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Beach recovery after 2004 Indian Ocean tsunami from Phang-nga, Thailand

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A B S T R A C T

The 2004 Indian Ocean tsunami devastated the coastal areas along the Andaman western coast of Thailand and left unique physical evidence of its impact, including the erosional landforms of the pre-tsunami topography. Here we show the results from monitoring the natural recovery of beach areas at Khuk Khak and Bang Niang tidal channels of Khao Lak area, Phang-nga, Thailand. A series of satellite images before and after the tsunami event was employed for calculating the beach area and locating the position of the changed shoreline. Field surveys to follow-up the development of the post-tsunami beach area were conducted from 2005 to 2007 and the yearly beach profile was measured in 2006. As a result, the scoured beach areas where the tidal channel inlets were located underwent continuous recovery. The return of post-tsunami sediments within the beach zone was either achieved by normal wind and wave processes or during the storm surges in the rainy season. Post-2004 beach sediments were derived mainly from near offshore sources. The present situation of the beach zone has almost completed reversion back to the equilibrium stage and this has occurred within 2 years after the tsunami event. We suggest these results provide a better understanding of the geomorphological process involved in beach recovery after severe erosion such as by tsunami events.

1. Introduction

The 2004 Indian Ocean tsunami, triggered by the Mw 9.1–9.3 Sumatra–Andaman earthquake (Lay et al., 2005; Okal and Titov, 2007), devastated the coastal areas of the Indian Ocean countries. The tsunami extended across the Indian Ocean to damage the beach area of the Andaman coast of Thailand and left behind unique physical evidence of its impact, made up of the vast areas of erosional landforms of the pre-tsunami topography. In particular, the beach zone between the Pakarang Cape and the Khao Lak, Phang-nga province, was one of the severely affected areas in Thailand. The morphology of beach zone changed suddenly and the extensive scoured features remained both on the beach and in the embayment of tidal channels. The position of the normal coastline was shifted inland causing the lowering of beach elevation and the loss of beach sediments. Clearly, tidal inlet/outlets and the banks of the channels were opened wider to a distance of about 1 km inland (e.g. Choowong et al., 2007; Fagherazzi and Du, 2007). Thus, the monitoring of the beach and tidal zones during the natural recovery of the beach area after the tsunami event until the beach returned to a normal situation is essential to better understand the geomorphological beach recovery process following severe erosion.

A considerable and diverse array of satellite images displaying the aerial comparison of the beach zones before and after the tsunami were quickly published a few days after the 26th December 2004, including images detected by the IKONOS satellite during the event from Sri Lanka, and after the event from Indonesia and Khao Lak area of Phang-nga, Thailand (e.g., CRISP, 2004; GISTDA, 2005; NASA, 2005). Thereafter, the scoured features from beach zone both generated by the tsunami inflows and the outflows have been reported from India (Chadha et al., 2005), Sri Lanka (Papadopoulos et al., 2006), Indonesia (Moore et al., 2006; Meilianda et al., 2007), Myanmar (Satake et al., 2006), and Thailand (Matsutomi et al., 2005; Szczucinski et al., 2005; Hori et al., 2007; Umitsu et al., 2007; Choowong et al., 2007, 2008a,b). To date, only a few reports on the detailed analysis of the erosional patterns within the scoured beach zone have been published, e.g. Indonesia (Meilianda et al., 2007) and Thailand (Fagherazzi and Du, 2007).

1.1. Study areas

In this paper, we selected the tidal inlet/outlet at Khuk Khak and Bang Niang to monitor the episodic changes of geomorphological landforms after the 2004 tsunami incisions (Fig. 1). Here, we show the systematic monitoring, and especially the spatial changes, in the beach area using a series of satellite images from 2002 to 2007.

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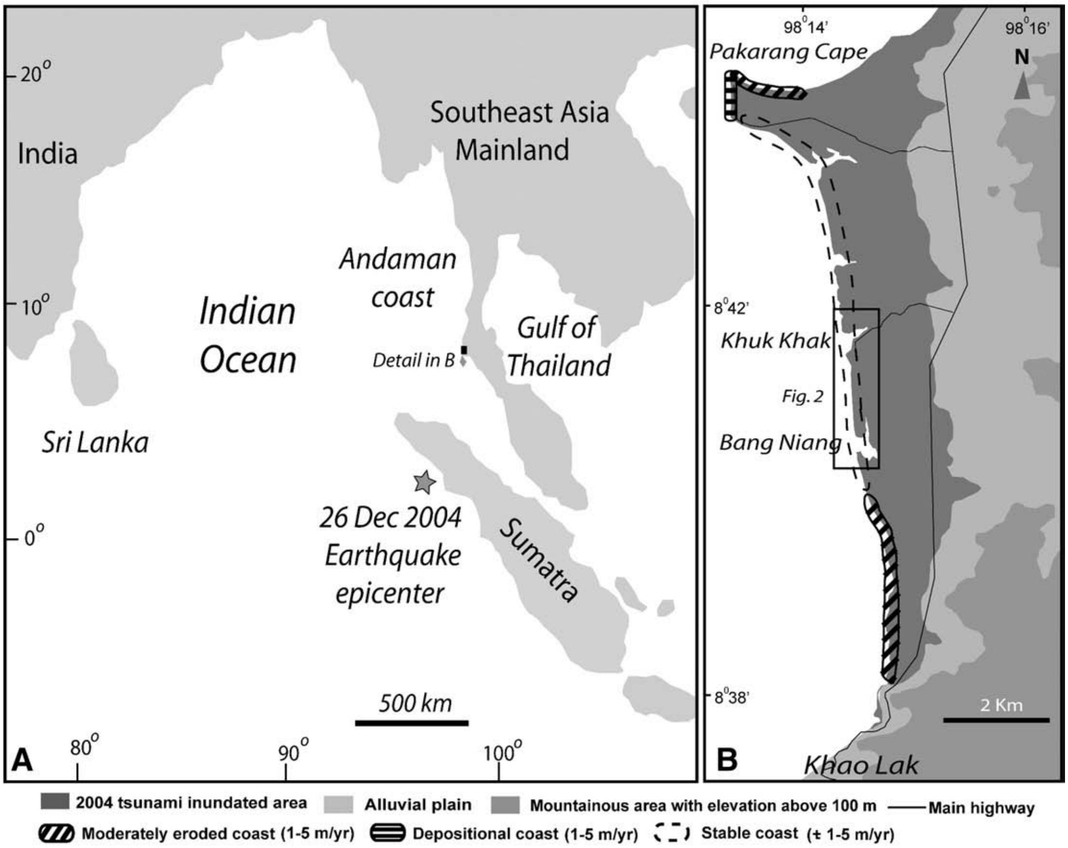

