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Geomorphology and Ground Penetrating Radar Profiles of Holocene Coastal Dune, Western Coastal Plain of the Gulf of Thailand

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Abstract

At Bang Berd Bay, a remarkable wind blown sand dune lies almost parallel to the present coastline with its highest elevation about 20 m above the present mean sea level. The formation of sand dune here has not yet concluded. This paper shows a result of Ground Penetrating Radar (GPR) to visualize the invisible dune structures as well as applying a remote sensing data to map the distribution. As a result from aerial photograph interpretation, dune morphology shows a majority of parabolic and transverse patterns. GPR profiles revealed some obvious macro-scale sedimentary patterns, clear boundary of dune overlying on the prograded beach ridge plain. Based on macro-scale sedimentary patterns, lee and stoss angles of some burial dunes from GPR signals and dune morphology indicated the direction of wind blown mainly from the east to the west. Series of beach ridges underneath sand dune indicated seaward progradation. This seaward progradation of beach ridges inferred its formation possibly after the mid-Holocene highstand. Thus, the formation of dune may have occurred during a dry condition probably during and after the mid-Holocene regression. OSL datings also reveal that the upper part of dune profile depth at 1-3 m formed between 2,220 to 2,960 years ago.

Keywords: Coastal dune, dune formation, Holocene, GPR

1. Introduction

The distribution of wind blown sand dune in the western coastal plain of the Gulf of Thailand is very limited and left behind some significant geological challenges for the explanation of its formation in relation with the past climate condition. Thus, this study is aimed to characterize sand dune morphology and sedimentology as the basic geological clues for explaining its formation. The GPR is also applied to visualize internal dune structures.

At Bang Berd Bay, a remarkable wind blown sand dune lies almost parallel to the present coastline with its highest elevation about 20 m above the present mean sea level. The highest elevation of dune is generally located in the south of Bang Berd Bay and decreased both altitude and its extension to the north ending at the northern headland.

Bang Berd sand dune is located at Bang Berd Bay, Pathio district, Chumphon province, in the western coast of the Gulf of Thailand (figure 1).

2. Methods

Ground-penetrating radar (GPR) is a geophysical method that basically uses radar pulses to image the subsurface morphology. The GPR images are also available to document and enhance the macro-scale internal dune structures both within the dune itself and the beach deposition underneath. GPR was undertaken for the first time at Bang Berd sand dune during October 2008. In this study, Plus 200 MHz GPR was used. The radar frequency and the properties of sand dunes limited the penetration of the radar signal to the uppermost 5 m. The reflections are recorded in real time and displayed on a monitor in the field to provide real-time data quality. During the survey, traces were collected every 0.50 m. A survey shore-normal and shore-parallel transect were 12 lines, with a total length of 1,510 meters (figure 1) were also assigned to characterize the continuity of deposit, boundary between beach and dune and thickness of dune. Basically, GPR lines were conducted along – transects oriented parallel and perpendicular to the dune's downwind axis. Transects parallel to the prevailing wind are labeled as GPR 4, GPR 5, GPR 7, GPR 9, GPR 10, GPR 11, and GPR 12. Transects perpendicular to the prevailing wind are labeled GPR 3, GPR 6, GPR 8, GPR 13, and GPR 14. Consequently, the profiles were not extended onto the slip-face.

