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Coastal geomorphic conditions and styles of storm surge washover deposits from Southern Thailand

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ABSTRACT

The characteristics of tropical storm washover deposits laid down during the years 2007 to 2011 along the southern peninsular coast of the Gulf of Thailand (GOT) were described in relation to their different geomorphic conditions, including perched fan, washover terrace and sheetwash lineations preserved behind the beach zone within 100 m of the shoreline. As a result, washover terrace and sheetwash lineations were found where the beach configuration was uniform and promoted an unconfined flow. Non-uniform beach configurations that promoted a confined flow resulted in a perched fan deposit. Washover sediments were differentiated into two types based on sedimentary characteristics, including (i) a thick-bedded sand of multiple reverse grading layers and (ii) a medium-bedded sand of multiple normal grading layers. In the case of thick-bedded washover deposits, the internal sedimentary structures were characterized by the presence of sub-horizontal bedding, reverse grading, lamination, foreset bedding and wavy bedding, whereas, horizontal bedding, normal grading, and dunes were the dominant structures in the medium-bedded washover sand. Rip-up clasts were rare and recognized only in the washover deposits in the bottom unit, which reflects the condition when a mud supply was available. All washover successions were found in the landward inclined-bedding with a basal sharp contact. A high elevated beach ridge associated with a large swale at the backshore proved suitable for a thick-bedded washover type, whereas a small beach ridge with uniformly flat backshore topography promoted a medium-bedded washover sediment.

1. Introduction

Washover deposits are one of the significant results of high energy seawater flooding across a beach or dune. They can be generated from such high intensity processes as tsunamis and storms. In the past decades, rapid flooding from tsunami and coastal storms have been among the main coastal hazards and have caused damage to coastal communities and infrastructure, e.g. 1960 Chilean tsunami, 1989 Typhoon Gay in Thailand, 2004 Sumatra tsunami, 2005 Hurricane Katrina in USA, 2008 Cyclone Nargis in Myanmar, 2009 Typhoon Morakot in China and Taiwan, 2011 Great East Japan tsunami, and 2011 Hurricane Irene in USA. These high energy flows usually bring the sediments from the seaward side, especially from nearshore to beach, to be deposited on the landward side beyond the beach zone.

In fact, the sedimentary characteristics and physical properties of storm-induced washover deposits have been published since the 1960s. The first observable features of storm incidence are changes in beach morphology, which has led to the subsequent study of the changes in the coastal morphology after storm events (Hayes, 1967; Wright et al., 1970; Schwartz, 1975; Morton, 1976; Kahn and Roberts, 1982; Morton and Paine, 1985; Thieler and Young, 1991; Wang et al., 2006; Claudino-Sales et al., 2008). Along these lines, Schwartz (1975) presented the common stratigraphy of storm washover deposits as a horizontal stratification of laminated sand which usually shows foreset laminae in its distal part if it penetrates into a pond or lagoon. Morton and Sallenger (2003) classified the changes in the coastal landform features after storm events into two types, (i) the erosional features (dune erosion, channel incision, and washout) and (ii) the depositional features (perched fan, washover terrace, and sheetwash lineations), based on their formation processes. Since then, these features are often applied as the key criteria to assist in the identification of the intensity and flow conditions of each storm event. Sedgwick and Davis (2003) also reported the five subfacies in storm deposits that represent the differences in flow conditions during overwash, the position relative to sea level, and

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variable degrees of reworking after deposition. Wang and Horwitz (2007) reported the different erosional and depositional characteristics of washover sediments induced by hurricanes from several barrier-island sub-environments, including dune field, interior wetland and back-barrier bay. They proposed that the different erosional and depositional characteristics are caused by the different overall barrier-island morphologies, vegetation types and densities, and sediment properties.

Within the literature, the sedimentary characteristics and bedform surfaces of storm deposits that have been characterized have included normal grading (Andrews, 1970; Sedgwick and Davis, 2003; Morton et al., 2007; Wang and Horwitz, 2007; Phantuwongraj et al., 2008; Spiske and Jaffe, 2009), reverse grading (Leatherman and Williams, 1983; Sedgwick and Davis, 2003; Morton et al., 2007; Wang and Horwitz, 2007; Phantuwongraj et al., 2008; Spiske and Jaffe, 2009), laminae/laminaset (Leatherman and Williams, 1977; Sedgwick and Davis, 2003; Morton et al., 2007; Wang and Horwitz, 2007), sub-horizontal bedding (Deery and Howard, 1977; Schwartz, 1982; Phantuwongraj et al., 2008), foreset bedding/laminae (Schwartz, 1975; Deery and Howard, 1977; Schwartz, 1982; Davis et al., 1989; Nanayama et al., 2000; Morton et al., 2007; Wang and Horwitz, 2007), antidune (Schwartz, 1982), rhomboid bedform (Morton, 1978 and Schwartz, 1982) and current ripples (Deery and Howard, 1977; Schwartz, 1982; Morton et al., 2007; Komatsubara et al., 2008). However, most of these sedimentary features are also found in tsunami deposits (e.g., Gelfenbaum and Jaffe, 2003; Choowong et al., 2007; Morton et al., 2007; Choowong et al., 2008a,b; Jankaew et al., 2008; Shanmugam, 2012). Thus, it is sometimes challenging to distinguish whether sand sheets in the geological records were originally formed as the result of a tsunami or a storm. This challenge has led many geologists and sedimentologists to develop the key criteria for distinguishing tsunami from storm deposits (Nanayama et al., 2000; Goff et al., 2004; Tuttle et al., 2004; Kortekaas and Dawson, 2007; Morton et al., 2007; Komatsubara et al., 2008; Switzer and Jones, 2008a; Phantuwongraj and Choowong, 2012). However, the identifiable features, such as the sedimentary characteristics, washover geometry and biological evidence, that are used in the differentiation of these two types of high energy flows are still equivocal because their deposition often depends on the topographical control, local source of sediments and the intensity of the event, and these factors usually differ from place-to-place.

