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Ancient high-energy storm boulder deposits on Ko Samui, Thailand, and their significance for identifying coastal hazard risk

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ABSTRACT

Coastal geomorphic processes associated with high-energy storm events are difficult to estimate over recent geological history, though their frequency and magnitude are important to assess in order to understand present-day coastal vulnerability. Studying ancient coastal boulder deposits can shed light on the previous physical conditions necessary for their deposition. In this study, we estimated the physical processes required to move reef-derived coral boulders on the east coast of Ko Samui, a rapidly developing tourist island off eastern peninsular Thailand. The position and dimensions of 97 coral boulders (weight: mean 2.9 t, max. 12.7 t; transport distance: max. 125 m) were measured at two sites and dated using uranium/thorium methods. Flow velocities of 2.3–8.6 m/s were required to transport the measured boulders, with individuals deposited up to 4.7 m above mean sea level. Age-dating suggests that events capable of the highest flow velocities occurred around AD 1600 and AD 1750. These were probably driven by tropical cyclones (typhoons). Boulder transport by events of similar magnitude has not been detected within the last 250 years. The non-occurrence of similar events in living memory has implications for hazard perceptions at this important tourist destination. However, there is also evidence of substantial Holocene sea-level changes in the Gulf of Thailand, as observed at nearby Ko Phaluai. This potentially offers a challenge for the interpretation of older boulders dating from the mid-Holocene, as sea level may have been more than 2 m higher than present. Thus, studies using coral boulders as a proxy for past storm-wave conditions must consider the broader sea-level history, and are probably best limited to the period post-2000 BP in the Gulf of Thailand.

1. Introduction

The coast is a zone of continued rapid population expansion; over 40% of the world's population currently lives in the coastal zone (McGranahan et al., 2007), with further population increases driven by migration for industrial and tourism activities. These rapidly increasing coastal populations are vulnerable to a range of marine natural hazards, including accelerated sea-level rise, tsunamis and extreme storm events (the latter two known as high energy wave (HEW) events). By 2050, 350 million people globally are expected to be vulnerable to a 1-in-100-year coastal flooding event, with vulnerability disproportionately high in the tropics (IPCC, 2014). Tourism is a key driver of coastal population growth in emerging tourism markets such as Southeast Asia, which is currently the fastest growing tourism market (UNWTO, 2014). Ko Samui (9°30′N 100°00′E), a small island in the Gulf of Thailand, is indicative of broader regional trends, having experienced a rapid increase in tourism since the first European visitors in the 1970s. In coastal tourism hotspots such as Ko Samui, densely (though seasonally) populated urban developments are often located in the low-lying coastal zone owing to the suitable topography and easy access to tourism activities. Yet such locations may be at particular risk from coastal flooding events.

A common problem in natural hazard management is the issue of risk perception, especially for low-frequency HEW events that may have occurred beyond personal memory (sensu Kurita et al., 2007) or before written records began. An incomplete knowledge of event frequency may lead to an underestimation of risk and vulnerability. Thus, researchers are increasingly using geological evidence for palaeo-HEW events as a way of understanding long-term event frequency and estimating the probability of future events. Emerged coastal boulder deposits were first described as a potential proxy for high energy events in the early 20th century (e.g. Hedley and Taylor, 1907), and this is now an established field in palaeogeomorphology. The technique is particularly useful for coastal vulnerability studies for two reasons. Firstly, measuring the size, orientation and position of coastal boulder deposits may allow a distinction between different types of high energy event (Weiss, 2012), and thus has been used to identify potential tsunami- (Nott, 1997; Frohlich et al., 2009; Ramirez-Herrera et al., 2012) and

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storm-prone locations (Goto et al., 2009, 2011; Etienne and Paris, 2010; Etienne and Terry, 2012; Terry et al., 2016). Secondly, the subset of coral boulders in particular can give us an indication of frequency and return period of HEW events when combined with age-dating techniques (Nott, 1997; Suzuki et al., 2008). Both reasons allow coastal managers to understand the type and frequency of hazard local shorelines may experience, although distinguishing between tsunami and storm boulders is not always straightforward and often subject to controversy (Terry et al., 2013).

Coral boulder deposits quarried from adjacent living reefs may provide a good estimate of the frequency of HEW events through recent geological history, with some of the oldest boulders in the Gulf of Thailand and the South China Sea dated to approximately 4850 BC and AD 1050 respectively (Yu et al., 2009; Terry et al., 2016). Nonetheless, assessing the position of boulders faces two principal challenges over millennial time scales. Firstly, there is an assumption that the boulder was put into its current position due to a HEW event that corresponds to the date that the coral died, though boulders may have been reworked by several HEW events since coral death (Goto et al., 2010). Secondly, sea levels have varied markedly in many locations since the mid-Holocene, though boulder deposition studies normally examine position relative to the current observed sea level. Higher past sea level thus has an implication for interpreting the reach of palaeo-HEW events, an issue addressed in several previous coastal boulder deposition studies (Hearty, 1997; Kennedy et al., 2007; Pérez-Alberti et al., 2012).

The aim of this study was to assess the long-term vulnerability of Ko Samui to HEW events caused by tropical cyclones, using age-dated coral boulder deposits. To fully appreciate the coastal hazard exposure to large storms on the island, it is necessary to seek information that extends beyond historical records into the recent geological past. However, the period of time over which coral boulders can be deposited also encompasses long-term sea-level changes. Thus, a secondary aim is to consider the influence of past sea levels in the Gulf of Thailand on coral boulder production and on the appropriateness of using measured ages of coral boulders to represent the timing of past HEW events.

