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A mid-Holocene candidate tsunami deposit from the NW Cape (Western Australia)

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ABSTRACT

Although extreme-wave events are frequent along the northwestern coast of Western Australia and tsunamis in 1994 and 2006 induced considerable coastal flooding locally, robust stratigraphical evidence of prehistoric tropical cyclones and tsunamis from this area is lacking. Based on the analyses of X-ray computed microtomography (μCT) of oriented sediment cores, multi-proxy sediment and microfaunal analyses, optically stimulated luminescence (OSL) and ^{14}C-AMS dating, this study presents detailed investigations on an allochthonous sand layer of marine origin found in a back-barrier depression on the NW Cape Range peninsula. The event layer consists of material from the adjacent beach and dune, fines and thins inland, and was traced up to ~400 m onshore. Although a cyclone-induced origin cannot entirely be ruled out, the particular architecture and fabric of the sediment, rip-up clasts and three subunits point to deposition by a tsunami. As such, it represents the first stratigraphical evidence of a prehistoric, mid-Holocene tsunami in NW Western Australia. It was OSL-dated to 5400–4300 years ago, thus postdating the regional mid-Holocene sea-level highstand.

1. Introduction

The NW coast of Western Australia is impacted by 1–2 tropical cyclones per year, and ten tsunamis have been recorded since 1858, including those following the 1883 Krakatoa eruption and the earthquakes off the coast of Indonesia in 1977, 1994 and 2006 (Goff and Chagué-Goff, 2014). Although observations during these tsunamis are rather sporadic, wave heights of ~6 m (Cape Leveque) and a run-up of ~8 m Australian Height Datum (AHD) (Shelter Bay, Shark Bay) locally occurred during the 1977 Sumba and 2006 Java tsunamis, respectively (Prendergast and Brown, 2012; Goff and Chagué-Goff, 2014). At the North West Cape, the 1994 Java tsunami overwashed the dune barrier at Baudin (Fig. 1), 3.6 km S of the study area. Inundation extended up to 300 m inland, and a run-up of ~7 m AHD was inferred (Gregson and van Reeken, 1998). In addition, tropical cyclones cause extensive coastal flooding. As one of the most powerful cyclones in Australia's historical record, category 5 tropical cylone Vance (March 18th–22nd, 1999) resulted in water levels of ~7 m above event tide in the Exmouth Gulf (Nott and Hubbert, 2005). However, little is known about the geological imprint of historical (Prendergast and Brown, 2012; May et al., 2015a) and prehistorical extreme-wave events in northwestern Western Australia. So far, prehistorical tsunamis or storms were inferred from corals or large molluscs in washover deposits and dunes up to 1 km inland, or from marine organisms attached to wave-emplaced boulders (Scheffers et al., 2008, and references therein). These findings lack stratigraphic contexts, and uncertainties related to radiocarbon dating of reworked marine organisms (May et al., 2015a) or the marine palaeo-reservoir effect may bias the inferred chronologies.

This paper provides, for the first time, detailed stratigraphic evidence of a prehistoric extreme-wave event from northwestern Western Australia. Based on multi-proxy sediment and microfaunal analyses, optically stimulated luminescence (OSL) and ^{14}C-dating, an allochthonous sand layer of marine origin was identified in a mud-filled back-barrier depression at the NW coast of the Cape Range peninsula. As a novel approach in the context of tsunami deposits, X-ray computed microtomography (μCT) scans of oriented cores reveal characteristic sediment fabrics, which have been described from modern (Wassmer et al., 2010) and historical (Cuven et al., 2013) tsunami deposits but are rarely preserved in palaeotsunami deposits. We discuss the origin of the event layer against the background of its sedimentary characteristics and the local sedimentary environment.

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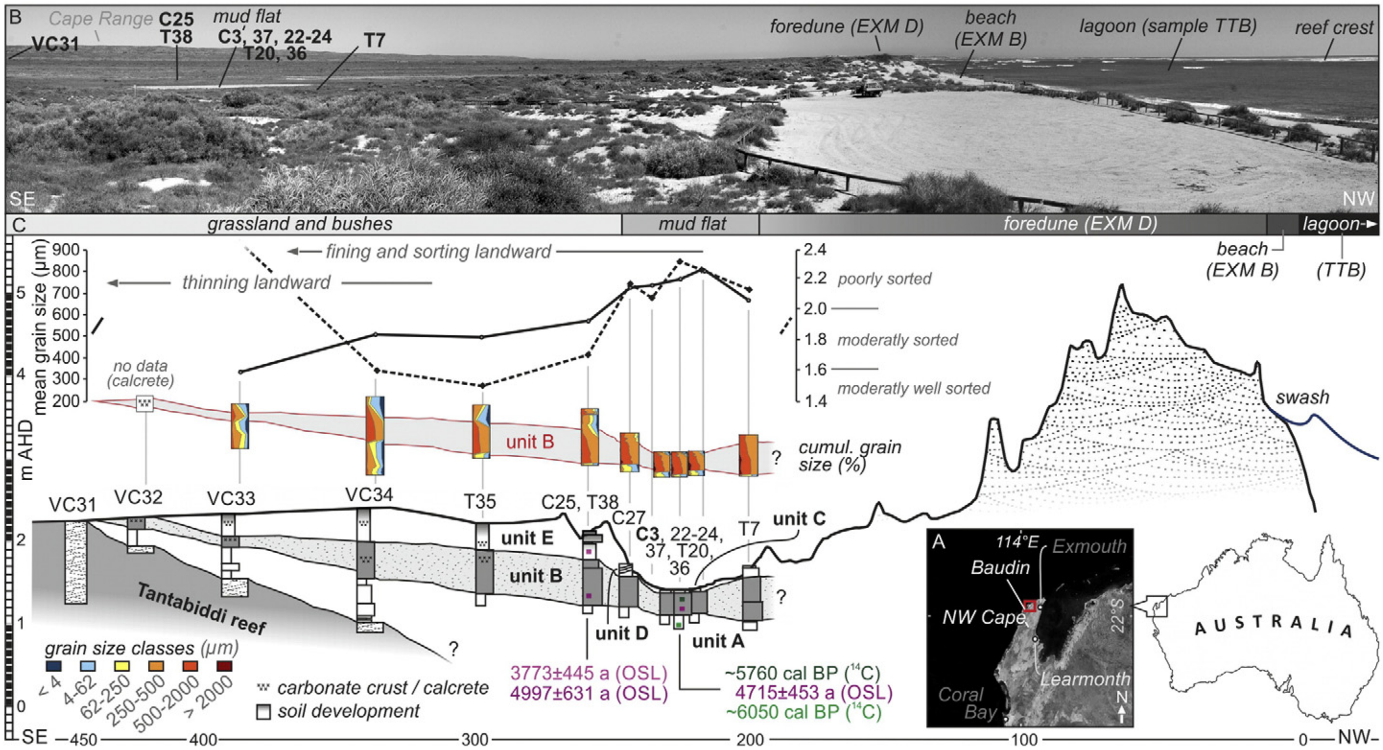