The coast of Thailand has also been attacked by storm surges which cause damage to coastal communities. Although, Thailand has experienced storm surges at least three times recently from tropical storms ("Harriet" in 1962, typhoon "Gay" in 1989 and typhoon "Linda" in 1997), only a few reports on the storm deposits have been published (e.g. Roy, 1990). Phantuwongraj et al. (2008), subsequently, reported the possible storm deposits found along the coast at Surat Thani and Nakhon Si Thammarat on the Gulf of Thailand (GOT). The discovery in tracing the storm deposits was extended northwards along this coastline to Chumphon where Phantuwongraj et al. (2010) found multiple layers of paleo-storm sand sheets in a swale located 1 km inland and far away from the present shoreline. However, more detailed studies of the sedimentary characteristics, topographical and flow conditions of the washover deposits induced by storms are still required, particularly for Thailand where so little is known.

Here, in this paper, the sedimentary characteristics of storm washover deposits from different geomorphic conditions associated with the storm events during the period 2007–2011 in Thailand are described systematically. We start from the identification of the distinctive sedimentary features of washover deposits from the three different geomorphic settings preserved along the GOT coast. Comparison of the topographical and flow conditions from the individual and geological settings related to washover sediment features is also made. This study presents the first detail of recent storm deposits from the Southeast Asia region which also can be used as a modern analog for storm deposits from other areas. The similarity and differences in the sedimentary features found in storm deposits from different geological settings may help geoscientists to understand further what (and how) storms leave behind as their evidence in the geological record.

2. Setting and method

The climate of Thailand is under the influence of two main monsoon winds that are seasonal in character, being the southwest (SW) monsoon and NE monsoon. The SW monsoon in May–October brings a stream of warm moist air from the Indian Ocean towards the Thai Peninsula, resulting in an abundance of rain over the country. Subsequently, the NE monsoon in October–February, originally forming as cold and dry air, is driven from mainland China towards Thailand. This gradually causes the cold condition in the winter season, especially in the northern and NE highlands, whereas in the southern part of Thailand this NE monsoon normally causes a mild weather and heavy rain along the eastern (GOT) coast of the Thai Peninsula. During the NE monsoon season, sea level in the GOT is normally raised higher than mean sea level (MSL) (Fig. 1) due to seawater from South China Sea moving downward and then flowing into the GOT corresponding to the prevailing wind from the NE direction. In contrast, in SW monsoon season, the prevailing wind blows to the opposite side which leads to seawater moving out of the GOT, thus sea level in the GOT is lower than the average MSL. The average change of sea level in the GOT caused by the change in monsoonal wind is 0.4 m. Additionally, during November–December, the eastern side of southern Thai Peninsula is usually affected by depressions or tropical storms and sometimes typhoons from the eastern side of GOT, which can generate storm surges and cause overwash flow in the low-lying coastal area. However, Thailand has experienced storm surges induced by tropical storm or typhoon only three times since the 1960s. Apart from the storm events, the temporary increase in monsoonal wind velocity above its usual speed for a few successive days during NE monsoon season also causes a storm surge up to 1.25–2.5 m high in the low-lying coastal area along the Southern Thailand coast (Fig. 1). According to the frequency of their occurrence, at least once a year, washover deposits resulting from temporary strong NE winds are found to be more in number than the washover deposits induced by tropical storms or typhoons. This phenomenon of storm surge being induced by temporary strong NE winds usually occurs during November to January as it is the period of highest sea level during the year. A storm surge induced by strong winds during the NE monsoon season is also found in Singapore (Tkalich et al., 2012).

We focused on three sites (Fig. 2a), (1) Ban Takrop (BT) in Surat Thani (Fig. 2c), (2) Laem Talumphuk (LT) in Nakhon Si Thammarat (Fig. 2d), and (3) Khao Mai Ruak (MR) in Prachuap Khiri Khan (Fig. 2b), that were effected by storm surges during the period 2007–2011. Five storm surge events during this time were induced by (i) seasonal sea-level rise accompanied with temporary strong NE winds over 2007 to 2010 and (ii) a low-pressure system in 2011. The maximum wind speed measured from three weather stations closest to each study site was 20–22 knots. The potential heights of storm tide were at 2.30–2.96 m above MSL, as calculated from tide gauge data and significant wave height data at each study site (Fig. 3). Storm surges caused erosion to the beach and also expanded the inlet/outlet channels. The damage also extended to a road and house along the shoreline.

At the study sites, we investigated the damage and particularly aimed to record how the beach morphology had changed. The evidence of erosion and deposition features along the coastal area resulting from storm surges were measured and photographed. Trenching, coring, and pitting were made for examination of the washover sediment characteristics. The washover sediments were sampling systematically layer by layer from top to bottom. A detailed coastal topographical profile, using a digital survey camera, was performed. Grain size analysis was