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Paleogeographic Reconstruction and History of the Sea Level Change at Sam Roi Yot National Park, Gulf of Thailand

PEERASIT SURAKIATCHAI[1], MONTRI CHOOWONG[1*], PUNYA CHARUSIRI[1], THASINEE CHAROENTITIRAT[1], SAKONVAN CHAWCHAI[1], SANTI PAILOPLEE[1], AKKANEEWUT CHABANGBORN[1], SUMET PHANTUWONGRAJ[1], VICHAI CHUTAKOSITKANON[1], STAPANA KONGSEN[1], PARISA NIMNATE[1,3] AND RAPHAEL BISSEN[2]

[1] *Morphology of Earth Surface and Advanced Geohazards Research Unit (MESA RU), Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, THAILAND*
[2] *Department of Mining and Petroleum Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, THAILAND*
[3] *Division of Geoscience, Mahidol University, Kanchanaburi Campus, Kanchanaburi 71150, THAILAND*
[*] Corresponding author. Montri Choowong (monkeng@hotmail.com)
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ABSTRACT.– In this study, the paleogeography and the natural history of sea level change was reconstructed for the Sam Roi Yot National Park, Prachuap Khiri Khan, Gulf of Thailand, one of the tropical natural conservation areas. Beach ridge sand and marine shells attached to sea notches were dated by Optically Stimulated Luminescence and conventional C^{14} radiocarbon techniques. The paleo-landform features recognized in the inland region of the national park were a coastal bay, beach ridge plain and tombolos. The semi-circle paleo-coastal bay possibly developed at the same time as the upper sea notch, some 6,500–6,000 y ago. These inland landforms have subsequently become a tidal flat after tombolos connected the limestone islands to the mainland. This process coincided with the formation of the middle sea notch, 3,000–1,000 y ago. A total of 163 shells were collected from 10 locations with different environments, including the beach ridge, swale, tidal flat and former tidal flat. They were classified into 57 species (12 Gastropoda and 45 Bivalvia species). *Anadara inaequivalvis, Anadara pilula*, *Saccostrea cucullata*, *Anomalocardia squamosal, Meretrix meretrix* and *Dosinia cretacea* were found extensively in most areas. All these species indicated a mangrove environment to the intertidal zone.

KEY WORDS: Paleo-coastal bay, Holocene sea level change, beach ridge plain, progradation, Gulf of Thailand

INTRODUCTION

Coastal zones are dynamic and their evolution is related to climate change (global warming) and sea level history. Global warming has been considered to be a key factor for local-scale sea level changes, which have led to the loss of coastal equilibrium, including along Thailand's coast (e.g., Sinsakul, 1992; Choowong et al., 2004; Choowong, 2011; Phantuwongraj and Choowong, 2012; Phantuwongraj et al., 2013; Williams et al., 2016). Climate changes can pose a threat to coastal lowland areas, including the coastal plain along the Gulf of Thailand (GoT) in Thailand. Basically, to better understand the evolution of each low-lying coastal area, a combination of geomorphology, sedimentology, paleontology and isotope dating are needed. Geological records of marine transgression and regression are preserved more or less in the form of ancient landforms and their deposits. These geological records have led to frequent discussions about the paleoenvironment and paleogeography, and have become the key background information for inferring the history of sea level changes.

Most previous geological studies regarding coastal evolution in Thailand have set their focus on the Lower Central Plain of the upper GoT (e.g., Takaya, 1971; Thiramongkol, 1983; Choowong, 2011) and excluded the other coastal zones. This is because the Central Plain is a low-lying plain at 1–4 m elevation above the present mean sea level (MSL), and so is sensitive to the effect of rising sea level in the future. Although the study of coastal evolution has been extended to the other coastal regions, for example, peninsular Thailand (Horton et al., 2005) and the Chumphon coast at the southwest coast of the GoT (Nimnate et al., 2015), the evolution of the Sam Roi Yot (SRY) coastal plain has never been analyzed in detail.

Among the literature on coastal evolution research in Thailand, the coastal changes along the Andaman Sea have been reconstructed by episodic evolution of a beach ridge at Phrathong Island (Lansai, 2004; Brill et al., 2014), as well as sea notches and caves in the limestone bedrock from Phang Nga to Satun (Scheffers et al., 2012). Outside of the Lower Central Plain of the Chao Phraya and Tha Chin River s(Takaya, 1971; Thiramongkol, 1983; Choowong, 2011), the history of sea level change with respect to paleogeography is limited because their landforms have been changed tremendously by rapid urbanization (Supajanya, 1983; Choowong et al., 2004; Nimnate et al., 2015). In this study, we present new geomorphological and geological evidence of the GoT coastal evolution from the conservation area of the SRY National Park (NP), Prachuap Khiri Khan, on the northwestern coast of the GoT. The reconstruction of the paleogeography is also presented.

The SRYNP was established in 1996 as Thailand's first coastal NP and covers an area of 98.8 km² (Fig. 1), extending from 12° 04´ to 12° 21´N and 99° 51´to 100° 02´E. This conservation area has a significant ecological value as it is home to a large variety of animals, including several hundred bird species, both common and migratory, which use it as breeding and resting areas.

Based on the Köppen climate classification, SRY is located in a tropical monsoon climate (Köppen, 1918). The amount of rainfall is higher than 100 mm between May and November and decreases to about 20 mm between December and February (Manisarn, 1995). From October to May, the temperature is approximately 23–32 °C and from June to September it is 20–30 °C (Manisarn, 1995). In Thailand, coastal processes are generally controlled by waves and tides. At Cha-am (Upper west-coast of the GoT), the mean tidal range is 1.26 m and mean sea level is 1.76 m. At Kui Buri, about 100 km south of Cha-am, the mean sea level is 1.61 m at the mean lowest low water and the mean tidal range is 1.03 m (Williams et al., 2016). Wave action is mainly influenced by the seasonally reversing wind of the northeast and southwest monsoons from May to October and from November to April, respectively. The southwest monsoon generates the surface waves along the Andaman coast. The waves along the GoT coast, however, are mainly influenced by the northeast monsoon (Manisarn, 1995).

MATERIALS AND METHODS

Aerial photographs

Aerial photographs taken in 1955, 1967 and 1970, a topographic map compiled in 1964 and satellite images taken in 2014 were used to classify the coastal landforms (Table 1). Ancient and present day coastal

FIGURE 1. Coastal landforms overlying a topographical map (Royal Thai Survey Department and Department of Mineral Resources of Thailand). Sample locations for ^{14}C and optically stimulated luminescence (OSL) datings, and the index map of Figs. 2 and 5, were included.

landforms were identified using stereo-pair aerial photos and a mirror stereoscope. Oblique air-photographs and video records were performed using a drone (Phantom 3 standard type).

Field survey

Field investigations were used to search for the evidence of sea-level changes, possibly preserved along the coast of the SRYNP. Classification of shells deposited within each landform from 11 locations was

TABLE 1. Series of topographic maps and aerial-photographs used in this study.

Material used	Detail (year of air-photo taken; map sheet; series)	Compiled and published year	Publisher
Topographic map	Interpreted from air-photos taken in 1954 (ID 49472) with hydrographic charts I produced in 1941 Map sheet 4947 II, L708 Sathani Kui Buri	1961	RTSD
	Map sheet 4933 II; L7018 Amphoe Kui Buri	2000	RTSD
Aerial photographs	1955 (ID 23962)	1955	RTSD
	1968 (ID 0002)	1970	RTSD
	1994 (ID 0012)	1994	RTSD
Satellite image	2015	2015	Google Earth

RTSD = Royal Thai Survey Department

comparatively based on the previous published catalogues (Surakiatchai, 2006; Robba et al., 1993, 2002, 2004, 2007). Oyster fossils from several levels of sea notch walls, both far inland and from limestone headlands, were collected. The height at which the fossils were attached to the notch wall was measured and related to the astronomical tides. The astronomical tide level records from the Ko Lak tide gauge data at Prachuap Khiri Khan Bay were used as reference datum. The level of mean high tide was measured from additional significant biomarkers. An example of such a biomarker is the small oyster, *Saccostrea cucullata*. Its uppermost horizontal level of occurrence was assumed to represent the Mean High Water level (MHW) with a fluctuation of ± 10 cm (Scheffers et al., 2012). Both, the level of oysters attached to the sea notch wall as well as the horizontal line of the recent biomarker, were used to determine the height of the biological sea level indicators and contributed to improving the accuracy of the ancient sea level curve. A theodolite, SOKKIA total station series 10, was applied for topographical leveling. Direct vertical distances of biomarkers and oysters in sea notches, located close to the present shoreline, were measured. A digital handheld GPS (Garmin) was used to get the position of the inland ridge and swale along with the topographic survey.