Fig. 1. Index maps of the area. (A) a regional map showing the 26th December 2004 earthquake epicenter and (B) close-up map showing 2004 tsunami inundation area and pre-tsunami coastal change characteristics (modified from Sinsakul et al., 2003) along Khao Lak to Pakarang Cape of Phang-nga, Thailand. The study areas, Khuk Khak and Bang Niang tidal channels, are indicated by the black square inset.

The hypothesis was made that these two opened inlet/outlet tidal channels provided a large accommodation space after the 2004 event and, therefore, beach sediments could be returned to maintain the equilibrium profile (e.g. Dean, 1991) within the beach zone. Spatial and temporal distributions of the beach areas and the rate of sediment returned were also tested. Field surveys to recognize the episodic changes of beach behavior have been made since 2005. The measurement of beach profiles was done throughout 2006. Additionally, surface sediments from the beach zone were characterized to document the yearly depositional cycle in 2006.

The area of beach recovery we evaluated in this paper extends from the south of Pakarang Cape to Khuk Khak, Bang Niang and Khao Lak beaches, on the western side of the Thailand peninsula. Khuk Khak and Bang Niang beaches are located between Pakarang Cape and Khao Lak in the Phang-nga province (8° 41′ north, 98° 14′ east). The coastal area from Pakarang Cape to Khao Lak has previously been classified into three types based on its erosional and accretional characteristics (Sinsakul et al., 2003) (Fig. 1B). Firstly, the coastal area from the southern part of Pakarang Cape, extending to where the tidal channel in the south is located, was characterized as a depositional coast with an accretion rate of 1–5 m/year. Secondly, the next southward area from the first tidal channel down to Bang Niang beach was defined as a stable coast with a depositional rate of ±1 m/year. Lastly, the area extending from Bang Niang beach to Khao Lak beach was identified as a moderately eroded coast with an erosional rate of 1–5 m/year. The two tidal channels we focused on in this study thus appeared to represent a depositional and stable coast before the tsunami event and became the most seriously eroded zone after the 2004 tsunami.

1.2. Climate and tidal conditions

The coastal area we investigated is located in a tropical climate with generally three seasons. The rainy season, from mid-May to November, is characterized by moderate to heavy rain. The southwest winds usually generate moderate waves about 0.3–1.5 m high. Conversely, during November to mid-February, the northeast monsoon presents a reversal of air movement and the waves are generally small with a height of lower than 2 m. The longshore current commonly flows from the south to the north. However, during the monsoon wind, wave heights of more than 5 m can be generated. Tides are semidiurnal with two high and low tides in 1 day, with an average tidal range of 1.55 m.

2. Materials and methods

2.1. Satellite images

A series of satellite images was used to analyze the gross change in shoreline position and beach area. We followed the most commonly used proxy for shoreline position, that is the high water line (HWL), as proposed in the literature (e.g. Stafford, 1971; Dolan et al., 1980; Leatherman, 1983; Anders and Byrnes, 1991; Crowell et al., 1991; Morton, 1991). In addition, to quantify the spatial distribution of the beach area and its changes, both the seaward and landward beach margins were digitized. The line of the high tide water mark and the edge of trees were used as the limiting boundary of the beach area. Satellite images from 2002 to 2007 at different time records were employed to estimate the spatial changes of the positions of coastline and

Table 1
Series of satellite images used in this paper

Date	Satellite	Acquisition time (Thai)	Tidal time[a]	Source
15/11/2002	ASTER	N/A	Low tide	NASA[b]
13/1/2003	IKONOS	11:11:49 AM	Low tide	CRISP[c]
1/3/2004	LANDSAT-5 TM	10:24:29 AM	Low tide	GISTDA
9/9/2004	LANDSAT-5 TM	10:29:09 AM	Low tide	GISTDA
29/12/2004	IKONOS	10:53:46 AM	N/A	GISTDA
30/12/2004	LANDSAT-5 TM	10:31:23 AM	N/A	GISTDA
31/12/2004	ASTER	N/A	N/A	NASA[b]
16/2/2005	LANDSAT-5 TM	10:32:03 AM	Low tide	GISTDA
5/4/2005	LANDSAT-5 TM	10:32:34 AM	High tide	GISTDA
29/6/2005	SPOT-5	11:13:26 AM	Low tide	GISTDA
16/3/2006	SPOT-5	11:11:30 AM	High tide	GISTDA
26/11/2006	SPOT-5	11:07:50 AM	High tide	GISTDA

N/A = Not Available.
[a] Tidal time compares with the nearest tides table at Ao Tab Lamu station, Phang-nga province.
[b] NASA = NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team. Data published at http://observe.arc.nasa.gov/nasa/exhibits/tsunami/.
[c] CRISP published at http://www.crisp.nus.edu.sg/tsunami/tsunami.html.

for the precise calculation of the eroded areas from the 2004 tsunami event within the foreshore and the backshore zones (Table 1). All satellite images were processed by Erdas Imagine 8.7 software and then ArcView 3.2a was utilized to calculate the beach area and to identify the morphological changes before and after the tsunami event.