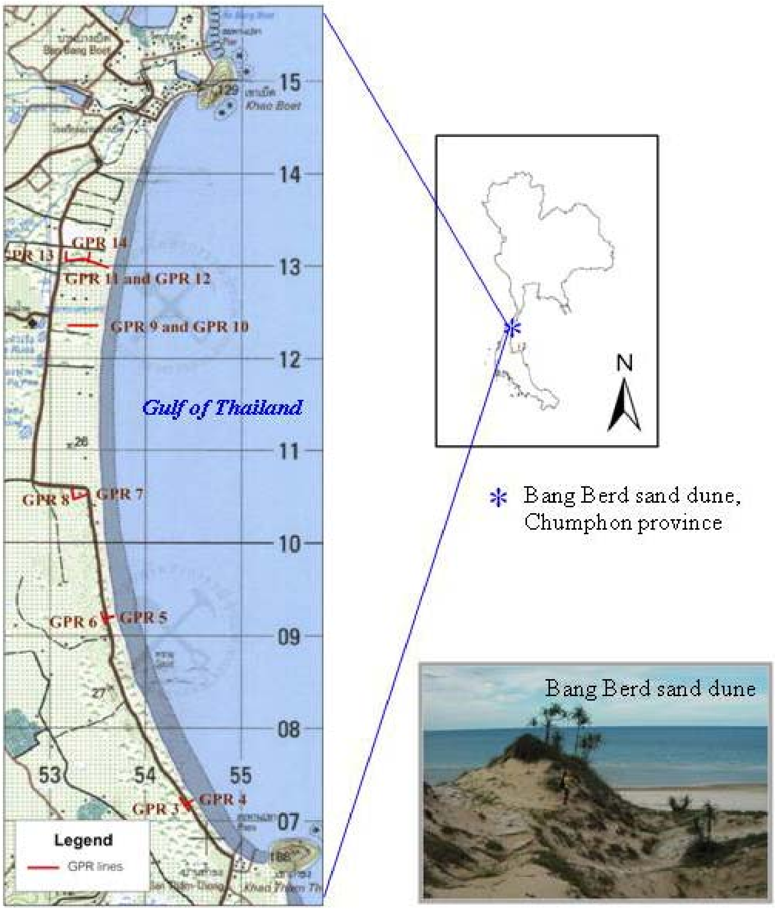

Figure 1. Bang Berd sand dune is located at Pathio district, Chumphon province, the western coast of the Gulf of Thailand. GPR lines survey was conducted along – transects oriented parallel and perpendicular to the dune's downwind axis, 12 lines (total length 1,510 m).

3. Results

3.1 Distribution of sand dune and dune morphology

As a result from aerial photograph interpretation, dune field distributes along the coastal plain mostly parallel to the present shoreline. In general, dune field can be sub-divided into two zones; the coastal dune close to shore and the former dune close to swampy area in the west.

Coastal dune lies parallel to the shoreline in almost north-south trending with dimension of the dune body as wider as 500-600 m in the north and subsequently narrower to the south. Dune in the northern part of the area owns very low elevation with small irregular topography in comparison with the southern part. However, the widest dune field is recognized in the middle part of the area where the highest elevation reached about 20 m above the present mean sea level. Dune in the southern part becomes narrow but the elevation is somewhat equivalent to dune in the middle part. Old sand dune is interpreted to overly on top of the former beach deposits with its wider distribution than those younger dunes.

Dune morphology shows a majority of parabolic and transverse patterns. Star shapes were rarely and locally recognized (figure 2). Most of dune morphology indicated the direction of wind blown mainly from the east to the west.

