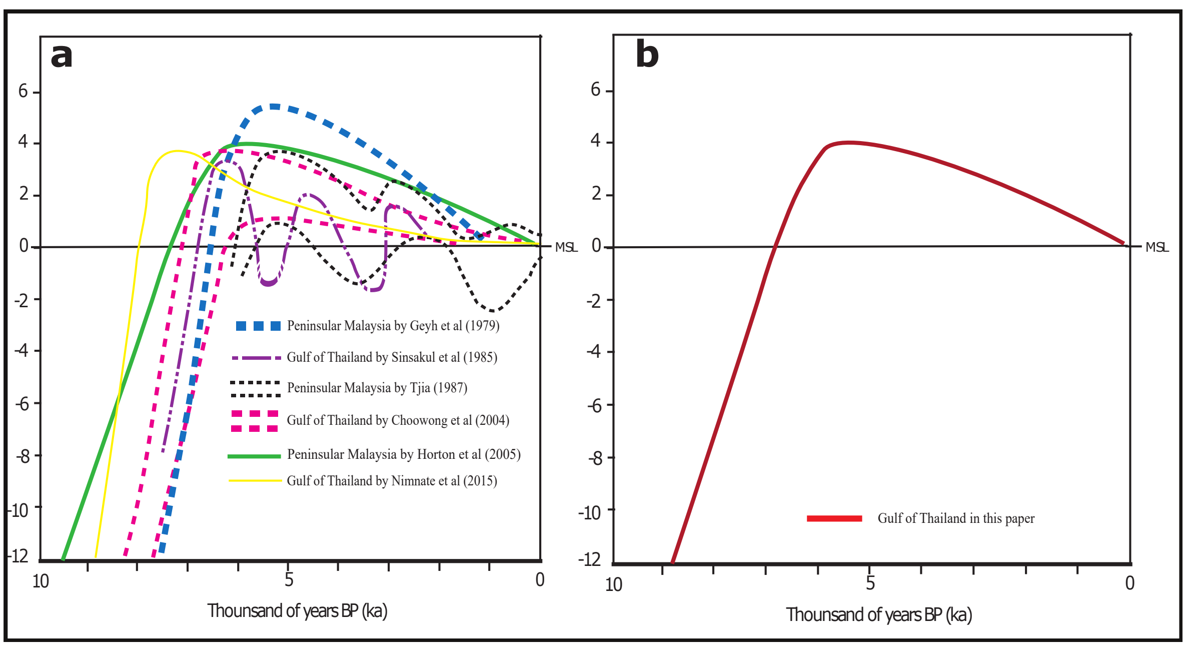

Fig. 6 (a) Sea-level curves from Southeast Asia. (b) Sea-level curve of Chaiya coast from this study.

Table 1 OSL dating from beach ridge plains at Chaiya coast of the Gulf of Thailand.

Transect	U (ppm)	Th (ppm)	K (%)	W (%)	AD (Gy/ka)	ED (Gy)	OSL Age (Yr)
Transect 1							
LP 1-1	0.19	8.16	3.00	18.87	4.84	4.63	950 ± 30
LP 1-2	0.00	5.27	3.43	6.75	4.51	11.17	2,470 ± 130
LP 1-3	0.26	2.93	2.35	4.38	2.99	9.94	3,320 ± 200
LP 1-4	0.06	4.86	2.46	6.60	3.56	22.34	6,270 ± 430
Transect 2							
LP 2-1	0.39	4.86	2.70	4.87	2.93	1.67	570 ± 20
LP 2-2	0.20	4.68	1.14	4.31	1.51	2.96	1,960 ± 160
LP 2-3	0.00	4.23	1.98	4.39	2.15	5.93	2,750 ± 110
LP 2-4	0.07	5.03	1.11	3.89	1.47	6.80	4,620 ± 280
LP 2-5	0.07	6.54	1.62	3.50	2.03	9.50	4,680 ± 240
LP 2-6	0.27	4.68	1.33	4.04	1.69	10.59	6,280 ± 450
LP 2-7	0.33	2.61	1.42	4.16	1.63	11.68	7,170 ± 460
Transect 3							
LP 3-1	0.08	4.93	2.03	3.98	3.19	3.06	950 ± 30
LP 3-2	0.13	2.41	0.51	3.83	1.26	5.15	4,090 ± 240
LP 3-3	0.24	3.56	0.25	4.39	1.30	5.48	4,200 ± 410
LP 3-4	0.00	3.11	0.89	4.21	1.76	5.56	3,160 ± 170
LP 3-5	0.00	6.81	1.41	3.91	3.11	4.92	1,570 ± 60
LP 3-6	0.61	4.31	0.00	4.38	1.27	7.39	5,830 ± 370
LP 3-7	0.55	2.50	2.21	5.67	2.76	8.71	3,150 ± 140
LP 3-8	0.00	4.95	0.74	4.72	2.07	7.55	3,650 ± 160
LP 3-9	0.00	7.01	2.08	5.42	3.75	9.67	2,570 ± 100
LP 3-10	0.00	5.82	1.67	4.66	3.10	9.78	3,150 ± 150
LP 3-11	0.44	3.28	1.92	5.35	2.70	6.78	2,510 ± 150
Transect 4							
LP 4-1	0.79	6.84	2.10	16.32	3.72	1.65	440 ± 10
LP 4-2	0.23	4.10	3.89	23.52	4.63	0.72	150 ± 5
LP 4-3	0.09	6.29	3.95	5.80	5.22	0.62	110 ± 4