2.2. Beach profiling and sediment sampling

We conducted a detailed field survey in early 2005 to map the regional morphological features in beach and tidal channel zones and then followed this with a yearly measurement of beach profiles, and sampling of beach sediment in 2006.

2.2.1. Beach profiling

An accurate time series of beach profile measurements is essential for any method used to decipher the shoreline erosion and accretion trends and also for tracking beach recovery after storms or severe events like a tsunami. Beach profiles were measured both perpendicular and parallel to the coastline with a normal 5 m interval between the surveyed points. Supplementary surveyed points were also measured in places where the micro-topography was investigated. The measurements of the vertical and lateral beach profiles and the angle of beach face and slope were carried out on four separate occasions throughout 2006 for our two investigated areas. The measurement of the beach profile was made in January (for Khuk Khak) and February (for Bang Niang), and in May, August and November for both localities, which represents the winter, summer, and rainy seasons, respectively. Local time series of water level during the measurement were also recorded for the conversion of profile levels to the level of mean tide.

2.2.2. Beach sediment sampling

Although any given beach can display a large range of sizes and shapes, we expected that each beach would be characterized by a particular texture and composition. Textural trends alongshore and cross-shore are indicative of the depositional energy and the stability or instability of the foreshore and nearshore zones (Larson et al., 1997). Surface sediments provide information about the energy of the environment as well as the long-term processes and movement of materials.

Surface samples of beach sediments were collected systematically and shallow pits were dug along the surveyed profiles. The bulk samples were grabbed within a 10 cm depth with a 20 m interval between pits. Likewise, the surface beach sediments were sampled on four occasions in 2006, similar to the times when the profiles were measured. Grain sizes were analyzed by a sieving method and the calculation of statistical parameters was based on the moment method (Folk and Ward, 1957). We also described the stratigraphy of the post-2004 beach deposits along the north–south profile of Khuk Khak area. The five representative stratigraphies were documented and the bulk samples of one depositional event were kept for analyzing the vertical distribution of grain size diameters. The aim of analyzing these stratigraphies was to elucidate the typical depositional sequences that likely represent the formation of a new beach as sand spit to the north alongshore. The sedimentary structures within the individual depositional event were also carefully observed and recorded as part of the stratigraphical correlation to distinguish the normal beach formation from storm process.

3. Results

3.1. Position of the coastline

The positions of pre-tsunami coastlines, measured from a series of satellite images during 2002 to 2004, show the equilibrium cycle on the beach zone at Khuk Khak and Bang Niang areas (Fig. 2A). Changes in the shoreline positions before the 2004 tsunami event were mainly responses to the seasonal change with a rate of deposition and accretion of ±1–5 m/year (Sinsakul et al., 2003). Three days after the 2004 tsunami, the position of coastline had changed, as indicated by traces of high tide and flood scour at the open tidal inlet (Fagherazzi and Du, 2007). The calculated change in position of the coastline

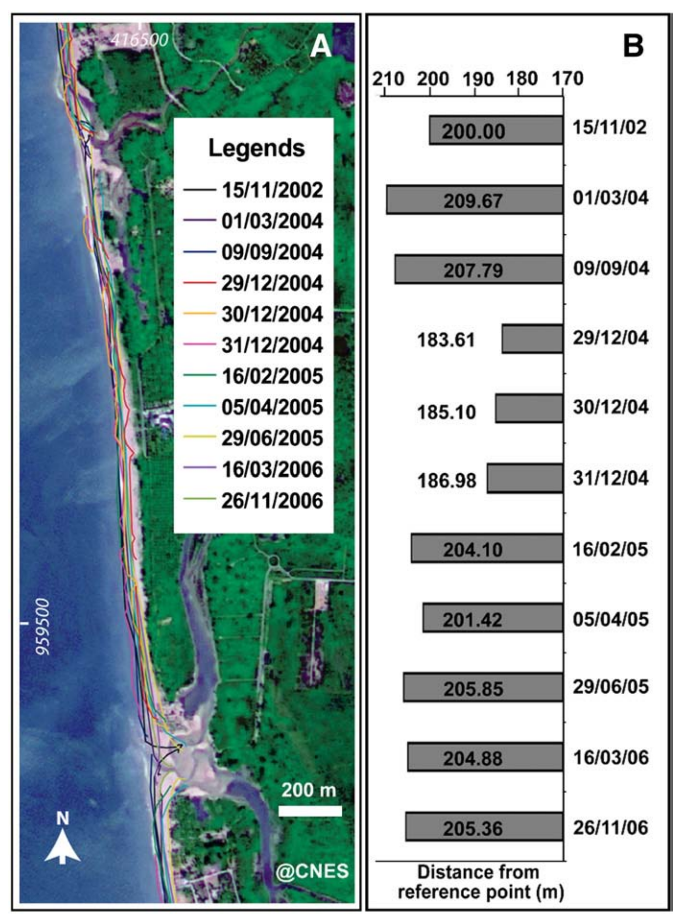

Fig. 2. (A) Series of shoreline positions overlain on SPOT-5 taken on November 2006 and (B) a diagram showing the positions of the shoreline changed from 2002–2006.

showed that it was moved 24.18 m inland. At the bottom of the tidal inlet, the sediments had almost disappeared. The low elevation of the remaining sediments was possibly due to deposition during the slow outflow following the tsunami (Choowong et al., 2008a). As a result, the widening of tidal inlet/outlet and channel banks produced a large accommodation space (Coe et al., 2003). This condition will have likely favored the trapping of new sediments with a likely faster rate of deposition than what we would have expected for a stable beach zone (Fig. 3B).