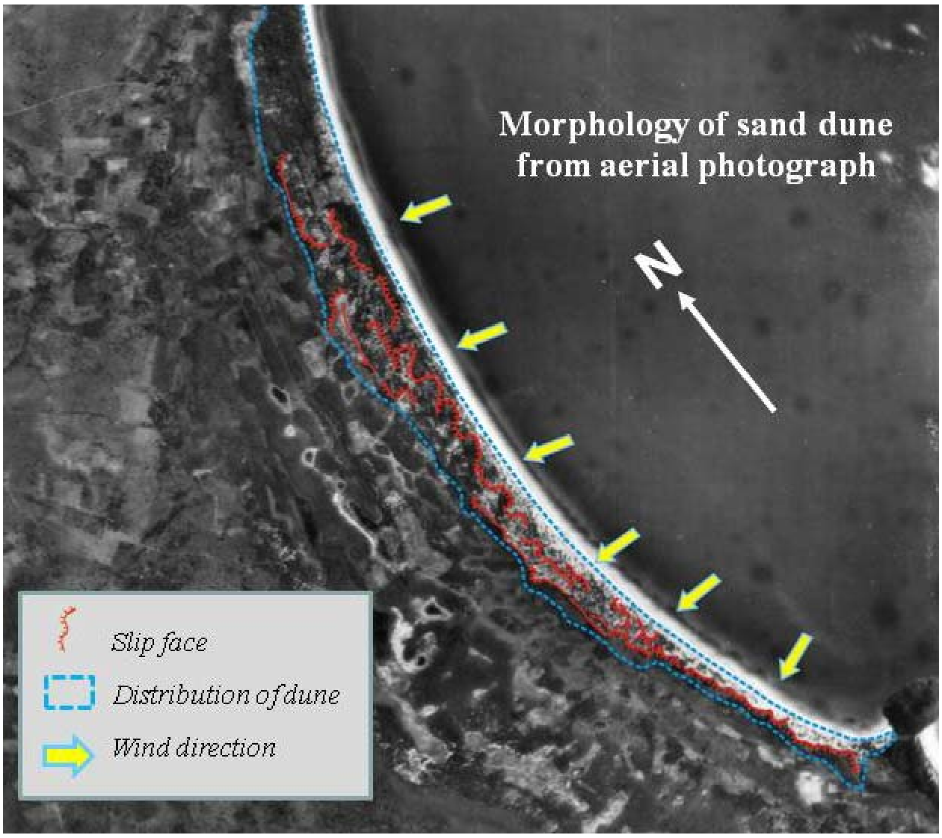

Figure 2. Patterns of sand dune with their distributions. Parabolic shape dominates in the outer part of dune field close to shore; transverse pattern is dominates in the western end of dune field and star pattern is locally recognized in the southern portion.

3.2 Ground Penetrating Radar

The characteristic reflection patterns of radar signal related to depositional environment from this dune field is mainly followed by Overmeeren (1998), Neal (2004), Hogenholz and Moorman (2007) and correlate with logging data from DMR (2006) and hand augers drilling.

3.2.1 GPR profiles oriented parallel to the prevailing wind

The resolution in the radargrams was sufficient enough to view in detail the internal sedimentary structures. Most of profile shows the clear contact between marine sediments on bottom and eolian sediment on top. The characteristics of marine sediment are classified into 2 types. The first is beach ridge (unit B1) generally dip seaward and littoral deposit (unit B2) (Figure 3). Within unit B1, radar profiles of GPR 9 and GPR 10 showed the sharp contact between three different dune generations (unit D1, D2 and D3) by third order bounding surface (Figure 4). All sub-units represents to coastal sand dune with cross-bedding in foresets and bounding planes. Sets of foreset dipping are rather steeply to the east. Major slip-faces are inclined to the western part of dune, representing the probable major direction of wind blown of its formation was from the east to the west. Although, radar signals at the top most of the dune in some places were chaotic, but they represented the winds have changed the direction seasonally. The water table was also detected and its depth was checked by measuring the depth from hand auger drilling and DMR logs (2006). The regional water table can be related with continuous high-amplitude reflection inside the beach ridge structure (Figure 4). Channel filled deposit (unit C) underneath beach ridges (Figure 5), is described as the trough-shaped reflections that possibly belong to braided small channels. Gravels are also found in this channel-filled deposit.

3.2.2 GPR profiles oriented perpendiculars to the prevailing wind.

GPR transects of the actively migrating on crest of dune showed the characteristic of coastal sand dune with cross-bedding in foresets and bounding planes. Sets of foreset dipping are rather steeply both to the north and the south. Profiles in GPR 13 and GPR 14 showed the contact between marine sediments on bottom and eolian sediment on top. Radar signals of beach ridges are sub-parallel and continuous.

3.2.3 Radar surfaces, Packages, and Facies

Radar lines along the windward slope and the crest of dune revealed a downwind dipping foreset bedding plane to which this structure is commonly recognized in the parabolic dunes, as well as other features visible within and below the dunes.

From the foregoing description of the radar profiles, those features of internal structures within the dune are possible to distinguish into GPR units using the principles of radar stratigraphy, which relies on the identification of systematic terminations or boundaries, to qualitatively classify different reflection patterns from the profiles. This classification is the first used of GPR facies in this area and can be served as a basis for the comparison with the other future dune studies. Parabolic dune description here may also serve as a reference for comparing with other dune morphology elsewhere along this coastal area.