Dating methods

The age of the fossils was determined by ^{14}C radiocarbon dating, performed at the Office of Atomic Nuclear for Peace of Thailand (OANP). The ^{14}C data was calibrated with the Calib 7.0 online program, using the northern hemisphere terrestrial calibration curve (Reimer et al., 2009; Southon et al., 2002).

Beach ridge sands were dated by Optically Stimulated Luminescence (OSL) (Roberts and Plater, 2006). In the sample preparation process, each sample was divided into two portions and used for evaluating the (i) equivalent dose (ED) and (ii) annual dose (AD) including the water content measurement. The portion used to evaluate the ED was performed in subdued red light whereas that for the AD, including the water content, was prepared with light exposure. Dried samples were sieved and treated with hydrochloric acid, hydrogen peroxide and sodium oxalate to remove carbonate, organic material and clay. After density separation, the pure quartz was etched with concentrated hydrofluoric acid.

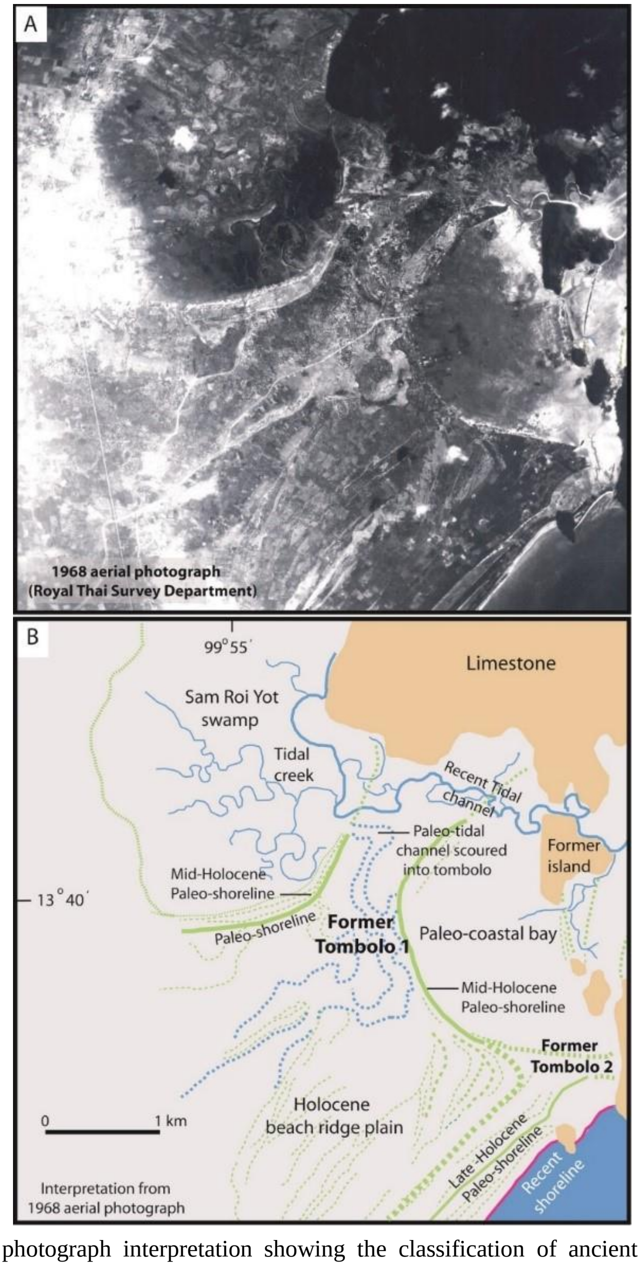

FIGURE 2. Aerial photograph interpretation showing the classification of ancient landforms and their paleogeography. Former tombolo 1 was recognized in the middle part leading to the formation of brackish swamp in the west and the semi-circle paleo-coastal bay. The inner part of the beach ridge plain found in the south formed at the same time as tombolo 1. The outer ridges set formed at the same time as tombolo 2 (Aerial-photo taken in 1968; Royal Thai Survey Department).

The Risø TL/OSL DA 20 instrument with a $^{90}Sr/^{90}Y$ beta source was operated at the Department of Geology, Chulalongkorn University. Luminescence signals were detected through a Hoya U340 filter (7.5 mm) after blue LED stimulation, performed

TABLE 2. OSL dating results from the beach ridge plain (Locations in Fig. 1)

Sample no.	Distance from shoreline (m)	U (ppm)	Th (ppm)	K (%)	Water (%)	De (Gy)	Age (y)	Age (BP)
K4-1	170	1.91±0.10	0.35±0.14	2.40	0.58±0.05	0.55±0.01	950±80	884±80
K4-2	430	2.48±0.12	0.53±0.14	12.36	0.67±0.05	1.58±0.03	2350±220	2284±220
K4-3	1180	2.62±0.12	0.53±0.16	3.20	0.84±0.06	2.08±0.06	2463±250	2397±250
K4-4	1500	2.63±0.04	0.57±0.27	0.34	0.85±0.06	3.37±0.12	3980±200	3914±200
K4-5	1900	2.53±0.10	0.55±0.16	1.43	0.80±0.05	6.54±0.19	8186±700	8120±700
K4-6	2200	2.80±0.01	0.65±0.06	4.00	0.88±0.03	6.41±0.31	7270±450	7204±450
K4-7	2480	2.70±0.03	0.72±0.04	1.69	0.96±0.03	6.18±0.15	6410±260	6344±260
K4-8	3100	4.05±0.03	0.73±0.06	1.98	1.10±0.04	6.94±0.23	6282±340	6216±340
K4-9	3500	5.13±0.05	0.85±0.08	1.77	1.34±0.05	9.08±0.31	6756±390	6690±390
K4-10	3800	4.73±0.07	1.01±0.08	2.02	1.41±0.05	10.34±0.30	7339±390	7273±390

at 125 °C for 50s. The equivalent doses were measured by the SAR protocol of Murray and Wintle (2000, 2003). Mean equivalent doses were calculated from the concentrations of the ^{40}K, ^{232}Th and ^{238}U radionuclides.

RESULTS

Recent and paleo-coastal landforms

The central part of the SRYNP area is dominated by high limestone mountains with cliffs and bounded in the east by a coastal plain, including marshy swale, tidal flat, beach and swampy areas. The limestone is grey to bluish-grey with fossils indicating reef limestone interbedded with light brown feldspathic and calcareous sandstone. A Permian age was derived for the sequence (DMR, 1999). The Quaternary unconsolidated sediment lies beneath the low-lying coastal zone. This led to a subdivision of the study sites according to geomorphological units, such as beach ridge plain, alluvial, colluvial and high-relief units (Fig. 1). The area in the west part of the NP is composed of a swampy environment, including tidal creeks, inlets and outlets (Klong Khao Daeng). In the southern part of the swampy area, a semi-circle shape was interpreted as a paleo-bay, connected to the headland by a tombolo (see Fig. 2). A beach ridge plain was also dominant in the southern part of the area. The inner part of the beach ridge consisted of narrow ridges intervened with shallow swales. The orientation of the ridges conformed to the direction of the former tombolo 1 formation. Between the inner and outer beach ridge sets, a large swale with traces of a tidal channel, developed in swale, was recognized. The orientation of the outer set of ridges started with a cuspate sand cape and conformed to the direction of the former tombolo 2. The OSL dating derived from the sand ridges (sample locations are shown in Fig. 1) are shown in Table 2. Progradation of the beach ridge plain also unveiled the gradual regression until reaching the MSL at the present day coastline.