After the 2004 tsunami, the recovery of beach sediments rapidly prograded seaward, with a spatial accretionary distance of 20.49 m calculated from January to February 2005 (Fig. 2B). A rapid deposition within the first 2 months after the 2004 tsunami revealed that coastal process had played a dominant role in recovery of the beach areas and returned sediments back into a large accommodation space of the opened tidal channel. Thereafter, the rate of accretion slightly decreased and tended to become stabilized by November 2006 (Fig. 2). In conclusion, the average distance of the mean high tide shoreline to the reference point before the 2004 tsunami was 205.82 m, and this was reduced to 183.61 m by tsunami-induced erosion. However, within 2 years, which is by November 2006, the distance had returned to 204.32 m and has remained stable since then to date, leading us to conclude that the morphology of beach zone at Khuk Khak and Bang Niang areas had recovered by November 2006.

3.2. Calculation of beach area

The total beach area extending from Khuk Khak to Bang Niang before the 2004 tsunami was 86,660 m^2, as measured on November 2002 (Fig. 3A and E). The area decreased slightly to 72,680 m^2 in March and 70,560 m^2 in September 2004, which indicated the normal seasonal change within the equilibrium cycle of beach zone erosion and accretion. After the 2004 tsunami the beach area was reduced by essentially two thirds, to 23,790 m^2, compared to the pre-tsunami beach area on September 2004 (Fig. 3B and E). Thereafter, the beach area increased rapidly to 66,860 m^2 in 2 months (February 2005) and to 98,180 m^2 by November 2006 (Fig. 3C, D, and E). Interestingly, a number of beach areas calculated in November 2006 were slightly higher than the average area before the 2004 tsunami (Fig. 3E). Regardless, this situation of beach deposits again suggested that the beach area from Khuk Khak to Bang Niang was completely recovered.

3.3. Change in coastal landforms

The formation of sand spit in the Khuk Khak area from 2005 to 2006 showed a trend of deposition towards the north which reflected the northward longshore drift that dominates in this area (Fig. 4A to E). The position of the inlet at Khuk Khak was also shifted northwards along the direction of the spit growth, presumably mainly due to the influence of the dominant alongshore current. In the rainy season, small washover fans were found superimposed on the surface of the backshore slope some 100 m inland from the coastline (Fig. 4F). The traces of high-energy deposits were also recognized within the stratigraphy of the sand spit at Khuk Khak. In contrast, the formation of beach at Bang Niang area was characterized by a beach barrier with a flood tidal delta. The position of the channel bed at Bang Niang was changed laterally throughout 2006 due to meandering of the tidal channel. We observed at Bang Niang during a storm event in May

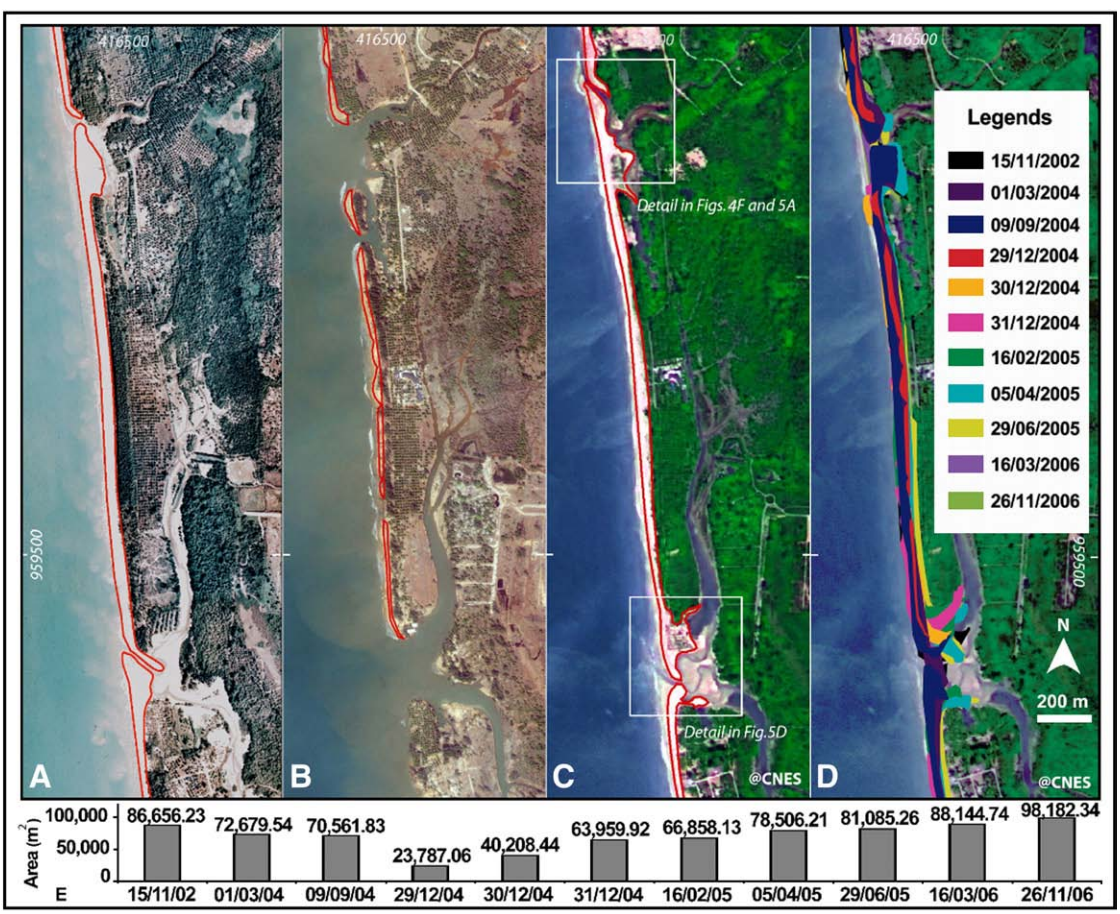

Fig. 3. Satellite images showing the pre-, syn- and post-tsunami beach area changes; (A) from aerial-photo taken in 2003, (B) from IKONOS taken on 29th December 2004, and (C) SPOT-5 taken on November 2006. (D) Series of beach area from 2002–2006 overlain on SPOT-5 taken on November 2006. (E) Diagram showing the beach area changes from 2002–2006.