The main feature from the radar profiles can be classified into 2 radar surfaces, 2 radar packages and 5 radar facies (figure 6). A qualitative scene was used to describe the relative dip of reflections because, however, it is not know whether or not the migration produced accurate dip angles (i.e., high-, moderate-, and low-angel). It is important to recognize that the discrimination of sedimentary surfaces, packages, and facies is highly subjective and dependent in the term of reference. The classification of radar surface in this paper is mainly followed the terminology proposed by Neal (2004) and Hogenholz et al. (2007) in order to identify and describe the main radar surfaces, packages, and facies.

Radar surfaces are termed as the bounding surfaces and represent depositional breaks or unconformities in the sedimentary sequence. Radar packages are depositional units consisting of genetically related strata that are bounded top and bottom by radar surfaces or bounding surfaces. Radar facies are comprised of sets or reflections with distinctive shapes, dip, and continuity that represent the bedding and internal structure of a sedimentary facies (Neal, 2004; Hogenholz et al. (2007).

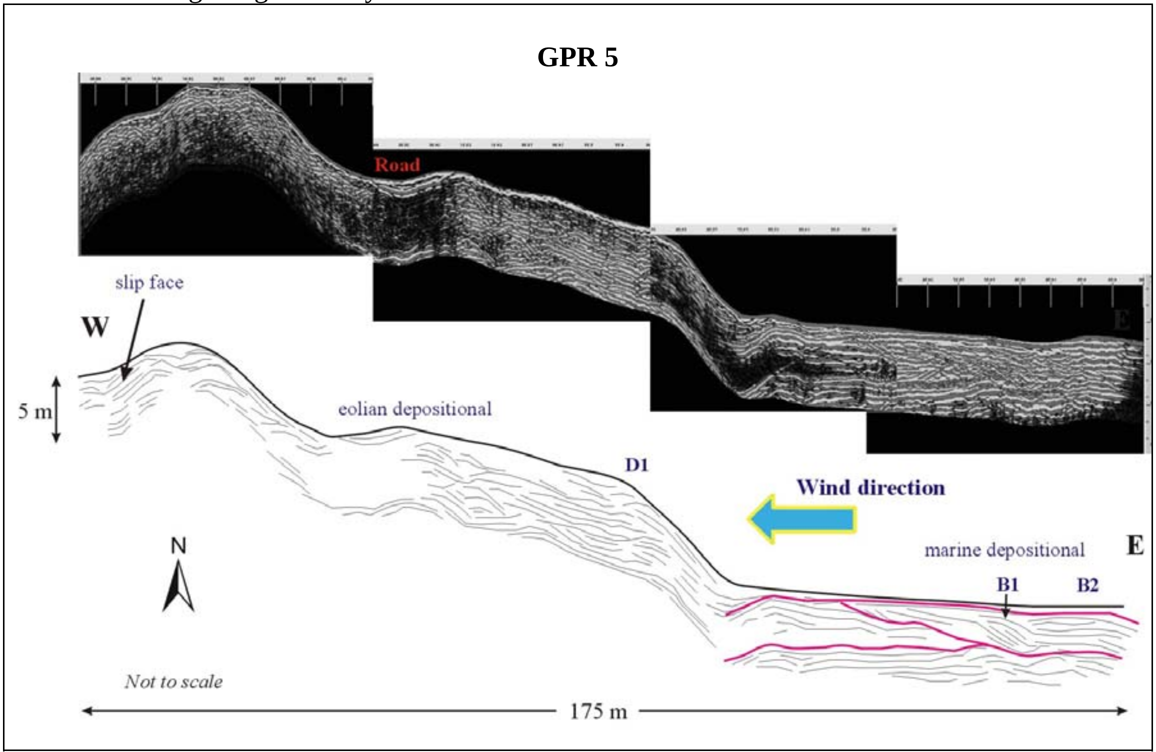

Figure 3. GPR 5 was conducted along – transects oriented parallel to the dune's downwind axis. The characteristics of marine sediment are beach ridge (unit B1) generally dip seaward and littoral deposit (unit B2) horizontal layer. Slip-faces of dune represent the probable direction of wind blown from the east to the west.