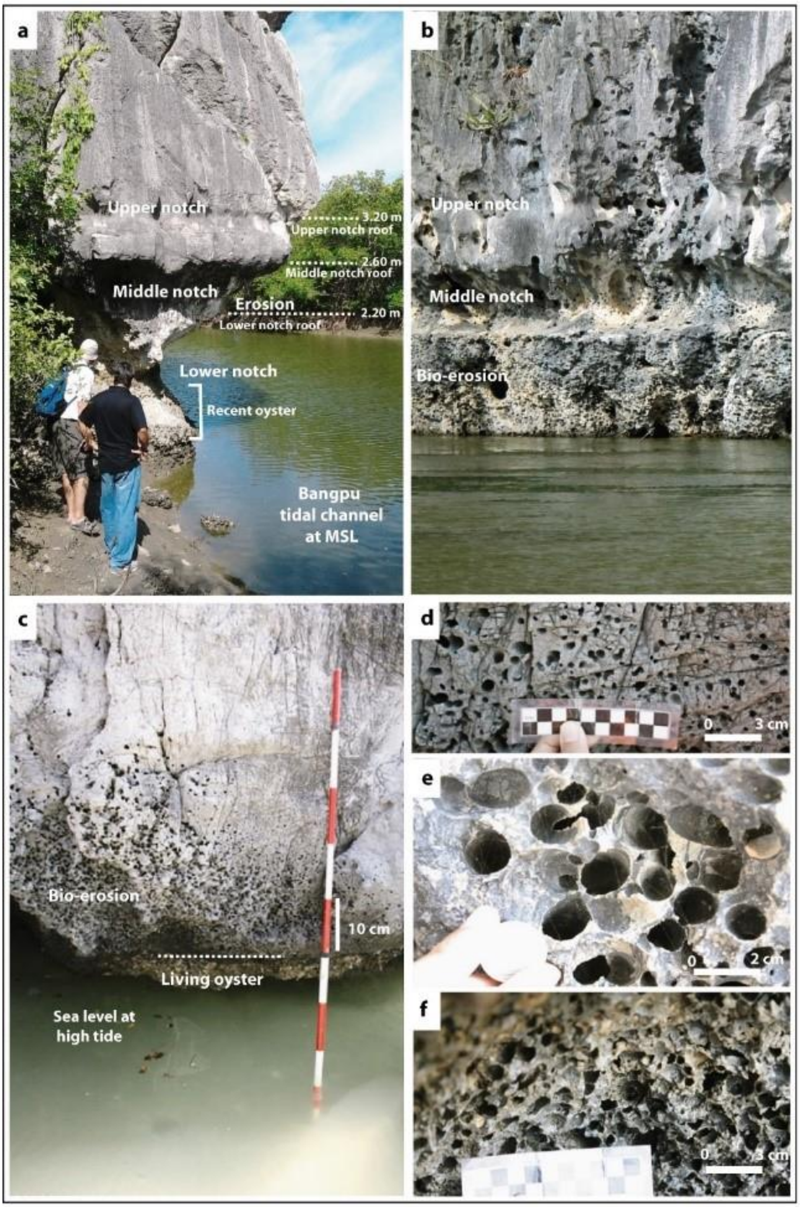

FIGURE 3. Photographs of different levels of sea notches as well as bio-construction and erosions in notches. (a and b) Three levels of notches at Bangpu tidal channel. Middle notch was scoured by the lower one, (c) limestone headland with bio-erosion (*Lithophaga* boreholes) and bio-construction (living oyster), (d, e and f) close-up of *Lithophaga* boreholes.

Geological and biological indicators of sea level change

Sea notch

Permian limestone terrain dominated, as a karst mountainous area, the middle part of the SRYNP and at the headlands in the eastern part. Tidal notches, which are formed when the sea level remains relatively stable, have been used as a sea level indicator in microtidal marine areas,

TABLE 3. Radiocarbon (^{14}C) dating of oysters attached to the notch walls.

Sample no.	Notch level	Altitude (m a MHW)	Material	Conventional age (y BP)	Cal. age (a BP) (2SD)	Mean cal. age (a BP)
Khao Thian						
O-01	Middle	2.0	Oyster	3400±170	2789–3610	3216
Ban Khung Tanot						
O-02	Lower	1.0	Oyster	2480±150	1714–2477	2100
Ban Thung Noi						
O-03-1	Middle	1.4	Oyster	5160±160	5062–5854	5476
O-03-2	Middle	1.2	Oyster	2140±210	1255–2202	1702
O-03-3	Lower	1.0	Oyster	1380±150	641–1216	902
Khao Khwang						
O-04	Middle	2.0	Oyster	2680±200	1858–2806	2352
Khao Luk Klom						
O-05	Middle	2.5	Oyster	3090±110	2596–3159	2851
Ban Bang Pu						
O-06-1	Middle	2.6	Oyster	780±180	45–633	366
O-06-2	Middle	2.3	Oyster	1060±180	288–940	617
O-06-3	Middle	2.0	Oyster	2420±120	1741–2314	2028

for example, in the Mediterranean (Pirazzoli, 2005; Pirazzoli and Evelpidou, 2013) and along the GoT coast (Choowong, 2002, 2011; Choowong et al., 2004). At least three distinctive levels of sea notches are common at the base of the limestone cliffs in the SRY area (Fig. 3a). The highest notch, generally less incised than the lower one, was located as far as 3 km inland and had no bio-construction features. The distance between the roof and base is about 45 cm, with 10 cm vertex (Fig. 3b). The highest sea notch level is on average 2.67 m above the present mean tide level (Dusitapirom et al., 2008). Bio-construction, especially oysters, was recognized in the middle and lowest sea notch level (Fig. 3c). Results of ^{14}C dating from the oysters attached to the sea notch wall are shown in Table 3. At the shore and in places where tidal channels are located, only the lowermost notch is actively formed.

Bio-erosion

At the base of the limestone headland, bio-erosion (borings) was recognized (Fig. 3c). Bio-erosion in sea notches, formed by organisms living in the wave zone, can be used to infer the maximum tidal range (Kelletat, 1997). Evidence of bio-erosion (bio-corrosion and bio-abrasion), including the grazing traces of chitons and bivalves (*Lithophaga*), was found at SRY, and was similar to the fauna found at the Andaman coast (Kázmér and Taboroši, 2012; Scheffers et al., 2012). Chiton grazing trails and *Lithophaga* boreholes were recognized above the roof of an active notch (Fig. 3d–f).

Taxonomic identification of shell fauna

A total of 57 molluscan species (12 Gastropoda and 45 Bivalvia) belonging to 45 genera and 31 families (Figs. 4 and 5), were classified from the 10 sampled localities (M1–10; Fig. 1). *Anadara inaequivalvis*, *Anadara pilula*, *Saccostrea*

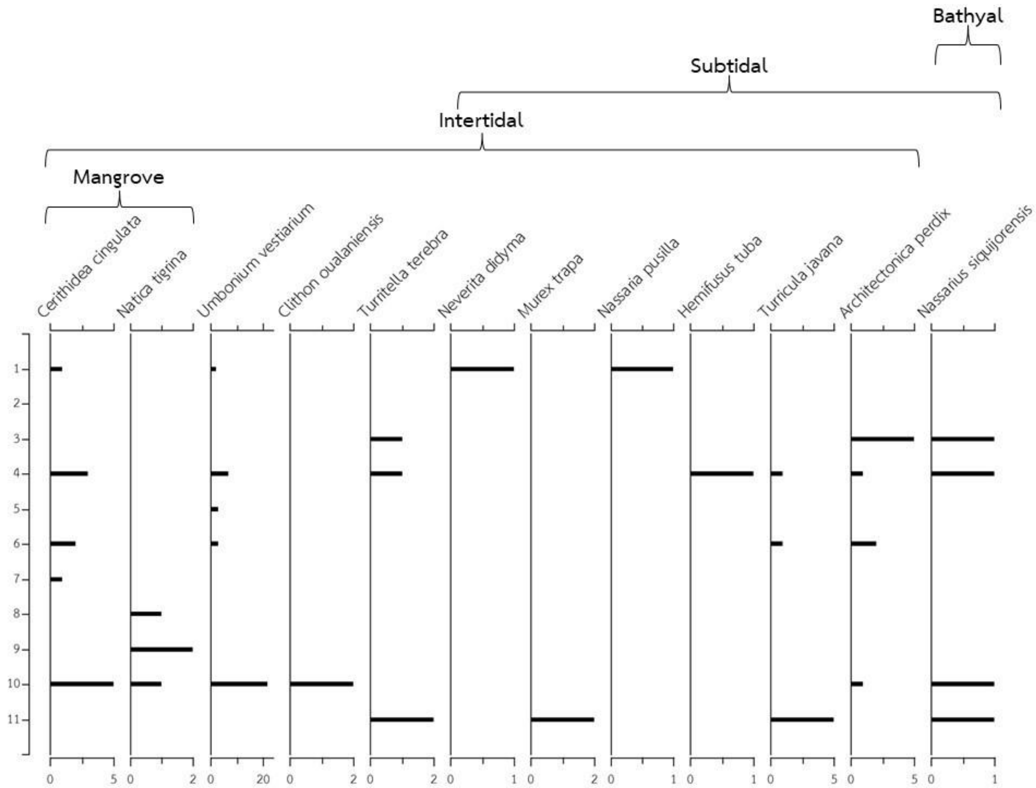

FIGURE 4. Chart of Gastropoda sorted by habitat (number). X-axis is the species of Mollusca and the Y-axis is the sample location.

cucullata, *Anomalocardia squamosal*, *Meretrix meretrix* and *Dosinia cretacea* were found in most areas, indicating a mangrove environment to the intertidal zone (Tables 4–6). All of these species are marine mollusks that lived in the Holocene (Surakiatchai, 2006; Robba et al., 2002, 2004, 2007) (Plates 1–5, in Appendix). The occurrence of fauna from location M8 indicated that the paleo-shoreline was located about 4 km inland from the recent shoreline.