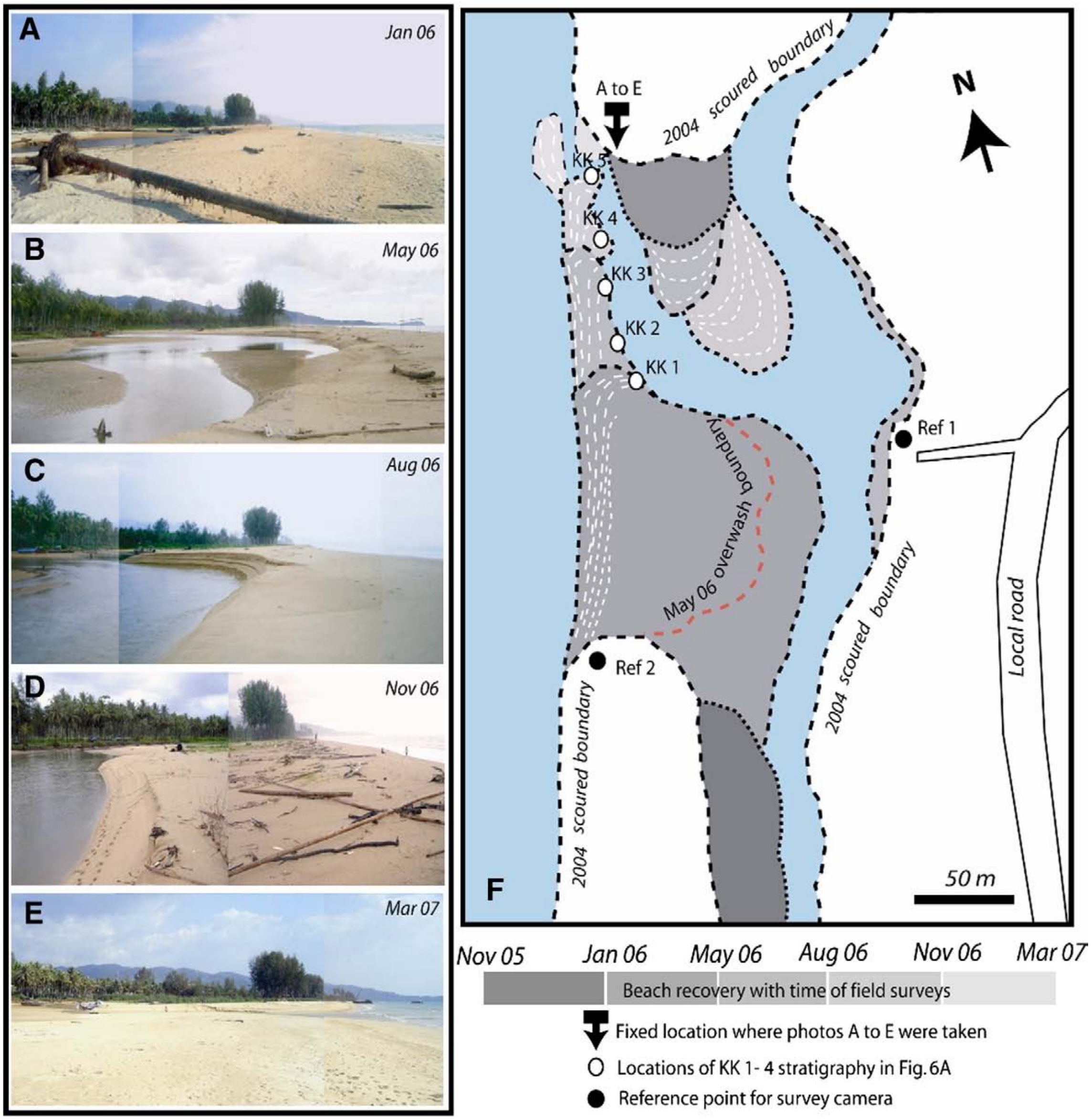

Fig. 4. Series of photographs taken from January 2006 to March 2007 at Khuk Khak tidal channel (A to E, all photos looking south). (F) Geomorphological map and the components of landforms and process that occurred within the 2 years after the tsunami event.

2006 that the inlet was closed and filled by a large amount of coarse- to very coarse-grained sand with extensive coral fragments. These situations suggest that the sediment supply to the shore along this coastline is mainly carried from marine sources rather than of terrestrial origin.

3.4. Beach profiles

We measured the profile across the beach zone at Khuk Khak to understand the morphological changes through time from January to November 2006 (Fig. 5A and B). From January to May, erosion occurred slightly at the foreshore, as recognized from a landward retreat of the beach ridge profile. After that, from May to August 2006, the crest of the beach ridge was slightly higher and the foreshore slope was steeper than those recorded in January to May. The level of the backshore surface was also slightly higher, which was probably caused by the overtopping of washover deposits left by storm surges. Then, from August to November, the crest of the beach ridge was slightly higher and the foreshore slope was also steeper than in May, with a concave shape. This feature indicated a normal translation of sand bar within the foreshore zone. The changes in profiles of the foreshore and backshore seem likely to support that the beach ridge here had started to achieve its equilibrium profile.