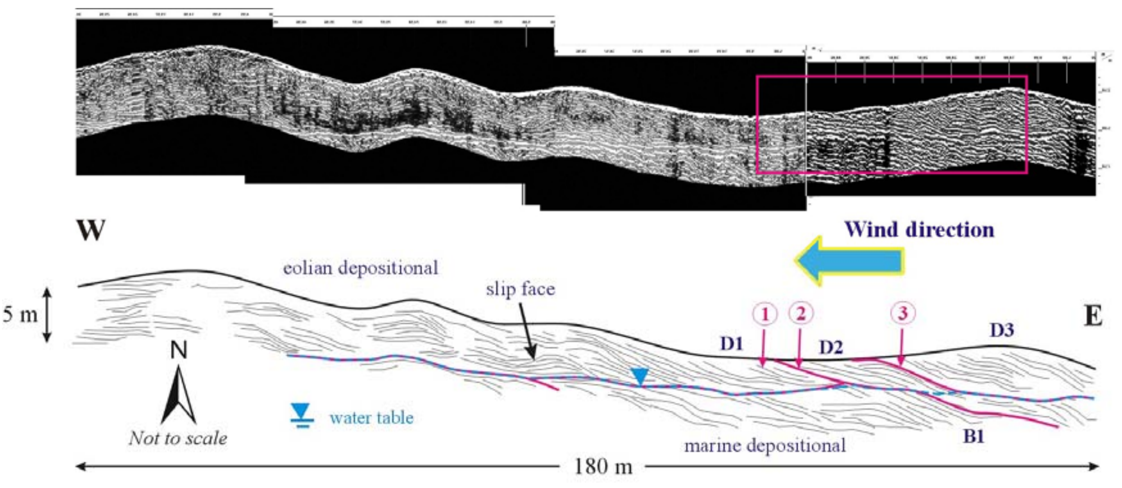

Figure 4. GPR 9 and GPR 10 were conducted along – transects oriented parallel to the dune's downwind axis, showing the contact between three different dune generations (unit D1, D2 and D3) by third order bounding surface (mark 1, 2 and 3 in picture). Direction of wind blown was expected from the east to the west.