DISCUSSION AND CONCLUSION

Middle to late Holocene paleogeography

Paleogeographic reconstructions of the inland coastal zone of the GoT, from the Central Plains of Thailand, have rarely been published (Umitsu et al., 2002). Coastal landforms around the GoT are somewhat different from those recognized along the west coast of Thailand (Andaman Sea coast). The GoT is classified as a depositional coast with a distinct sequence of beach ridges, lagoons with broad marsh plains and tidal flats (Choowong, 2011). Along the coast of GoT, a few paleo-shoreline delineations have been reported,

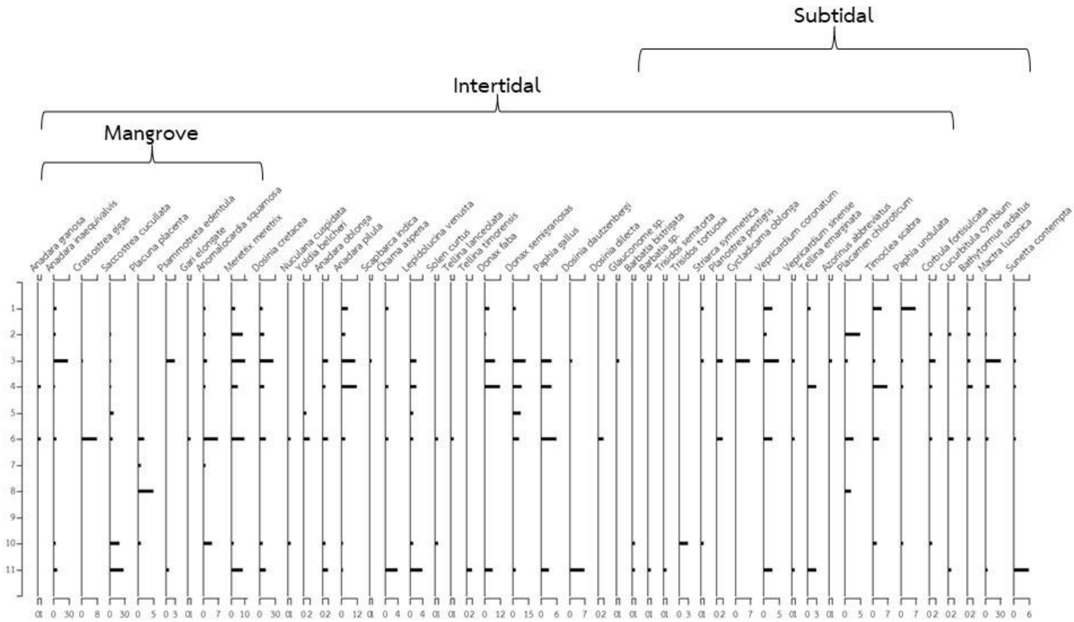

FIGURE 5. Chart of Bivalvia sorted by habitat (number). X-axis is the species of Mollusca.

such as at SRY (Chalermlarp, 1996) and Chumphon (Phantuwongraj et al., 2010; Nimnate et al., 2015). The most extensive invasion by the sea occurred in the central plain of Thailand, where the Holocene transgression reached as far as 70 km north of Bangkok (Nutalaya and Rau, 1981). Within peninsula Thailand, the furthest landward transgression occurred at the east coast at Nakon Srithammarat, and reached about 40 km inland from the present shoreline (Choowong, 2011).

In this paper, we approximately determined the boundary of paleo-coastal landforms in relation to the gradual regression of sea level from the middle to late Holocene (Fig. 6). Considering the aerial photograph taken in 1968 (Fig. 2), the land has been modified (Fig. 6A–D). Khao Daeng canal has supplied sediment to the

TABLE 4. Summary of mollusks and their environment in the study area.

Area	Species (Gastropoda/Bivalvia)	Depositional environment
M1	20 (4/16)	Intertidal to subtidal
M2	14 (0/14)	Intertidal (mangrove)
M3	32 (3/29)	Intertidal to subtidal
M4	27 (7/20)	Intertidal
M5	5 (1/4)	Intertidal
M6	34 (4/30)	Intertidal
M7	3 (1/2)	Intertidal (mangrove)
M8	4 (1/3)	Intertidal (mangrove)
M9	1 (1/0)	Intertidal (mangrove)
M10	23 (6/17)	Intertidal

TABLE 5. Number of Gastropoda found in the 10 study sites.

Species	Area									
	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**
Architectonica perdix	0	0	5	1	0	2	0	0	0	1
Cerithidea cingulata	1	0	0	3	0	2	1	0	0	5
Clithon oualaniensis	0	0	0	0	0	0	0	0	0	2
Hemifusus tuba	0	0	0	1	0	0	0	0	0	0
Murex trapa	0	0	0	0	0	0	0	0	0	2
Nassaria pusilla	1	0	0	0	0	0	0	0	0	0
Nassarius siquijorensis	0	0	1	1	0	0	0	0	0	2
Natica tigrina	0	0	0	0	0	0	0	1	2	1
Neverita didyma	1	0	0	0	0	0	0	0	0	0
Turricula javana	0	0	0	1	0	1	0	0	0	5
Turritella terebra	0	0	1	1	0	0	0	0	0	2
Umbonium vestiarium	2	0	0	7	3	3	0	0	0	22

coast (Fig. 6A), where traces of the subaqueous sand bar at the mouth of Khao Daeng canal were also observed (Fig. 6B). The inlet/outlet of the SRY swamp is located far inland between limestone hills (Fig. 6C), and was used to help to delineate the boundary of the paleo-shorelines, where the paleo-coastal bay and tombolo 1 were located far inland, as shown in Figure 2. Figure 6D shows the trace of wash-over sediment and submerging and emerging sand bars in transition at the shore.

The mollusks (Figs. 4 and 5) also provided evidence of the paleo-environment found inland, including bathyal, subtidal, intertidal and mangrove. They are extant species and their frequency and distribution helped to confirm the paleo-landforms of the area. The recognition of the paleo-bay and former tombolo highlights the better understanding of the paleo-geographical evolution of the area in relation to the records of sea level changes in Thailand.

History of sea level changes

Episodic coastal plain evolution in relation to sea level changes has been reported from many parts of the Thai-Malay peninsula (Geyh et al., 1979; Tjia, 1996; Hesp et al., 1998; Mallinson et al., 2014; Culver et al., 2015). Sedimentological, paleontological and geomorphological evidence helped to define the Holocene coastal evolution of the Setiu wetland region, part of the lower Thai-Malay peninsula, in the last 7 millennia (Mallinson et al., 2014), where a rapid sea level rise is suggested to have occurred between 5,700 and 3,000 y ago. Along the limestone and granite coasts of the Phang-nga Bay and Phuket (Andaman Sea), bio-erosive notches, benches of rock oysters, belts of boring bivalves and boring sea-urchins, as well as coral colonies have been recognized. Since they occur in recent as well as dead or inactive formations, they were used to precisely determine the past sea levels (Scheffers et al., 2012).

TABLE 6. Number of Bivalvia found in the 10 study sites.

Species	Area									
	M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**
Anadara granosa	0	0	0	1	0	1	0	0	0	0
Anadara inaequivalvis	6	4	28	3	0	7	0	0	0	13
Anadara oblonga	0	0	2	1	0	2	0	0	0	3
Anadara pilula	5	3	11	12	0	3	0	0	0	2
Anomalocardia squamosa	1	1	2	1	0	7	1	0	0	4
Azorinus abbreviatus	0	0	1	0	0	0	0	0	0	0
Barbatia bistrigata	0	0	0	0	0	0	0	0	0	2
Barbatia sp.	0	0	0	0	0	0	0	0	0	1
Bathytormus radiatus	1	1	1	2	0	1	0	0	0	0
Chama aspersa	1	0	0	1	0	1	0	0	0	4
Corbula fortisulcata	0	1	2	1	0	1	0	0	0	1
Crassostrea gigas	0	0	1	0	0	8	0	0	0	0
Cucurbitula cymbium	0	1	0	0	0	2	0	0	0	1
Cycladicama oblonga	0	0	7	0	0	0	0	0	0	0
Donax faba	4	1	8	12	0	0	0	0	0	6
Donax semigranosas	3	0	13	9	8	6	0	0	0	3
Dosinia cretacea	6	9	27	10	0	13	0	0	0	20
Dosinia dautzenbergi	0	0	1	0	0	0	0	0	0	7
Dosinia dilecta	0	0	0	0	0	2	0	0	0	0
Gari elongate	0	0	0	0	0	1	0	0	0	0
Glauconome sp.	0	0	1	0	0	0	0	0	0	0
Lepidolucina venusta	0	0	2	2	1	1	0	0	0	5
Mactra luzonica	2	3	32	8	0	6	0	0	0	5
Meretrix meretrix	3	9	11	5	0	10	0	0	0	11
Nuculana cuspidata	0	0	0	0	0	1	0	0	0	1
Paphia gallus	0	0	4	4	0	6	0	0	0	3
Paphia undulata	7	0	1	1	0	0	0	0	0	1
Placamen chloroticum	0	5	1	0	0	3	0	2	0	0
Placuna placenta	0	0	0	0	0	2	1	5	0	1
Planostrea pestigris	0	0	2	0	0	2	0	0	0	0
Psammotreta edentula	0	0	3	0	0	0	0	0	0	1
Saccostrea cucullata	0	4	4	4	9	7	0	1	0	49
Scapbarca indica	0	0	1	0	0	0	0	0	0	0
Solen curtus	0	0	0	0	0	1	0	0	0	1
Striarca symmetrica	1	0	1	0	0	0	0	0	0	1
Sunetta contempta	1	1	1	1	0	1	0	0	0	6
Tellina emarginata	1	0	0	3	0	0	0	0	0	3
Tellina lanceolata	0	0	0	0	0	1	0	0	0	0
Tellina timorensis	0	0	0	0	0	0	0	0	0	2
Timoclea scabra	4	0	1	7	0	3	0	0	0	2
Trisidos semitorta	0	0	0	0	0	0	0	0	0	1
Trisidos tortuosa	0	0	0	0	0	0	0	0	0	3
Vepricardium coronatum	3	1	5	0	0	3	0	0	0	3
Vepricardium sinense	0	0	1	0	0	1	0	0	0	1
Yoldia belcheri	0	0	0	0	1	2	0	0	0	0