The formation of the beach area at Bang Niang showed a similar pattern throughout 2006 to that discussed above for the Khuk Khak area. In February, the beach profile exhibited a steeper slope than in May (Fig. 5D and E). The rapid deposition that occurred in May led to the rising of the beach ridge crest. During the storm period in May, sediment deposited at the mouth of the inlet tidal channel with the crest of the beach ridge was slightly higher than the high tide water level (HTWL). The inlet was subsequently totally filled by beach and storm washover sediments favoring the channel becoming a temporary lagoon. By August, the inlet was open again and the channel connected to the sea, whilst from August to November the beach ridge was slightly higher than in May. Thus we suggest that the beach at Bang Niang inlet was likely to have reached its equilibrium profile by 2006. This cycle represents a

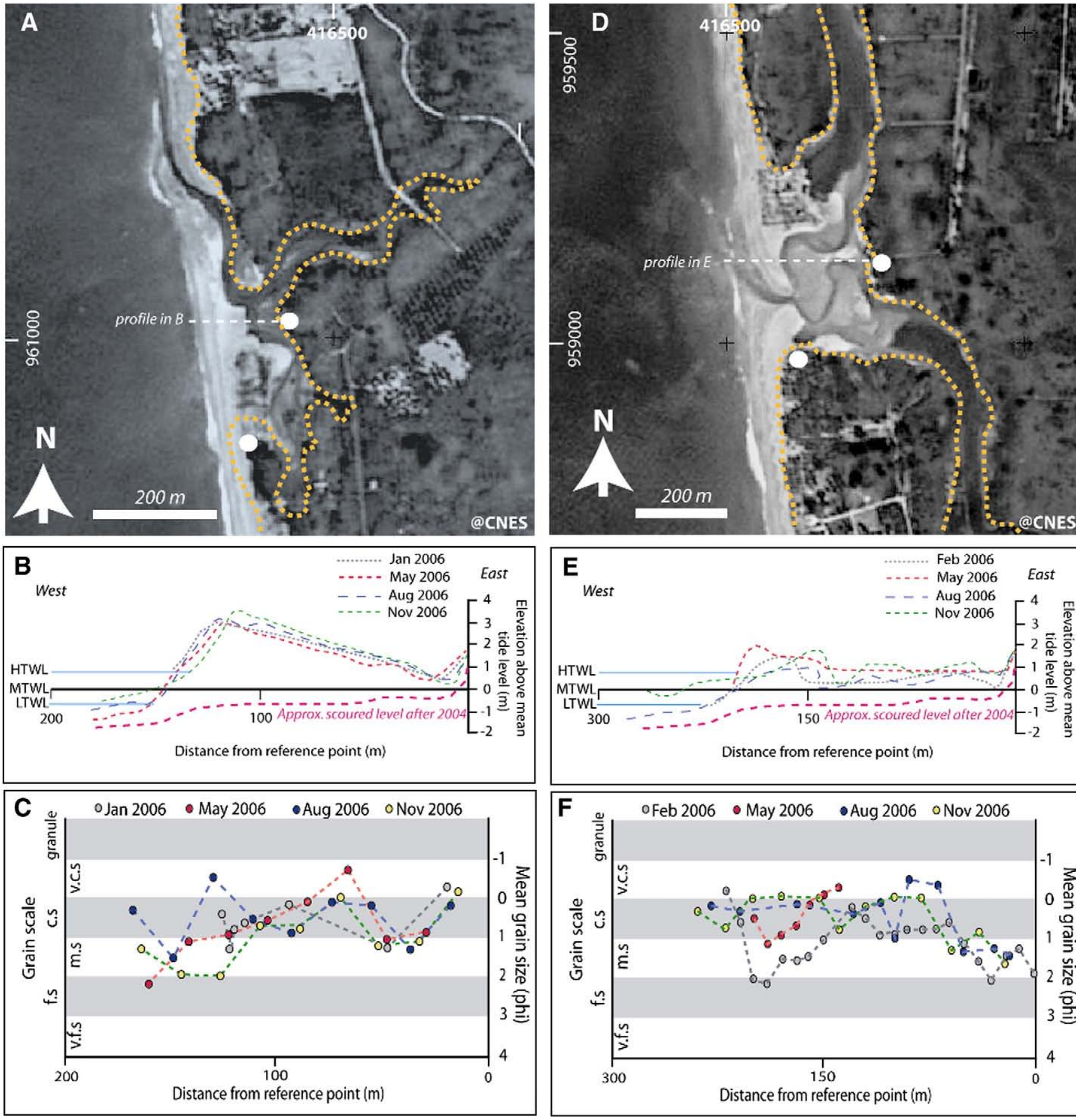

Fig. 5. Geomorphological map of beach area at the two tidal channels with profiles and distribution of surface grain size of beach sediments. Dashed-lines in A and B indicate the scoured boundary by the tsunami event. Two white dots are reference points. B and E are profiles of prograded beach ridges along transect measured in 2006. Two approximate scoured levels after 2004 were estimated from IKONOS high resolution satellite image on 29 December 2004. C and F show grain size distribution of the post-tsunami beach sediments.

series of erosional events during rainy seasons followed by beach recovery during dry seasons.

3.5. Sediment properties and stratigraphy

We examined 85 bulk samples of surface beach sediments from two areas. The average grain size of the post-2004 surface beach sediments at Khuk Khak showed a majority of coarse-grained sand (0.5–1.0 mm) (Fig. 5C). The recovery sediments show the seasonal change. In January 2006 (Table 2), the grain size of beach sediment was characterized by coarse sand with an average diameter of 0.682 mm, and then slightly finer to 0.669 mm in May. During the rainy and storm season from May to August, the grain size increased to 0.751 mm, and then decreased again to 0.561 mm at the beginning of the winter season.

The average grain size analysis at Bang Niang area (Fig. 5F) revealed a similar trend as that reported at the Khuk Khak area above, but was dominated by coarse-grained sand (Table 2). In February, the mean

Table 2
Change in grain size of beach sediment at Khuk Khak and Bang Niang in 2006

Area	January[a] and February[b] (mm)	May (mm)	August (mm)	November (mm)
KK[1]	0.682	0.669	0.751	0.561
BN[2]	0.507	0.783	0.899	0.777

1 = Khuk Khak; 2 = Bang Niang.
[a] Samples collected from KK.
[b] Sample collected from BN.

diameter of the surface beach sand was 0.507 mm, and this increased to 0.783 mm in May. During the rainy season in August, grain size increased to 0.899 mm. Finally, at the end of the rainy season in November, the grain size had decreased to 0.777 mm.

