Geomorphology 257 (2016) 155–163

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

The magnitude of a mid-Holocene sea-level highstand in the Strait of Makassar

Thomas Mann [a,*], Alessio Rovere [a,b], Tilo Schöne [c], André Klicpera [a], Paolo Stocchi [d], Muhammad Lukman [e], Hildegard Westphal [a,f]

[a] Leibniz Center for Tropical Marine Ecology (ZMT), Fahrenheitstrasse 6, 28359 Bremen, Germany
[b] Center for Marine Environmental Sciences (MARUM), Leobener Strasse, 28359 Bremen, Germany
[c] Helmholtz Centre Potsdam (GFZ), Telegrafenberg, 14473 Potsdam, Germany
[d] NIOZ Royal Netherlands Institute for Sea Research, 1790AB Den Burg, Texel, Netherlands
[e] Research and Development Center for Marine, Coastal, and Small Islands, Hasanuddin University (MaCSI-UNHAS), Jl. Perintis Kemerdekaan Km. 10, 90245 Makassar, Indonesia
[f] Department of Geosciences, University of Bremen, Klagenfurterstrasse 2, 28359, Bremen, Germany

ARTICLE INFO

Article history:
Received 1 June 2015
Received in revised form 28 December 2015
Accepted 30 December 2015
Available online 31 December 2015

Keywords:
Indo-Pacific
Spermonde Shelf
Sulawesi
Glacial isostatic adjustment

ABSTRACT

Knowledge on the timing and magnitude of past sea-level changes is essential to understand modern and future sea-level variability. Holocene sea-level data from literature on the west coast of Sulawesi, central Indonesia, suggest that this region experienced two relative sea-level highstands over the last 6000 years, with magnitudes exceeding two meters. However, recent datasets from the Indo-Pacific region do not support high-magnitude sea-level oscillations during the Holocene in tectonically stable far-field locations. Here we present a new, high-precision, mid-Holocene sea-level dataset from the Spermonde Shelf off southwest Sulawesi. We surveyed 21 fossil microatolls on the reef flats of two coral islands (Pulau Panambungan and Pulau Barrang Lompo) and referred their elevations to local mean sea level and to the height of living coral. Radiometrically calibrated ages from emergent fossil microatolls on Pulau Panambungan indicate a relative sea-level highstand not exceeding 0.5 m above present at ca. 5600 cal. yr BP. The highstand is followed by a relatively rapid sea-level fall towards present sea level that was reached at around 4000 cal. yr BP. Fossil microatolls from nearby Pulau Barrang Lompo show the same trend, however with a coherent negative vertical offset of about 0.8 m compared to their equivalents on Pulau Panambungan. The largely consistent gradients of both trends (~−0.14 mm yr^{-1}), the consistent elevation of living microatolls in the Spermonde, and a number of instructive geomorphic features indicate a localized, post-formational and probably recent drop of the fossil microatolls on the densely populated island Pulau Barrang Lompo. The relative sea-level trend inferred from Pulau Panambungan is well within the range of geophysical predictions based on ANICE-SELEN ice sheet model, which predict a highstand that is significantly lower than those predicted by other GIA models for this area. Although a complete interpretation of the Holocene sea-level history will require additional high-resolution datasets from this and surrounding territories in SE Asia, our results suggest that there was merely a single Holocene highstand in central Indonesia, the magnitude of which was substantially lower than hitherto assumed.

1. Introduction

Regional variability of sea-level changes since the Last Glacial Maximum (LGM; ~20 kyr BP) is the result of combined isostatic, gravitational and other post-depositional processes (e.g., tectonics) influencing the signal recorded in sea-level markers at each particular location on Earth (Shennan and Horton, 2002; Milne et al., 2005; Lambeck et al., 2014; Vacchi et al., 2014; Engelhart et al., 2015). Sites near the former ice sheets experienced strong isostatic lithospheric uplift after glacial retreat, combined with a simultaneous decrease of gravitational pull on the adjacent water masses. These combined processes caused a fall in relative sea level (RSL) along coastlines in higher latitudes during the Holocene (Shennan and Horton, 2002; Gehrels and Long, 2008).