2. Study area

2.1. Ko Samui description

Ko Samui is situated in the Gulf of Thailand (GoT), approximately 35 km from the mainland coast of the Thai peninsula (Fig. 1). The island forms part of the Chumphon archipelago, 550 km south of Bangkok and is the largest island in the eastern GoT with an area of 230 km^2. Ko Samui falls within Surat Thani Province. This province is a strategic tourism area for Thailand, receiving over 1 million local and foreign tourists in 2007 (Chatkaewnapanon, 2011) and generating the third largest tourism revenue in Thailand (Vieregge et al., 2007). This tourism surge has brought with it trade-offs between substantial economic development and negative social and environmental impacts on the island, including increasing populations due to internal migration, alongside population increases due to tourist visitors (Soontayatron, 2014).

2.1.1. Study site 1 — Chaweng reef

Owing to inaccessible topography across much of the island, the resident and tourist populations of Ko Samui are found almost exclusively on the low-lying coastal margin, or close to the beaches. From its beginnings in the 1980s as a series of beach bungalows, Chaweng town (Fig. 2), is the most densely populated tourism location on the island, stretching along 6 km of beach. Few coastal protection measures are evident along the Chaweng coast, which together with uncontrolled development along the exposed east coast of Ko Samui (Green, 2005), means that Chaweng may be vulnerable to intense storm events that periodically affect the Gulf of Thailand.

North of Chaweng beach there is a granite headland surrounded by fringing coral reefs. A shallow salt water lagoon less than 2 m deep separates reef from the mainland. The orientation of reef crests and reef fronts reflects the prominent wind and wave directions during different times of the year (Fig. 2). The reef crest remains exposed at low tide and is therefore presumed to be an exposed Holocene feature indicative of a higher sea level in the past. Living corals on the seaward reef slope grow

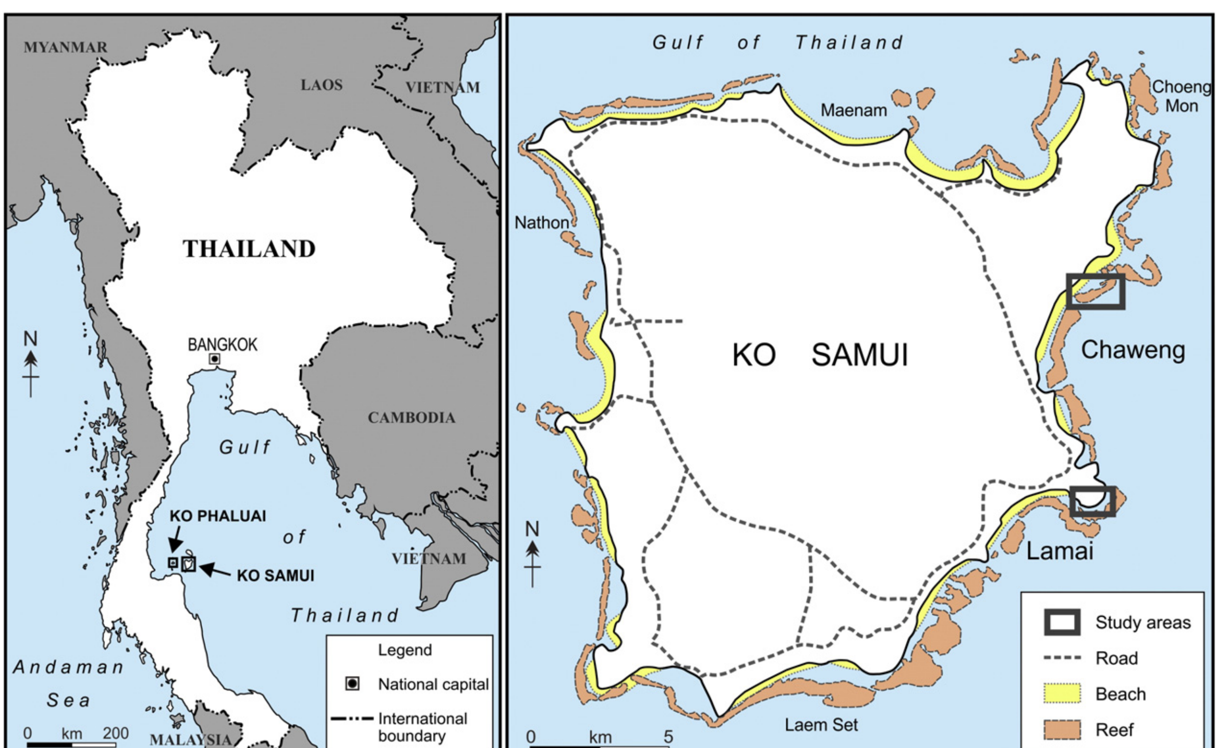

Fig. 1. Location of Ko Samui and Ko Phaluai in the western central Gulf of Thailand (Left). Coastline of Ko Samui showing the maximum extent of reefs and the location of Chaweng reef and Lamai cliff study sites on the exposed east coast (Right). Note: 'reefs' indicated are mainly shallow and discontinuous offshore features with veneers of living coral colonies.