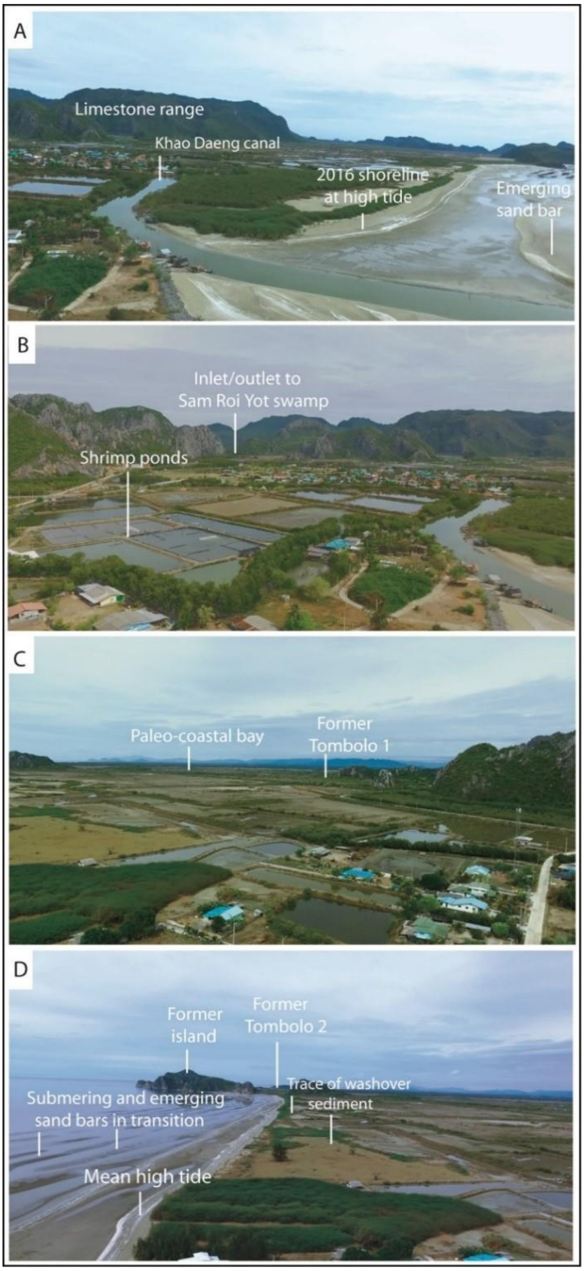

FIGURE 6. Oblique view of the recent morphology of the barrier system. (A) Khao Daeng canal is the main transport route supplying land sediment to the coast. Trace of present normal high tide in 2016 and subaqueous sand bar were also observed (looking northwest). (B) Inlet/outlet to SRY swamp is located far inland between limestone hills (looking northwest). (C) Locations of paleo-coastal bay and tombolo 1 are located far inland (looking southwest). (D) Trace of wash-over sediment and submerging and emerging sand bars in transition at the shore (looking south).

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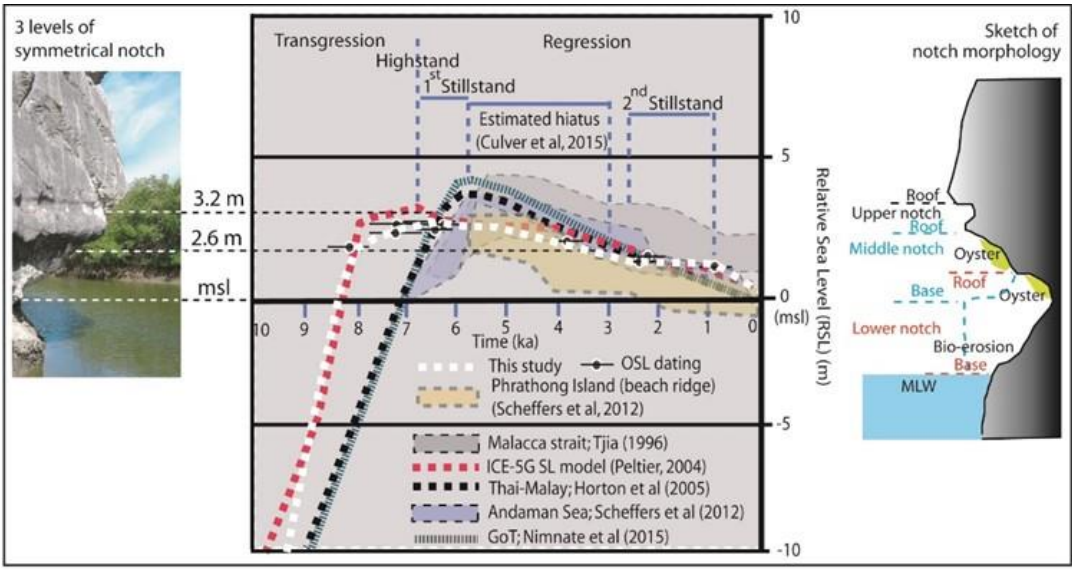

FIGURE 7. Compilation of sea level curves from Southeast Asia and South China Sea. Three levels of sea notch (left) and sketch of notch morphology (right) showed correlation with sea level curve. Proposed sea level curve derived from this study shows in white dash-line.

Sedimentological and palynological investigations from the Great Songkhla Lake (middle peninsula) revealed that the area was one of the earliest mangrove environments in Southeast Asia (8,420–8,190 cal. y BP), which was subsequently replaced by a freshwater swamp at 7,880–7,680 cal. y BP, owing to the decline of marine influence (Horton et al., 2005). Sea level observations from the Great Songkhla Lake and the other areas of the Malay-Thai Peninsula also revealed an upward trend in the Holocene relative sea level from a minimum of -22 m at 9,700–9,250 cal. y BP to a mid-Holocene high stand of 4,850–4,450 cal. y BP, which equates to a rise of c. 5.5 mm/y (Horton et al., 2005). In the Chumphon estuary, located in the upper part of the Thai peninsula, a series of beach ridge plains, which formed as a spit, were recognized as far as 10 km inland from the present shoreline. Progradation of beach ridge plains started after the sea had reached a highstand at around 6,500 cal. y BP (Nimnate et al., 2015).

In this paper, the relative sea level curves from the Thai-Malay peninsula were compiled (Fig. 7). We also propose a revised relative sea level curve from SRY based on ^{14}C radiocarbon and OSL dating (Fig. 7). We used the plotted OSL ages (y in BP) of beach ridge sands to reconstruct the sea level curve. The OSL errors were acceptable (less than 10%) and the elevation of dated sands was measured by precise survey camera. The obtained curve corresponded well with the ICE-5GSL model proposed by Peltier (2004). The ^{14}C dating results of fossils from the innermost to the outer parts of the former tidal flat within the former tombolo 1 (Fig. 1) provided ages of 7,360 ± 420, 2,200 ± 270 and 1,520 ± 250 y BP, respectively, (Surakiatchai, 2006). The ^{14}C radiocarbon dating results from this study of oysters from the sea notch walls provided at least