Studies that aimed to provide a better understanding of the eustatic component of RSL changes after the LGM have focused on tectonically stable far-field locations (Clark et al., 1978), located distant from the former ice margins and thus not directly affected by ice-proximal glacial isostatic adjustment (GIA). However, effects of GIA are also pronounced in low latitudinal zones (Mitrovica and Peltier, 1991; Peltier, 1999), mainly as a consequence of subsiding peripheral forebulges and sublithospheric mantle flow that caused a redistribution of water masses away from the equator to higher latitudes. This mechanism

* Corresponding author.
E-mail address: thomas.mann@leibniz-zmt.de (T. Mann).

http://dx.doi.org/10.1016/j.geomorph.2015.12.023
0169-555X/

(i.e. equatorial ocean syphoning) explains the late Holocene RSL fall in low latitudes which is predicted by geophysical models (Mitrovica and Milne, 2002) and detected, for example, in the Indian Ocean (Woodroffe et al., 1990; Kench et al., 2009).

A highstand preceding RSL fall may lead to locally subsiding seafloors (i.e. hydro-isostasy) depending on the viscoelastic structure of the underlying, heterogeneous mantle (Lambeck et al., 2002). Consequently, in far-field areas where water input and hydro-isostasy simultaneously offset each other, RSL stability is recorded during the middle to late Holocene (Woodroffe et al., 2012). In order to improve our understanding of climate dynamics, past ice volume changes, ice-equivalent sea level and solid Earth responses, additional RSL records from localities unaffected by major tectonic and glacial isostatic contributions are required (Lambeck et al., 2002, 2010).

This study presents new survey and radiocarbon data of living and fossil microatolls in the Spermonde Archipelago, southwest Sulawesi, Indonesia. The Republic of Indonesia is the largest island state in the world and, in the light of its dense population and a relatively low adaptive capacity, its coastlines may be particularly sensitive to future sea-level rise (Nicholls and Cazenave, 2010). Adaptation strategies to projected sea-level rise scenarios would benefit from information about RSL changes in the recent geological past, if available for the particular region. The aim of this study is to reconstruct mid-Holocene RSL trends in this area from microatoll records, and to evaluate the reliability of RSL oscillations that were inferred previously.

2. Regional setting and previous RSL investigations

Sulawesi is a volcanic island in the central part of Indonesia, roughly located between 2°00′N–6°00′S latitudes and 118°00′E–125°00′E longitudes (Fig. 1A). The Spermonde Archipelago is situated between the Strait of Makassar to the west and the southern arm of Sulawesi to the east (Fig. 1B, C). Sulawesi has a complex tectonic structure (Hall, 1997; Bird, 2003). North Sulawesi and the North Makassar Basin are characterized by the occurrence of subduction zones, continental rift boundaries and numerous major active faults (Bird, 2003; Fig. 1B). The largest lateral faults in that area (i.e. Paternoster Fault and Palu Korog Fault) show a sinistral direction of motion and strike NW–SE and NNW–SSE, respectively. These are complemented by several smaller lateral faults striking in the same general direction, and a number of thrust faults striking NE–SW with a southeastern dip direction.

The Spermonde Archipelago lies in the South Makassar Basin, distant from the active Paternoster Fault (Fig. 1B). While along and north of the Paternoster Fault major earthquakes and tsunamis occur (Prasetya et al., 2001), orogenic events in southwest Sulawesi were constrained to the period from Miocene to Pliocene/Pleistocene, and volcanic activity almost completely ceased in the early Quaternary (Sasajima et al., 1980). Unfortunately, little is known about the tectonic activity of the Spermonde Archipelago during the Holocene. Yet, in the available literature, there are no indications for major faults or fracture zones within the Spermonde (Prasetya et al., 2001; Bird, 2003). Recent-past GPS data indicate stable conditions for the study area, i.e. no differences in relative plate velocities (Walpersdorf et al., 1998), and today, only a few deep-focus earthquakes occur in southwest Sulawesi (http://earthquake.usgs.gov).