Abbreviations: U, uranium; Th, Thorium; K, potassium; W, water; AD, annual dose; OSL, optically stimulated luminescence.

Mode of coastal evolution

Mode of coastal evolution was constructed after the better understanding in the phases of progradation. Normally, the direction of progradation in this area started from the west to the east. The phases of progradation were categorized into 3 phases based on the trend of beach ridge orientation and ages. Phase A initiated between 7,170 to 6,280 years BP and located at the innermost part of beach ridge plains next to the western alluvial plain. Landforms were dominated by paleo-barrier island. Phase B subsequently covered between 4,600 to 2,500 years BP. Beach ridges in the southern part of the area had a short period of shoreline retreat and high progradation of sediments in seaward direction. Phase C started approximately from 2,000 years BP to the present and is being dominated by sand spit. The progradation is mostly in southwestward by wave current action. However, rate of progradation of sand spit in phase C is about 2.22 m/year (from 440 to 150 years BP) and about 12 m/year (150 to 110 years BP). The latter rate may possibly be caused by intense monsoon or storm events in that period, which is in agreement with William et al [27] reporting study from Cha-am and Kui Buri, the northern part of Chaiya, where the coastal areas were frequently attacked by typhoons.

CONCLUSION

This study aims to better understand the evolution of beach ridge plains at Chaiya coast of the GoT based on coastal geomorphology, sediment characteristics, and OSL dating. Landforms of the area were dominated by beach ridge plains and large tidal channel. Orientation of beach ridges shows seaward and southwestward progradation. Sediments were supplied to the coastal plain longshore current from the north to the south. The composition of beach ridges was dominated by quartz and feldspar. It suggested that the sediments were derived from weathered granite outcrops and islands located near the area. It is confirmed by the sub-angular roundness and sphericity of the sediments that were transported from the northern part along the Phum Rieng canal via tide dominated delta. Bioclasts were found abundantly at the nearshore area and sand spit part.

The age of beach ridge plains made it clear that the formation was responded to sea-level change during the Holocene. OSL dating of beach ridges confirmed that they started to form in the middle Holocene (7,170 ± 460 years BP) at the inner beach ridge plain.

Beach ridge plains in this area were partly formed by the reworked sediments. The progradation still occurs as the present-day sand spit is continuing to form in southwestward.

Appendix A. Supplementary data

Supplementary data associated with this article can be found at http://dx.doi.org/10.2306/scienceasia1513-1874.2023.027.

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Appendix A. Supplementary data

Fig. S1 (a) Aerial view of Chaiya beach ridge plain with positions of transects 2 and 3. (b) Lam Pho sand spit (looking north) showing transect 4. (c) Lam Pho sand spit (looking south) showing the end of spit curving to the southwest direction. (d) Topographic survey by a total station camera (Sokkia) for levelling along 4 transects. (e) Beach ridge profile and OSL sample collection in the inner ridge.