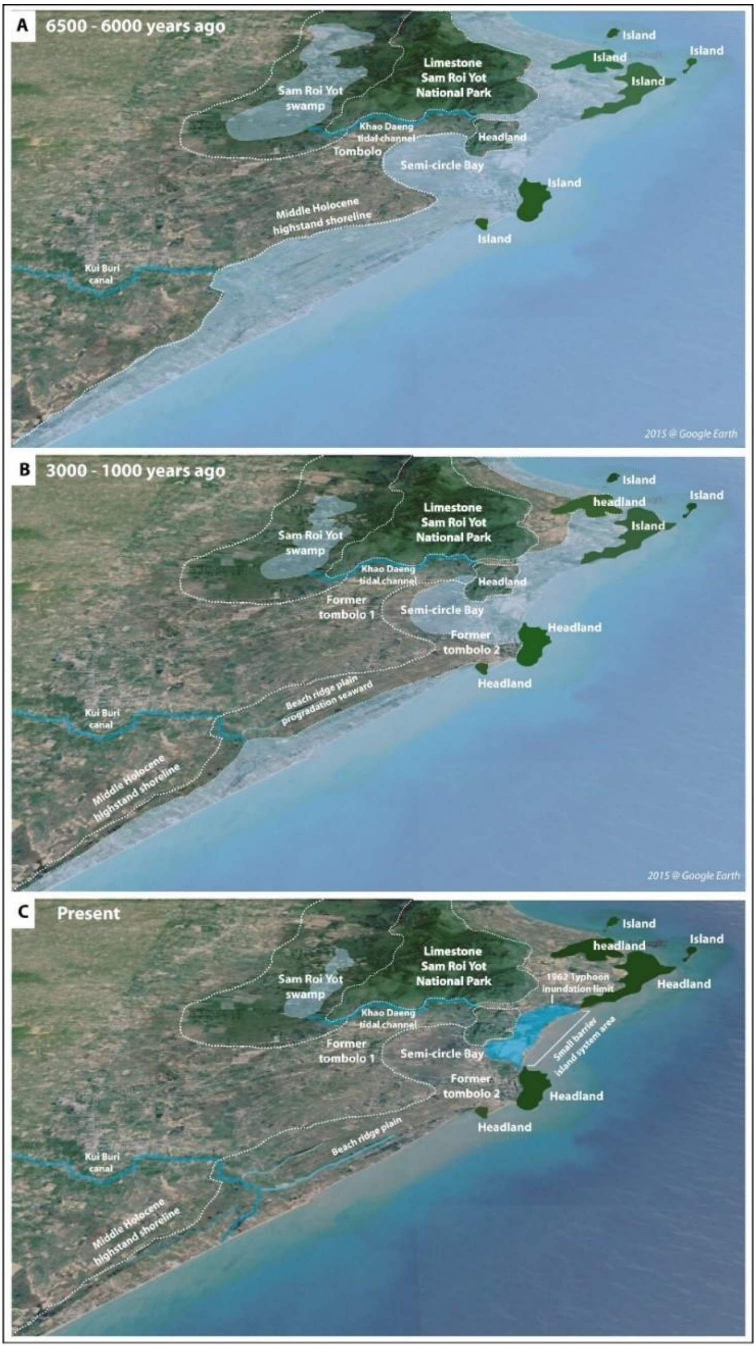

FIGURE 8. Reconstruction of paleogeography from the SRYNP. Background satellite image was taken from Google Earth.

the period of time the oysters lived in and tentatively reflected two breaks in the gradual regression, times when the sea level had been stable or come to a standstill. The sea level reached a highstand about 6,500 y ago (Fig. 8A) and presumably stagnated for 500–1,000 y, leading to the formation of the upper notch. The highstand was at 3–4 m height above the present MSL, as evidenced from the small uppermost sea notch. The lack of oysters in the upper notch is probably due to the small curvature of the notch, which was an unsuitable environment for the oysters to live in. The upper notches found inland (Fig. 2a and b) were possibly formed at the limestone base during the highstand.

The OSL dating data also unveiled the initiation of an extensive progradation of beach ridge plain around 6,000 y ago. A series of continuous beach ridges reflect the start of a continuously falling sea level from 6,000 until 3,000 y ago, leading to the extensive progradation of the beach ridge plain. The sea level seems to have remained stable once again from 3,000 to 900 y ago (Fig. 8B). Middle notches, with living oysters, and large swale, between beach ridges, were formed during this second stable sea level period. The OSL-dated beach ridge sand contained shells, which indicated the gradual progradation of the beach during the marine regression. The ^{14}C ages of the oyster fossils also indicated the time of gradual regression, and agreed with the results from dating shells in the beach ridge (Choowong et al., 2004).

This study aimed to reconstruct the paleogeography and history of sea level change during the Holocene from the east coast of the GoT. At SRYNP, evidence of sea level change was deduced from paleo- and recent landforms. A series of aerial photographs from different periods of time provided clues of the paleo-landforms and led us to a better understanding of the paleogeography of this well-preserved coastal environment. Overall, the physical and biological evidence coupled with a good chronology from this area unveiled the history of the sea level change, both transgressive and regressive formations. The set of innermost beach ridges is a significant transgressive formation, reported for the first time in this study. The OSL dating showed the progradation of beach ridges landwards after the sea reached a highstand around 6,500 years ago. The formation of solution sea notches, bio-erosion at the base of limestone and ^{14}C dating of oyster fossils, attached to sea notch walls, are all physical and biological clues to confirm the sea level at different periods of time. All the geological, geomorphological and biological evidence guided us to a successful reconstruction of the paleogeography, in close relation to the history of sea level change.

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APPENDIX

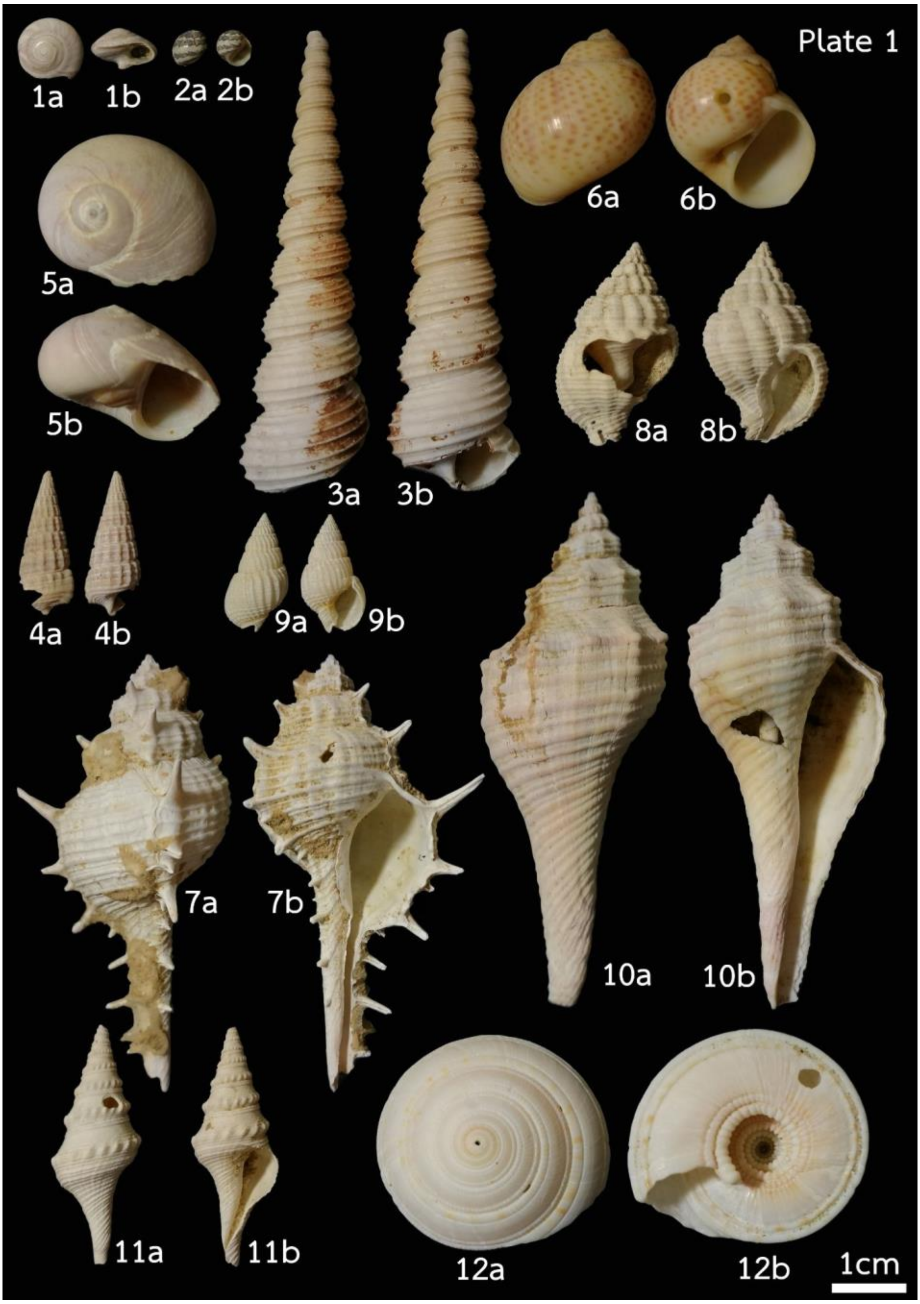

PLATE 1. Mollusca collected from the study areas 1) *Umbonium vestiarium*, 2) *Clithon oualaniensis*, 3) *Turritella terebra*, 4) *Cerithidea cingulate*, 5) *Neverita didyma*, 6) *Natica tigrina*, 7) *Murex trapa*, 8) *Nassaria pusilla*, 9) *Nassarius siquijorensis*, 10) *Hemifusus tuba*, 11) *Turricula javana* and 12) *Architectonica perdix*.

