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Elemental and mineralogical analysis of marine and coastal sediments from Phra Thong Island, Thailand: Insights into the provenance of coastal hazard deposits

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ABSTRACT

Sediment records left by coastal hazards (e.g. tsunami and/or storms) may shed light on the sedimentary and hydrodynamic processes happening during such events. Modern onshore and offshore sediment samples were compared with the 2004 Indian Ocean Tsunami, three palaeotsunami and a 2007 storm deposit from Phra Thong Island, Thailand, to determine provenance relationships between these coastal overwash deposits. Sedimentological and stratigraphic characteristics are generally inadequate to discriminate tsunami and storm deposits so a statistical approach (including cluster analysis, principal component analysis and discriminant function analysis) was used based on grain size, mineralogy and trace element geochemistry. The mineral content and trace element geochemistry are statistically inadequate to distinguish the provenance of the modern storm and tsunami deposits at this site, but the mean grain size can potentially discriminate these overwash deposits. The 2007 storm surge deposits were most likely sourced from the onshore sediment environment whereas all four tsunami units statistically differ from each other indicating diverse sediment sources. Our statistical analyses suggest that the 2004 tsunami deposit was mainly derived from nearshore marine sediments. The uppermost palaeotsunami deposit was possibly derived from both onshore and nearshore materials while the lower palaeotsunami deposits showed no clear evidence of their sediment sources. Such complexity raises questions about the origin of the sediments in the tsunami and storm deposits and strongly suggests that local context and palaeogeography are important aspects that cannot be ignored in tsunami provenance studies.

1. Introduction

Coastal areas offer favourable conditions to support dense human populations and critical infrastructure (Syvitski et al., 2009). These areas, however, are also vulnerable to coastal hazards, of which tsunamis and storms are the most disastrous (e.g. Switzer et al., 2014). A series of such disasters have occurred in the last decade, including the 2004 Indian Ocean Tsunami (IOT), Hurricane Katrina (2005), Cyclone Nargis (2008), the Tohoku-oki earthquake-induced tsunami (2011), Hurricane Sandy (2012), Typhoon Haiyan (2013) and Hurricane Patricia (2015). These disasters highlight the need for accurate coastal vulnerability assessments including the examination of the recurrence interval of such events. Understanding the recurrence interval of these events is crucial for future risk assessment (e.g., Switzer et al., 2014). Due to the inadequate and short historical records (i.e. frequently <100 years) in many affected areas, the geological record preserved along coasts may capture a much longer timeframe and provide evidence for historical occurrences and allow the determination of the recurrence intervals of tsunamis (e.g. Minoura et al., 2001; Jankaew et al., 2008; Monecke et al., 2008) and storms (e.g. Liu and Fearn, 2000; Nott, 2011).

Both tsunami and storm deposits are the result of overwash processes caused by high-energy events, and in many cases they exhibit very similar sedimentary signatures (e.g. Kortekaas and Dawson, 2007;

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Switzer and Jones, 2008). Thus, in order to accurately assess how frequently catastrophic events affect coastal regions, it is necessary to know whether the identified coastal washover deposit was caused by a tsunami or a storm event (e.g. Switzer et al., 2014).

Tsunami and storm deposits have been compared in numerous studies with an expectation of developing a suite of diagnostic criteria to distinguish deposits formed by different coastal overwash processes (e.g. Nanayama et al., 2000; Goff et al., 2004; Tuttle et al., 2004; Kortekaas and Dawson, 2007; Morton et al., 2007; Switzer and Jones, 2008; Phantuwongraj and Choowong, 2012). Nonetheless, criteria that have been used are still problematic and site specific or only valid for known events (Gouramanis et al., 2014b). Many of these studies have relied on sedimentological and stratigraphic signatures that can be found in both tsunamigenic and cyclonic deposits. For example, Shanmugam (2012) reviewed 15 sedimentological criteria that had been found in both tsunami and storm deposits and drew the conclusion that "there are no reliable sedimentological criteria for distinguishing paleo-tsunami deposits in various environments" (p. 23). Gouramanis et al. (2014b) used a multi-proxy approach (granulometric, loss on ignition, heavy minerals and microfossils) to statistically compare the 2004 IOT deposit and 2011 Cyclone Thane deposit superimposed at the same location along the southern coast of India. The Gouramanis et al. (2014b) study indicated that tsunami and storm deposits from the same site could not be distinguished using the standard sedimentological parameters typically used to identify coastal hazard deposits.

Thus, the difficulty of using conventional diagnostic criteria in differentiating coastal washover deposits requires the development of new and novel proxies.

In this study, we seek to test two hypotheses:

1. that the mineral composition, element geochemistry and grain size parameters of modern onshore, nearshore and offshore environments can be used to determine the provenance of the 2004 IOT and paleo-tsunami deposits, and the 2007 storm surge deposit preserved on Phra Thong Island, Thailand (Fig. 1); and
2. that the 2004 IOT, paleo-tsunami and the 2007 storm surge deposits can be distinguished using mineral composition, element geochemistry and grain size parameters.