The Tertiary carbonate platform underlying the Spermonde Archipelago consists of undeformed sediments and is bounded to the Strait of Makassar by a discontinuous barrier, separating the shallow-marine shelf from deeper waters (Bergman et al., 1996; Renema and Troelstra, 2001). On the shallow-marine platform, patch reefs form localized build-ups on top of which a number of coral islands developed (Fig. 1C; Umbgrove, 1928; Wijsman-Best et al., 1981; Renema, 2002). Most of these islands, including two of the islands studied here, Pulau Barrang Lompo and Pulau Sanane, are densely populated (Fig. 2A, B; Schwerdtner Máñez et al., 2012). The third study island, Pulau Panambungan, is uninhabited today and except for an abandoned resort

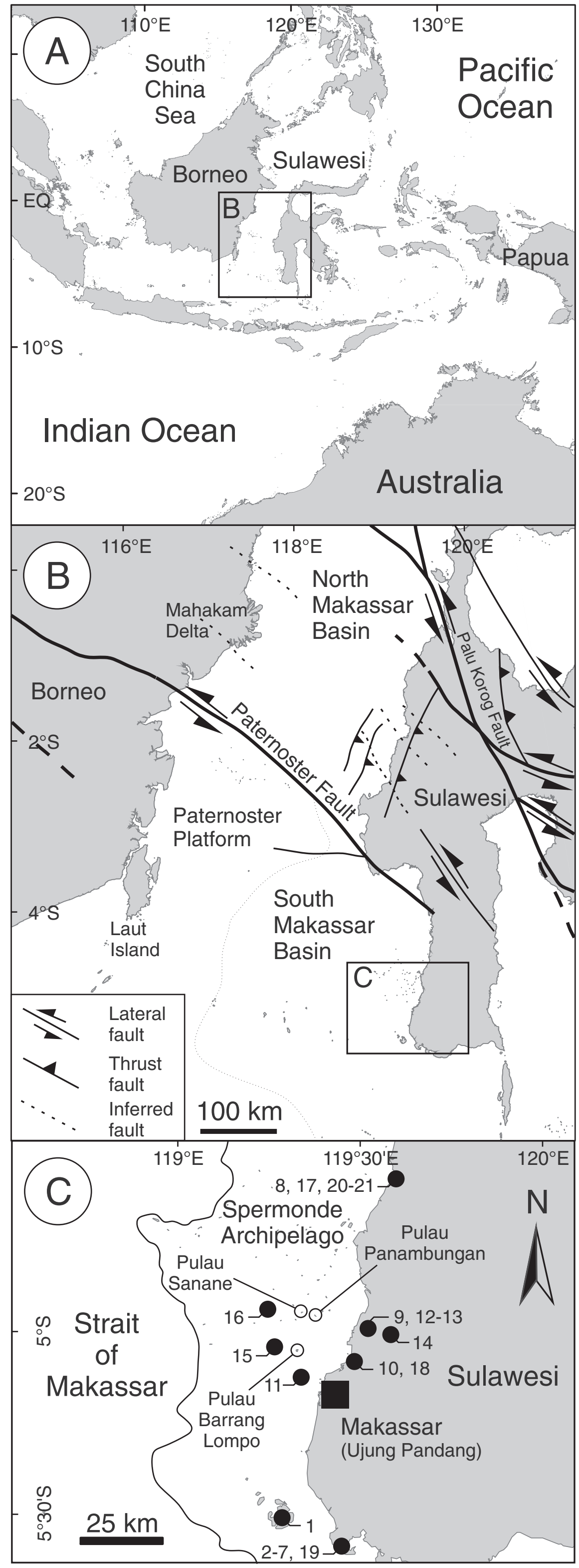

Fig. 1. (A) Location of Sulawesi in the central part of Indonesia. (B) General tectonic setting for western Sulawesi and the Makassar Strait region. Adopted from Darman (2014). For the classification of tectonic features see legend within the figure. (C) Location of the Spermonde Archipelago between southwest Sulawesi and the Strait of Makassar. The study islands, Pulau Barrang Lompo, Pulau Sanane and Pulau Panambungan, are encircled and named accordingly. Black solid circles indicate study locations of De Klerk (1982). For designated sample numbers refer to Table 1. The black solid line indicates the position of the shelf break.