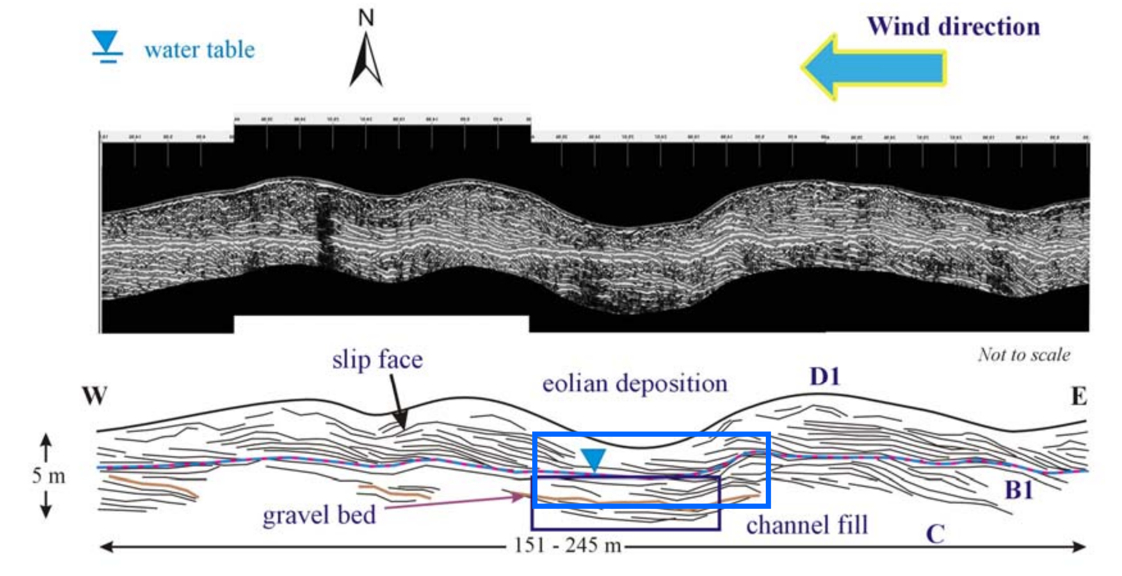

Figure 5. GPR 11 was conducted with orientation parallel to the dune's downwind axis, showing a trough shape underlie beach ridges represent to channel fill deposit (unit C). Direction of wind blown was expected from the east to the west.

In this survey, the two radar facies are classified as the concordant (Rs1) and the erosional truncation (Rs2). The two radar packages are spur (Rp1) and trough (Rp2) and the other 5 radar facies included a planar (Rf1a) and wavy (Rf1b) representing the reflection configuration of shape. High angel planar (Rf2b) and high-oblique angel tangential (Rf3b) represented the reflection configuration of dip.

Result from GPR showed some obvious macro-scale sedimentary patterns, especially the lateral and vertical extensions of the older dune superimposed by the younger one. Clear boundary of dune and the underlain prograded beach ridge plain is also detected from GPR. Based on macro-scale sedimentary patterns, lee and stoss angles of some burial dunes ascribed mainly two directions of wind. First was formed by wind blown from the north to the south and second was in almost northwest to southeast direction. This result in analyzing wind direction based on GPR signals is corresponded well with dune morphology interpreted from aerial photographs and the modern record of wind blown direction.

3.2.4 Radar facies from GPR

Stratigraphy units from the radargrams are shown as eolian deposit, marine deposit and channel fill deposit. Eolian deposits have signal represent to grain movement to form dune, comprised of sets of reflection with distinctive shape, dip and continuity that represent the bedding and internal structure of a sedimentary facies. Eolian unit can be identified by third order bounding surface (mark 1, 2 and 3 in figure 4.6), divided in to three sub-units are D1, D2, D3 represent to three phases of sedimentation. Eolian unit D1 is depositional history appears to be of more complex nature, judging by variation of the foresets dips inside D1. Units D2 and D3 shows dip angles about 30° in W-E direction. Therefore, judging by the similarities of the foresets dips inside D1, D2 and D3, the prevailing past wind was probably from the east to the west.

The horizontal layer of littoral deposit from GPR signal can correlate with the profile of sand sheet at the coastal, northern study area. The characteristic of seaward prograded can define to beach ridge. Sediments from dune and beach ridges are differentiable by characteristics of sand sediments, especially color. A trough-shaped reflection underlies beach ridges layer, correlated with the core logging of DMR (2006) can define to channel fill deposits. Radar surface is occurs between layer of dune deposit, marine deposit and channel fill deposit, represent depositional breaks or unconformities in the sedimentary sequence.

3.3 Optically Stimulated Luminescence (OSL) dating

Samples for OSL dating were taken from the topmost layer (depth at 1-3 m from surface) of dune profile. Result of OSL dating of sand grains indicates the age of dune deposited between 2,220 to 2,960 years ago.