A change in the mean grain size was also observed to exhibit a relationship with beach morphology as the degree of difference in grain size at the foreshore in each season was greater than at the backshore (Fig. 5B–C and E–F). Within the backshore zone, the average grain size seemed to show the same trend throughout the year, whereas at the foreshore the change in mean grain size with each season was clearly observed. In general, the foreshore, and especially in swash zone, was a dynamic area because waves impact on this part all the time and sediment also moves in and out in both horizontal and vertical directions. In contrast, at the backshore the effect from waves usually only occurs during storm surges, making sediments in this zone more stable than in the foreshore zone.

The compositions of surficial beach sediments of Khuk Khak and Bang Niang areas were mainly composed of quartz (60%), bioclasts (35%), and 5% of rocks fragment and heavy minerals. Bioclasts mainly contained coral fragments and shell fragments. Interestingly, the percentage of quartz during rainy season decreased whilst the percentage of bioclasts (i.e. shell fragments and coral fragments) increased (Table 3). All sediment samples were moderately sorted with angular to sub-angular sphericity morphology. These characteristics of beach composition helped us to distinguish the storm depositional events and a normal coastal deposit. We employed these depositional patterns to infer several depositions by storm events recorded in all the stratigraphies of the sand spit described in the Khuk Khak area (Fig. 6).

The succession of storm deposits (Fig. 6B and C) at Khuk Khak has some distinctive characteristics that help us to differentiate fair weather deposits from storm deposits. The composition and grain size of the sediment is the important key that we used to identify this kind of high-energy deposits. From KK1 log, two events of high-energy deposits were indicated by two fining-upward sequences from coarse to very coarse sand rich in bioclasts, such as shell fragments and coral fragments to the medium sand. These coarse to very coarse sands can be transported and deposited by high-energy flows during storm periods whereas the smaller grains are usually deposited either during the waning phase of a storm surge or during fair weather periods. Bioclasts, especially coral fragments which indicate an offshore source, were also found mainly in the coarse sand layer that indicated a high-energy flow which probably occurred during a storm event. In contrast, during fair weather periods bioclasts were rarely deposited in the successions, as evidenced in all five stratigraphical logs. These findings are also supported by the results of grain size analysis and the composition of sediment deposits. When they are present in the rainy season the average diameter of the grain size and percentage composition of bioclasts were respectively bigger and higher than in the other seasons. In conclusion, at Khuk Khak successive storm deposits consist of sand with an average grain diameter that is larger than other sand layers, and contain a bioclast composition which is associated with coarse sand layers and is rarely found in other layers.

4. Discussions

4.1. Large accommodation space

The coastal plain at Khuk Khak and Bang Niang tidal channels before the 2004 Indian Ocean tsunami event showed stability (Sinsakul et al., 2003) (Fig. 1B). Our analysis of the change in shoreline positions showed a localized seasonal change in the beach zone between these two tidal channels. It is simply explained that the stability occurs once the accommodation space of the area was returned to zero. After the 26th December 2004, the tsunami caused severe erosion with approximately 67% loss of beach surface area, and led to an extensive increase in the accommodation space within the opened and widened tidal channel embayment (Fig. 3B). The rapid rate of deposition that then ensued occurred due to the large positive accommodation space that favored sediment deposition. As a result, the shoreline was prograded rapidly in a seaward direction (Fig. 2). Results of satellite image analysis of the changes in beach area after the 2004 tsunami from both sites revealed a rapid formation of landforms and beach sediments, which represent the extensive formation of beach that started a few months after the event. Thus, from January to June 2005 the deposition of sediment in the scoured beach and tidal channel led to approximately 60% recovery of beach surface area, based on the results of beach area calculations from satellite images.

After sediments had filled up the large positive accommodation space, the rate of the recovery process decreased gradually from August 2005 to November 2006 (Fig. 3E); whilst the beach zone seemed to be stabilized. After November 2006, the accommodation space decreased to almost zero and both tidal channel areas became the sites of a sediment by-pass zone (Fig. 3C). If there is a negative amount of accommodation space, the previously deposited sediments will be eroded and transported to the area of (positive) accommodation space nearby, thus preserving the equilibrium profile (or depositional profile) where the available accommodation space is balanced by the amount of sediment supplied (Coe et al., 2003).

However, this rapid sedimentation was recognized only in the beach zone. We suggest that the widened cut banks along the tidal channel which now extend quite far inland may need several years to return to equilibrium, in agreement with the suggestion by Fagherazzi and Du (2007).

4.2. Source of 2004 tsunami and the post-recovered sediments

We inferred that the sources of quartz and bioclasts deposited along the coast of Khao Lak were derived mainly from the offshore bottom sediments. The angular to sub-angular morphology of the quartz grains and their moderately sorted surface samples were examined and all indicated they were from local sources of sediment supplied to the beach zone. The extensive presence of bioclasts (i.e. coral fragments) also helped to locate the nearshore sources of beach sediments. This is confirmed by Benzoni et al.

Table 3
The percentage of grain compositions in the post-2004 beach sediments

Area	January[a] and February[b] (%)		May (%)		August (%)		November (%)	
	Quartz	Bioclasts	Quartz	Bioclasts	Quartz	Bioclasts	Quartz	Bioclasts
KK[1]	62.86	23.57	61.25	36.38	65.00	34.19	67.00	30.78
BN[2]	63.48	32.48	66.71	32.29	60.55	37.18	67.92	28.25

1 = Khuk Khak; 2 = Bang Niang.
[a] Samples collected from KK.
[b] Sample collected from BN.