To investigate these hypotheses, we apply several novel and seldom-used (for coastal hazard deposits) statistical techniques to gain insight into the provenance of the washover deposits and compare the deposits from different events and causal mechanisms (i.e. storm, recent and paleo-tsunami).

To date, little attention has focused on the mineralogy and geochemistry of overwash deposits (Chagué-Goff, 2010 and references therein). It is believed that the geochemical signature and mineral composition of tsunami sediments are source-dependent (Chagué-Goff et al., 2011; Goff et al., 2012), and are expected to reflect the origin of coastal overwash deposits (Font et al., 2013; Chagué-Goff et al., 2015). Addressing these issues will contribute a greater understanding of the sedimentation and hydrodynamic processes (i.e. erosion and deposition)

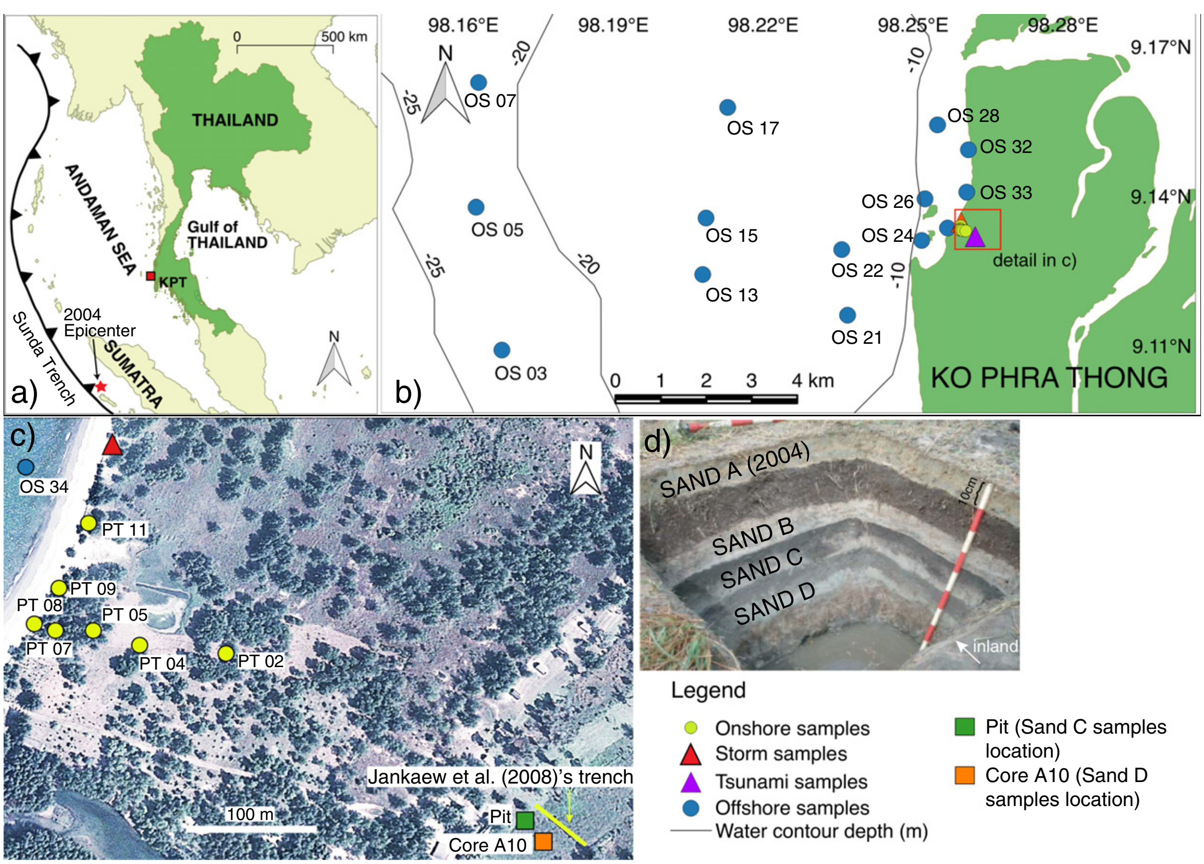

Fig. 1. a) The regional map shows the location of Phra Thong Island (Ko Phra Thong - KPT), Thailand (red square); b) the detailed map shows the locations of the offshore samples, onshore samples and the local bathymetry; c) A close-up view of the pre-2004 onshore samples (yellow dots), storm samples (red triangle), Sand C (green square, samples were collected from 40 to 43 cm depth from a pit), Sand D (orange square, samples were collected from 75 to 77 cm depth from an auger core (A10)) and the Jankaew et al. (2008)'s trench where Sand A and Sand B were taken; d) The stacked tsunami sand sheets from Jankaew et al. (2008).