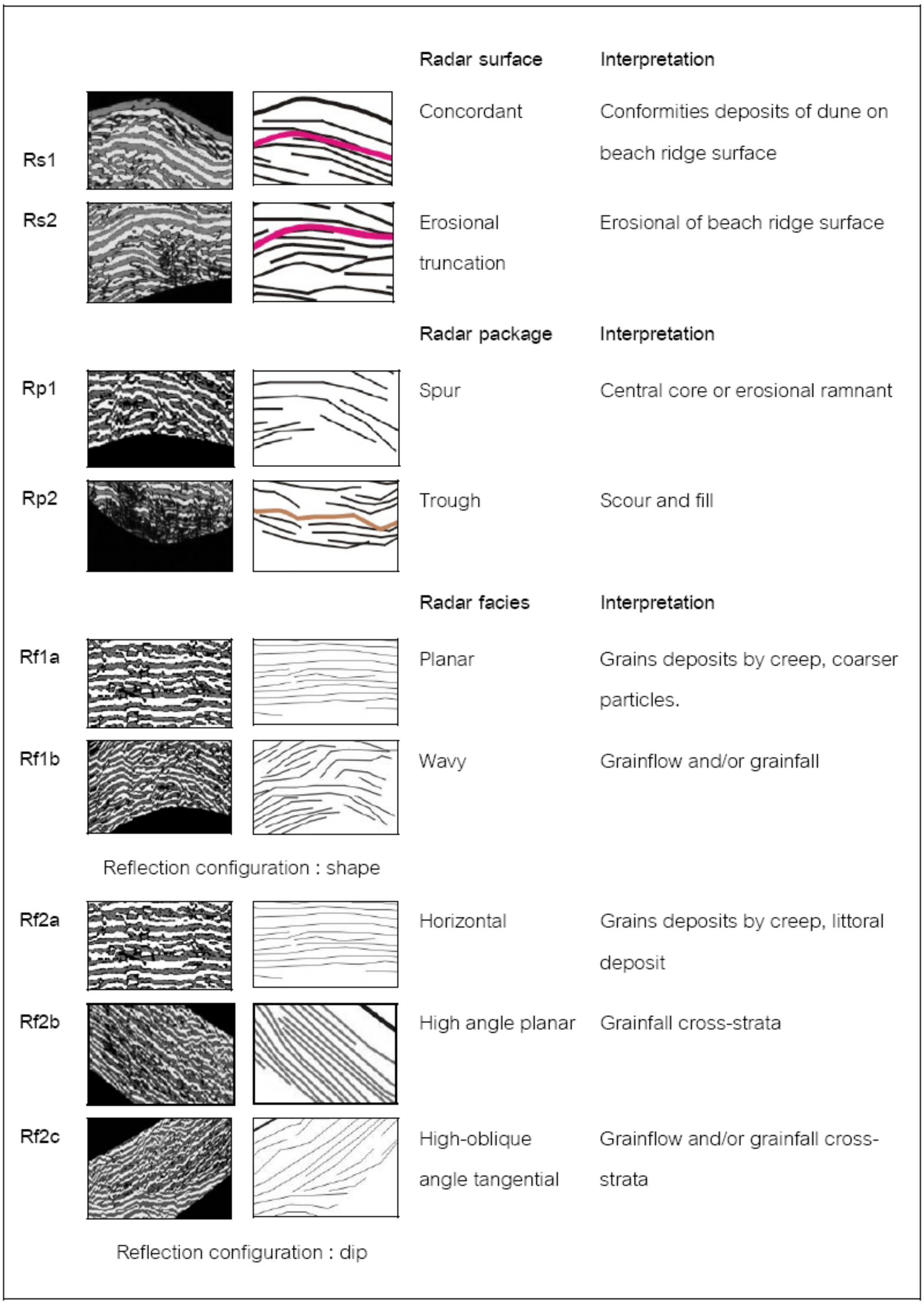

Figure 6. Main feature from the radar profiles can be classified into 2 radar surfaces. They are concordant (Rs1) and erosional truncation (Rs2). Two radar packages are spur (Rp1) and trough (Rp2) and five radar facies included a planar (Rf1a), wavy (Rf1b), horizontal (Rf2a), High angel planar (Rf2b) and high-oblique angel tangential (Rf3b).

4. Discussions

4.1 Wind-blown directions

Dune morphology and orientation detected from aerial photograph indicated a majority of parabolic and transverse patterns, whereas, star shapes were rarely and locally recognized. They formed under the condition that the wind energy was able to carry sediments from the beach in a landward direction and deposited them wherever an obstruction hinders further transportation. Source of sediment supply to form the dune was likely the key limiting factor in the explanation of dune development of this area. However, most of dune shapes indicated the major directions of wind blown from the east to the west.