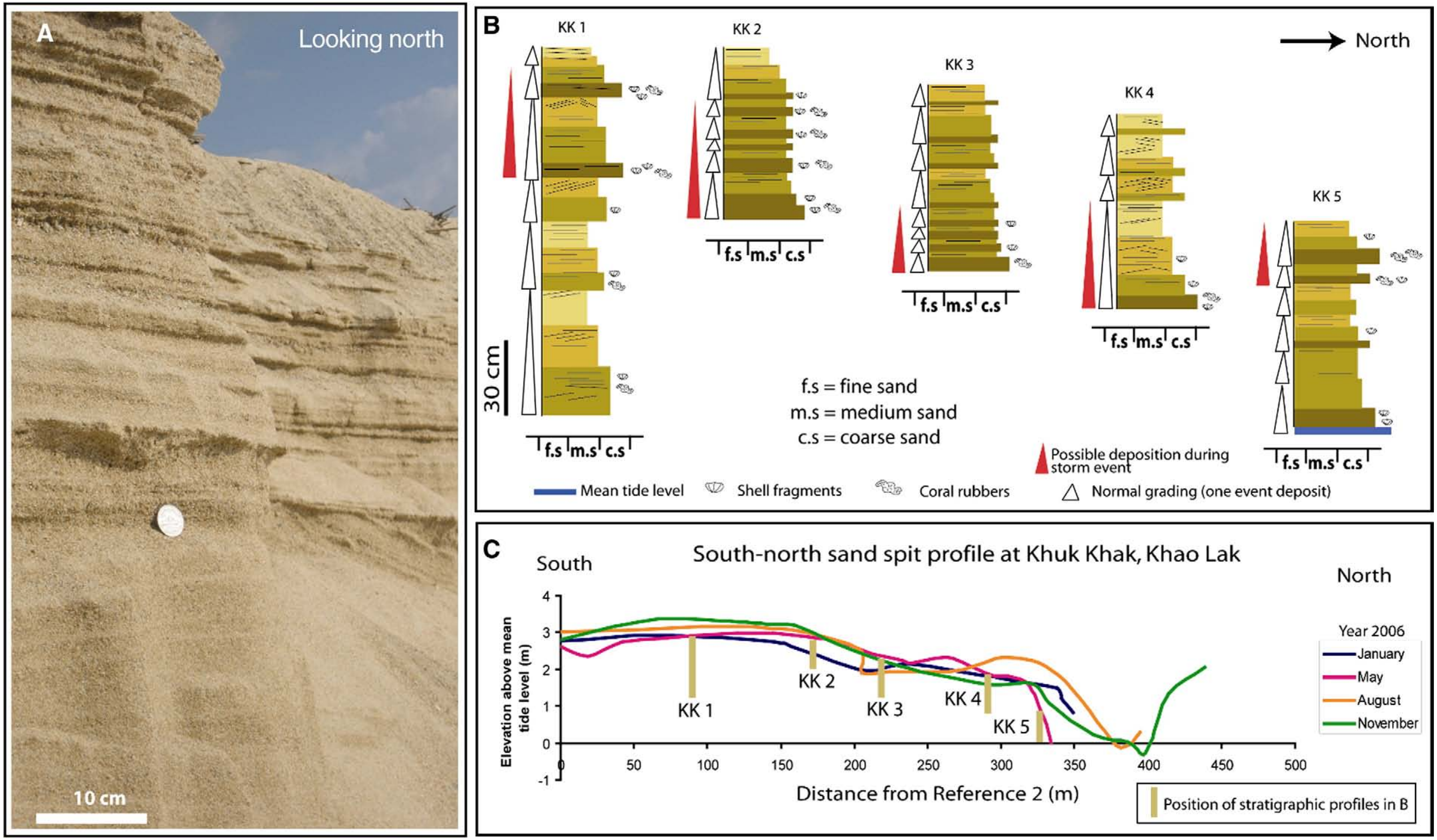

Fig. 6. (A) Photograph showing the depositional features of the post-2004 tsunami beach sediments; (B) stratigraphical correlation among pits along the south–north sand spit profile at Khuk Khak shows multiple normal gradings. Angular to sub-angular coarse-grained sand with coral fragments indicate deposition during storms occurred on May 2006 (red triangles). (C) Topographical profiles of sand spit developed in 2006 from south to north. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(2006) who showed that several locations of the offshore submerged coral platforms from Khao Lak to Pakarang Cape which had been broken by the 2004 tsunami. Much of the broken coral boulders and fragments were moved away from the coral platforms and re-deposited close to the shore (Goto et al., 2007). It therefore seems of little doubt that small fragments of coral remain offshore and can then be carried onshore by the storm waves during the monsoon season.

5. Conclusion

1) The result of field surveys from 2005 to 2007 showed the rapid development of landforms causing beach sediment to return to the shoreline along the Bang Niang to Khuk Khak coastline of Phang-nga, Thailand. We conclude that the beach area had recovered by late 2006 and slightly exceeded the average area measured before the tsunami event. The present morphological process in this area now is mainly the adjustment of the beach zone to maintain the equilibrium profile. The recent formation of the sand spit at Khuk Khak tidal channel tends towards the north and is generated by a sediment transport pathway due to the prevalent northward alongshore current.
2) Results of beach profile measurements can be related to the morphological changes through time. The changes in foreshore and backshore profiles also support that the beach ridges initiate the balance in the equilibrium cycle, similar to the results of beach area calculations. We suggest that the balance of deposition and erosion of sediment at Khuk Khak and Bang Niang inlet/outlet tidal channels was also achieved by late 2006.
3) Grain size analysis of the post-2004 surface beach sediments at both sites contains a majority of coarse-grained sand. Quartz and bioclasts are common. The grain size during the recovery period changed in accord with seasonal changes. We infer that the sources of quartz and bioclasts, the majority of the deposition along the coast from Bang Niang to Khuk Khak, were derived mainly from the offshore bottom sediments.

However, the return of beach area and sedimentation was recognized only in the beach zone and inlet/outlet of tidal channel. Small incisions in the beach face can be recovered, but the widened cut banks along the tidal channels inland may either need several decades to return or these incisions will now persist into the geological record.

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