Fig. 1. (A) Overview of NW Western Australia [based on NASA Worldview data (NASA EOSDIS)]. Study site is marked by a red frame. (B) Panorama photo of study site (Ninety Mile Beach access) as seen from the top of the foredune (view towards SW). Location of sampling sites along the ~400 m long shore-perpendicular sediment transect (Fig. 1C) as well as of the modern samples are depicted. (C) Sediment transect with landward thinning and fining of unit B, and grain size distribution of cores/trenches.

2. Physical setting

Investigations were carried out in the low-lying back-barrier zone at Ninety Mile Beach access (21°50′28.03″S, 114°2′54.06″E), located in the northwestern part of the NW Cape (Western Australia). The site comprises a circular mudflat some 200 m from the sea, and slightly elevated low and open shrublands (Fig. 1). A dune belt of ~5 m AHD separates the site from the Ningaloo Reef, the local producer of bioclastic skeletal fragments. Heavy winds, sustained rainfall and severe flooding are mainly related to tropical cyclones during summer. The post-glacial marine transgression approached its maximum at ~7000–6000 years BP, when the formation of the Ningaloo Reef off the NW Cape had just started (Collins et al., 2003). A relative sea-level (RSL) highstand of 1–2 m above present level followed by a marine regression is documented for several coastal sections of Western Australia (Lewis et al., 2013; Engel et al., 2015) and is also assumed for the NW Cape.

The continuously falling RSL resulted in low sedimentation rates in coastal settings since c. 5000 years, impeding the accumulation of sediment archives suitable for storing palaeo-wave events (Nott, 2004). However, although its deposits have not yet been presented, the 1994 Java tsunami explicitly showed that considerable flooding of near-coast sediment archives may occur (Gregson and van Reeken, 1998), and palaeotsunami and palaeocyclone deposits may be stored in topographical lows.

3. Methods

3.1. Sedimentary analyses

Samples were taken from cores and trenches at 16 locations along a shore-perpendicular transect crossing a circular mudflat (Fig. 1) at Ninety Mile Beach access, starting at c. 200 m from the coast. The stratigraphical transect comprises trenches T7, T20 and T35, T36 and 38, percussion cores VC31–34 and push cores C3 (master core; Fig. 2), 22–25, 27 and 37. Percussion cores were taken using an Atlas Copco Cobra Pro percussion corer and probes of 6 cm in diameter. Push cores were taken by pushing plastic tubes also with a diameter of 6 cm into the sediment by hand. Cores and trenches reached depths between 50 and 150 cm below surface (b.s.), and sediment recovery amounted to a minimum of 90% during coring. The distance between sampling sites was between 5 and 50 m. Percussion cores and trenches were photographically documented and significant facies were sampled. Push cores were opened and sampled in the lab in steps of 0.5–1 cm. Elevation of the cores and profiles were measured using a Topcon HiPer Pro differential global positioning system (DGPS) with an altimetric accuracy of ~2 cm. Elevations given in AHD (Australian Height Datum) are based on DGPS measurements using the static mode and AUSPOS post-processing. Modern samples were taken from the present beach (EXM B), the dune (EXM D) and the lagoon some 450 m off the beach (i.e., the Holocene reef platform, TTB).

The coarse- and fine-grained fractions (>2 mm and <2 mm) were separated using a 2 mm sieve and weighed; percentage of the gravel fraction (>2 mm) is separately illustrated for master core C3. The air-dried fine-grained fraction was carefully hand-pestled for particle disaggregation. Grain size distribution of the fine-grained fraction was measured using a Beckman Coulter LS 13320 laser particle analyser (<2 mm). Samples were pre-treated with H_2O_2 (30%) to remove organic carbon and 0.5 N $Na_4P_2O_7$ (55.7 g/l) for aggregate dispersion. Statistical measures were calculated after Folk and Ward (1957) using the GRADISTAT software (Blott and Pye, 2001). In order to determine sedimentary environments and sediment source areas, microfaunal analyses (foraminifers, ostracods) were carried out for samples of master core C3 and for the modern samples. Samples (10 cm^3) were pre-treated with H_2O_2 (30%) for dispersion and sieved to isolate fractions of >100 and <100 µm. The microfaunal content was investigated under a binocular microscope and quantitatively recorded. A minimum of ~300 (foraminifers) and ~100 (ostracods) specimens per sample were counted where possible. We distinguished reworked and non-reworked