It is interesting that dunes in this area formed where the constructive waves encouraged the accumulation of sand, and where prevailing onshore winds possibly blown this sand inland. There needed to be obstacles (e.g. vegetation, pebbles etc.) to trap the moving of sand grains. As the sand grains got trapped they started to accumulate, starting dune formation. The wind then started to affect the mound of sand by eroding sand particles from the windward side and depositing them on the leeward side. Gradually, this action caused the dune to migrate inland as it did so it accumulated more and more sand.

This work proofed that the GPR survey over the surface of an inactive parabolic sand dune in Bang Berd, Chumphon province provided excellent detail of the macro-scale internal structures within the dune itself and beach deposits. The radar was able to resolve a variety of high-angle, low angel, and curved reflections that are interpreted as the primary sedimentary structures. Radar profiles parallel to the direction of migration also revealed a complex arrangement of cross-strata that reflects different phases in the development of dune. Major slip-faces are found from the western part of dune, representing the possible major direction of wind blown of its formation from the east to the west.

4.2 Dune formation

The recent environmental history of coastal dune systems from Bang Berd, Chumphon province, has been examined using the combination of result from geomorphological, GPR, sedimentological and OSL dating techniques. Dune stratigraphies were determined mainly from 10 GPR survey lines. All dunes here are associated with the regressive shorelines consequently upon a fall in relative sea level (RSL) from its Holocene highstand peak, and indicated RSL functioned as a macro-scale control on dune development. Where dunes are anchored on terrestrial sediment, dune expansion may have been either transgressive or regressive in nature. Where near-shore marine sediments formed the dune substrate, a regressive (prograding) dune model seems most likely. Most dune building occurred probably in association with specific climatic and morpho-sedimentary conditions, principally periods of easterly circulation, a greater frequency of severe Gulf of Thailand storms, RSL fall, and sediment and accommodation space availability. The majority of dune formation here is, therefore, inferred to have formed in the early Holocene.

Stabilized parabolic sand dunes are extensive in the northern part of Chumphon province. Orientations of the parabolic dunes indicated a paleo-wind blown from the east to west. The age of dune formation (2,220-2,960 years ago) also confirmed its formation continued to the late Holocene to which an earlier dry phase is expected to cause the extensive eolian sands. The underlied parabolic dunes are likely formed during the early to middle Holocene; whereas some are currently exposed to the surface. Some of these older sands may represented the dry environment during the mid-Holocene where the river distributaries are rejuvenated leading to an increase in the supply of sand and silt. Meanwhile, beaches are widened and beach ridge dunes may possibly be able to form.

4.3 Possible sources of sand dune

Based on dune sedimentology, GPR and aerial photographs, the major sources of fine to very fine-grained sand to form a majority of parabolic dune here are possibly from the dry Quaternary sediments locating in the western and the northwestern parts of the bay. Series of prograded beach ridges underneath sand dune indicated seaward deposition. This seaward progradation of beach ridges are inferred its formation after the mid-Holocene highstand (Choowong et al., 2004). Thus, the formation of dune may have occurred during a dry condition probably during and after the mid-Holocene regression (Havholm et al., 2003; Orford et al, 2003; Pederson and Clemmensen, 2005; Tamura et al, 2008).

5. Conclusion

The goal of this paper is to characterize sedimentology and morphology of sand dune in the study area for evaluating the possible sources of dune and build up model dune formation of study area. Results of study are concluded as follows:

(a) Dune in this area showed a majority of parabolic pattern; whereas linear and star shapes are localized.

(b) Dune texture is characterized by very homogenous fine- to very fine grained sand mainly. Very rare micro-scale sedimentary structures were observed.

(c) Major direction of wind blown was expected from the east to the west direction.

(d) OSL datings in the top-half of sand dune profile revealed that the formation of this dune section was at around 2,220-2,960 years ago.

(e) Possible sources of Bang Berd sand dune are thought to come from the Quaternary sediments locating in the western and northwestern part of the bay, and transported to deposit by wind and the minor part on top of dune profile shows some clues of its formation during storms.

(f) Formation of dune may have occurred during a dry condition probably during and after the mid-Holocene regression.

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