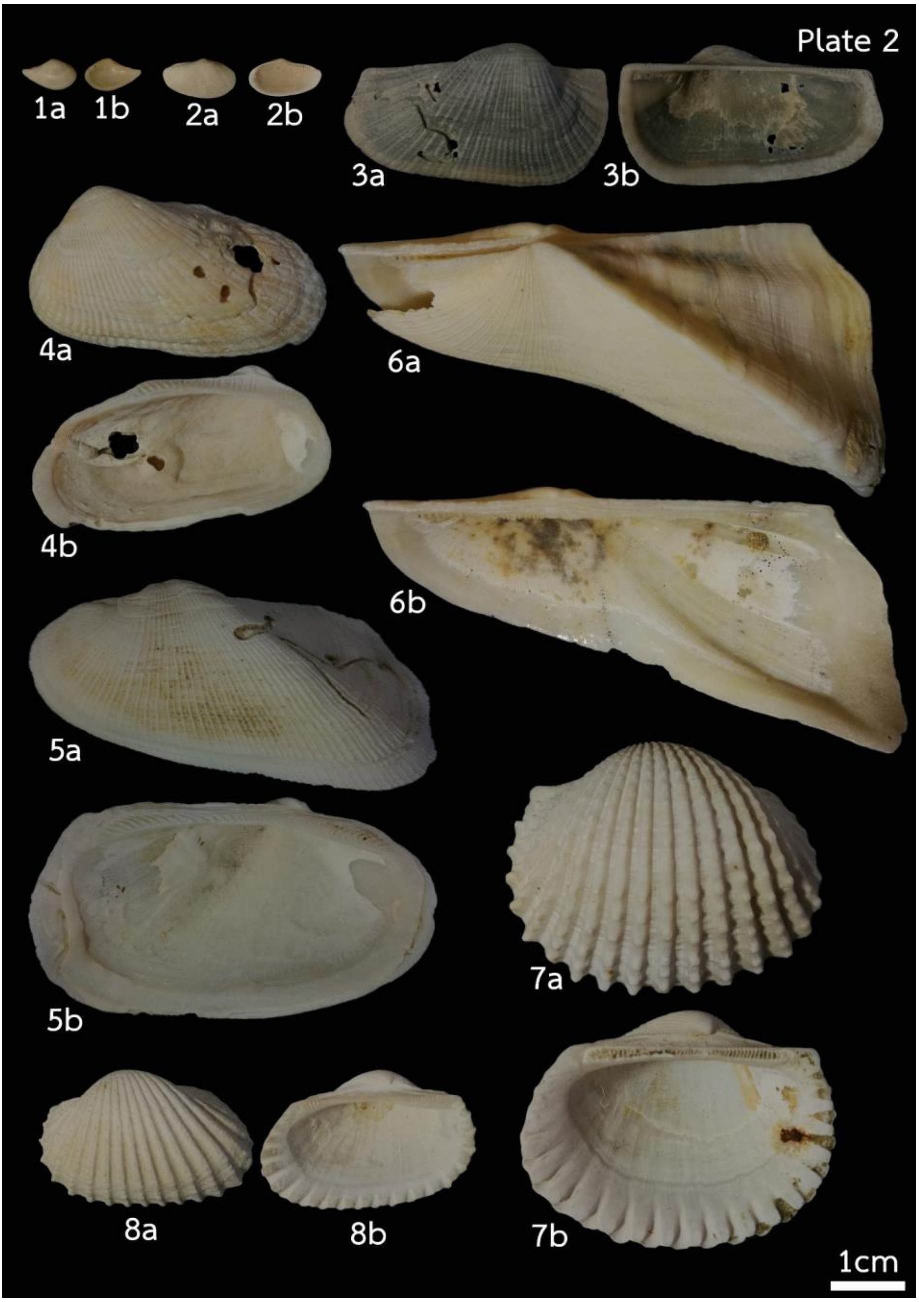

PLATE 2. Mollusca collected from the study areas 1) *Nuculana cuspidata*, 2) *Yoldia belcheri*, 3) *Barbatia bistrigata*, 4) *Barbatia* sp., 5) *Trisidos semitorta*, 6) *Trisidos tortuosa*, 7) *Anadara granosa* and 8) *Anadara oblonga*.

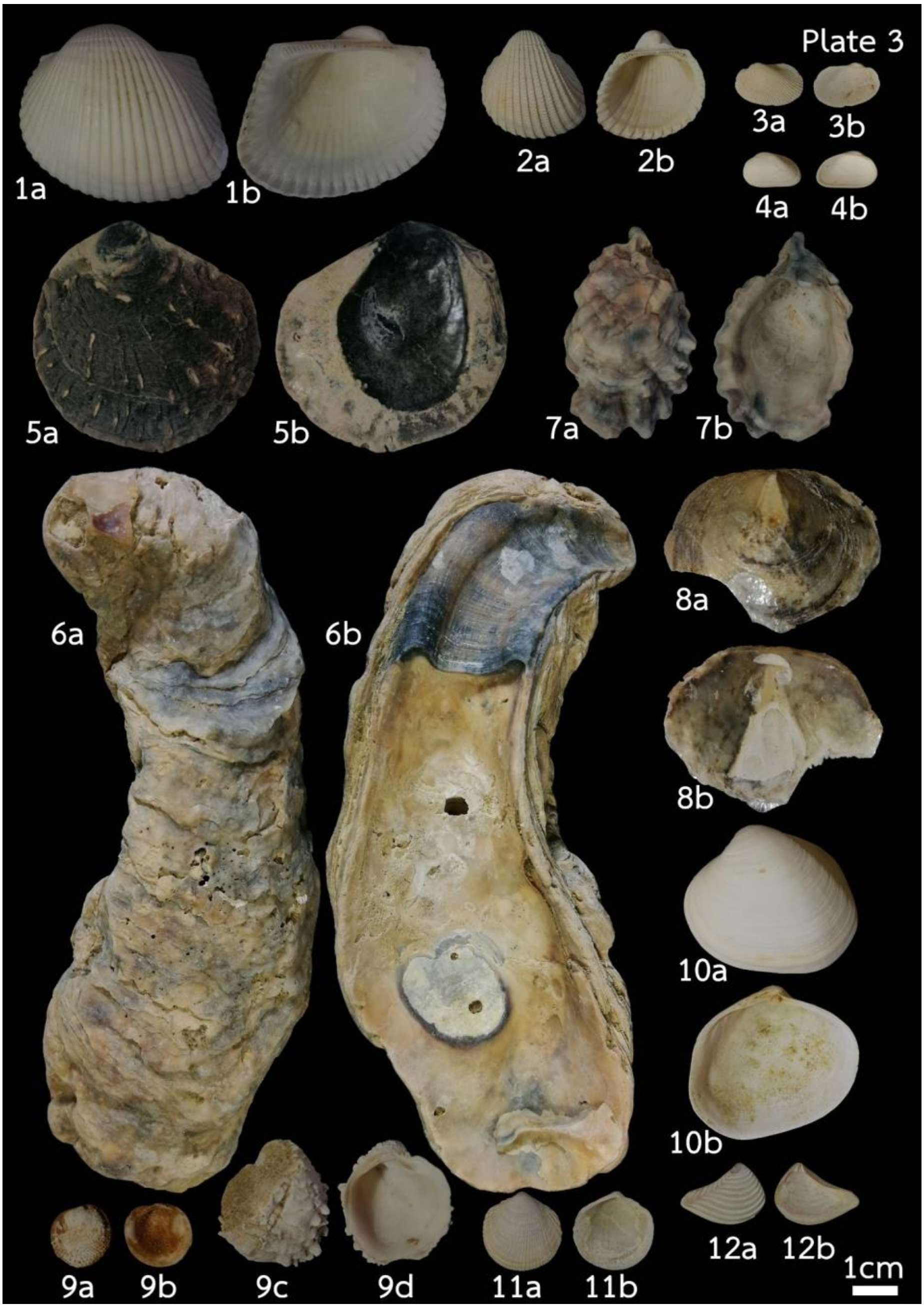

PLATE 3. Mollusca collected from the study areas 1) *Anadara inaequivalvis*, 2) *Anadara pilula*, 3) *Scapbarca indica*, 4) *Striarca symmetrica*, 5) *Planostrea pestigris*, 6) *Crassostrea gigas*, 7) *Saccostrea cucullata*, 8) *Placuna placenta*, 9) *Chama aspersa*, 10) *Cycladicama oblonga*, 11) *Lepidolucina venusta* and 12) *Bathytormus radiates*.

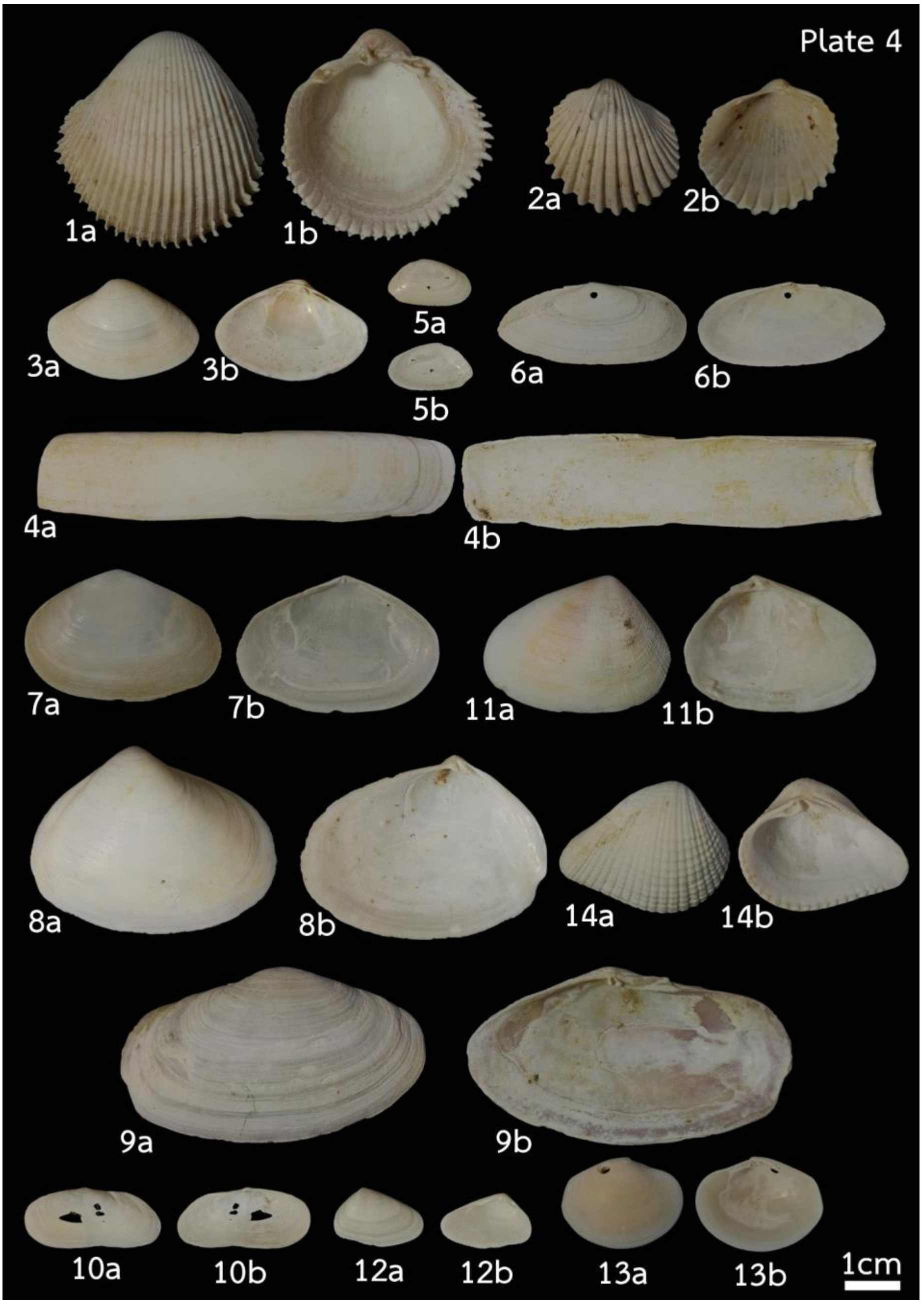

PLATE 4. Mollusca collected from the study areas 1) *Vepricardium coronatum*, 2) *Vepricardium sinense*, 3) *Mactra luzonica*, 4) *Solen curtus*, 5) *Tellina emarginata*, 6) *Tellina lanceolata*, 7) *Tellina timorensis*, 8) *Psammotreta edentula*, 9) *Gari elongate*, 10) *Azorinus abbreviatus*, 11) *Donax faba*, 12) *Donax semigranosas*, 13) *Sunetta contempta* and 14) *Anomalocardia squamosa*.

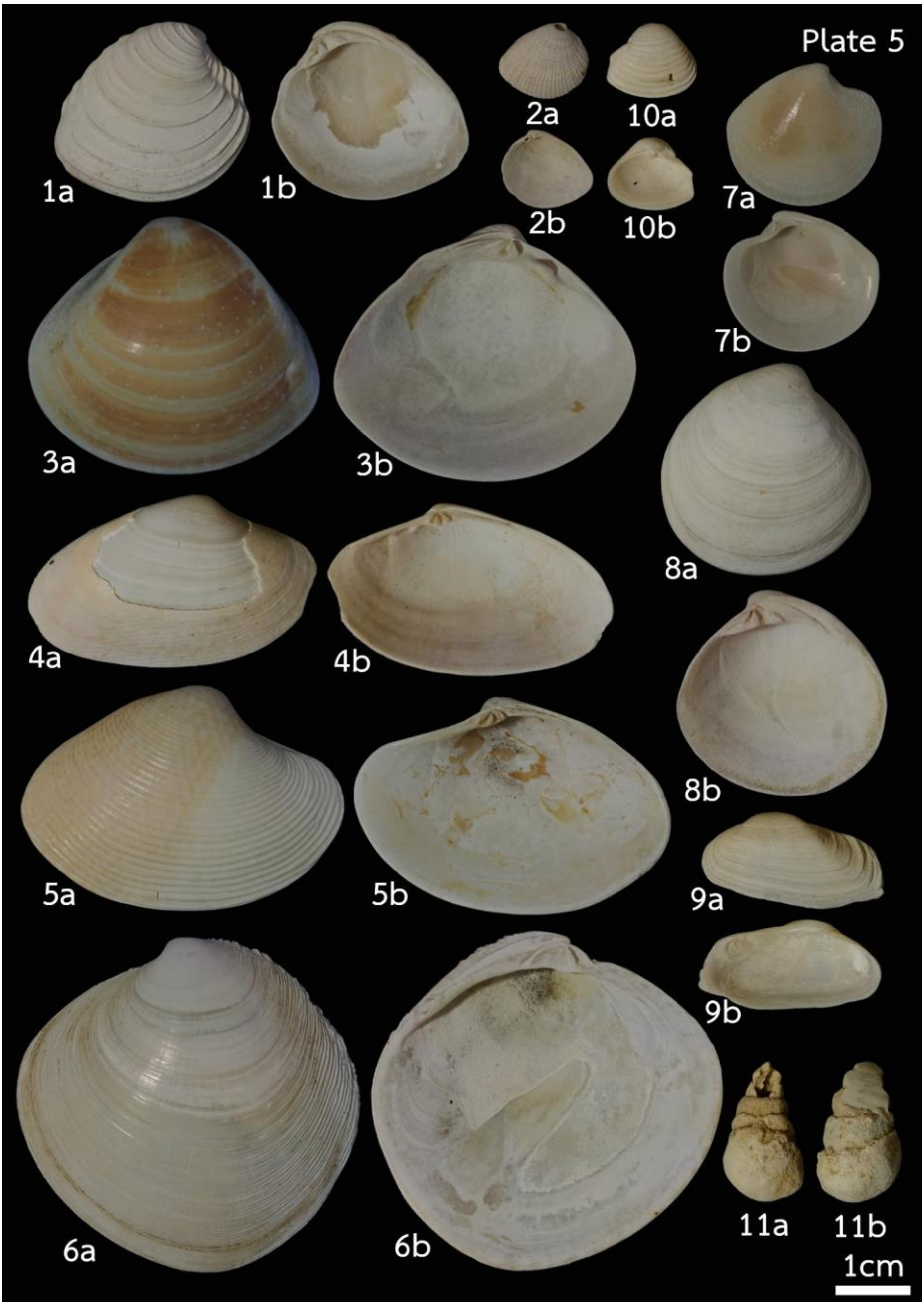

PLATE 5. Mollusca collected from the study areas 1) *Placamen chloroticum*, 2) *Timoclea scabra*, 3) *Meretrix meretrix*, 4) *Paphia undulata*, 5) *Paphia gallus*, 6) *Dosinia cretacea*, 7) *Dosinia dautzenbergi*, 8) *Dosinia dilecta*, 9) *Glauconome* sp., 10) *Corbula fortisulcata* and 11) *Cucurbitula cymbium*.