Marine Geology 348 (2014) 37–43

Contents lists available at ScienceDirect

Marine Geology

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

Letter

Sedimentary record of late Holocene event beds in a mid-ocean atoll lagoon, Maldives, Indian Ocean: Potential for deposition by tsunamis

Lars Klostermann [a,*], Eberhard Gischler [a], David Storz [b], J. Harold Hudson [c]

[a] Institut für Geowissenschaften, Goethe-Universität Frankfurt, Altenhoeferallee 1, 60438 Frankfurt am Main, Germany
[b] Biodiversity and Climate Research Center (BiK-F) Frankfurt, Senckenberganlage 25, 60325 Frankfurt am Main, Germany
[c] Reef Tech Inc., 8325 SW 68th Street, Miami, FL 33143, USA

ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form 20 November 2013
Accepted 23 November 2013
Available online 4 December 2013

Communicated by: J.T. Wells

Keywords:
Maldives
Holocene
atoll lagoon
tsunami
storm
event

ABSTRACT

Six Holocene sedimentary events (ranging in age from 420–890, 890–1560, 2040–2340, 2420–3380, 3890–4330, and 5480–5760 yrs BP) have been identified in the lagoon of Rasdhoo Atoll (Maldives; 4°N, 73°W), thereby underlining the importance of atoll lagoons as potential archives of environmental change. Holocene coastal sediments have been studied as archives for past tsunami and storm events but comparable sedimentological studies of mid-ocean atoll lagoons are rare. In ten vibracores covering the past 6.5 kyrs that are characterized by mudstone, wackestone, and floatstone background sedimentation, we found two types of event deposits: (1) several cm thick rudstone layers with redeposited corals like *Acropora* sp. and *Seriatopora* sp., which derive from the marginal and/or lagoonal reefs and have been transported into the lagoon and (2) thin (several mm) layers of wackestone, floatstone, and rudstone consisting of reef-derived components like coralline red algae, reef foraminifera (e.g., *Amphistegina* spp., *Calcarina* sp.), and redeposited coral fragments. Both types of event layers may be correlated among several cores, which we interpret as tsunami deposits. Five of the six events have temporal counterparts identified at the coasts of Thailand, Sumatra, and India. In the Maldives, close to the equator, no category 1–5 typhoons were recorded, but only tropical depressions and storms as potential triggers of event sedimentation have occurred rarely. Major earthquakes off western Indonesia and generated tsunamis, which potentially reach most parts of the Indian Ocean, are common.

1. Introduction

In the eastern Indian Ocean off Sumatra and the Andaman Islands, earthquakes are common due to the subduction of the Indian Plate beneath the Eurasian Plate (e.g., Newcomb and McCann, 1987). Strong earthquakes are generating tsunami waves that threaten human lives and ecosystems at the coastlines around and in the Indian Ocean. Kan et al. (2007) and Kench et al. (2008) described the effect of the tsunami on Maldivian islands generated by the catastrophic 9.2 magnitude Sumatra earthquake of 26 December 2004, which triggered wave heights of up to 1.8 m in the Maldives. Tsunami waves induce enough energy to transport and deposit grain sizes from clay to even boulders (Dawson and Stewart, 2007; Bahlburg and Spiske, 2012; Goff et al., 2012). Impacts of tsunami waves on atolls cause the transport of coarse skeletal material like coral fragments, coralline algae, and typical reef foraminifera from shallow marginal and lagoonal reefs to the deeper lagoon floor (Gischler and Kikinger, 2006). In a similar way, storms may cause reefal material to overtop reef margins and deposit coarse sediment in back-reef lagoons (Scoffin, 1993; Harmelin-Vivien, 1994; and references therein). However, evidence of tsunami and/or storm events has only been identified rarely in atoll lagoon cores. Yu et al. (2009) investigated sediment cores of an atoll lagoon in the South China Sea and dated several sedimentary events over the past 4 kyrs using redeposited coral blocks, but could not distinguish between tsunami and storm deposits. Based on grain-size variability in mid–late Holocene lagoon cores from a south Pacific reef lagoon, Toomey et al. (2013) identified two phases of increased storm activity during the past 5 kyrs.

Previous studies of Holocene tsunami or storm events at coastal sediment sites around the Indian Ocean focused on the west coast of Thailand (Harper, 2005; Jankaew et al., 2008; Fujino et al., 2009; Brill et al., 2011), northern Sumatra (Monecke et al., 2008), eastern India (Rajendran et al., 2006), and the Andaman Islands (Malik et al., 2010) and documented several events during the last 2 kyrs.

Differences between depositional events like gravity mass movements, storms, and tsunamis are discussed by Einsele et al. (1996) and Morton et al. (2007), nevertheless, robust criteria to distinguish storm and tsunami deposits are lacking. Einsele et al. (1996) explained that gravity mass movements are induced by storm and tsunami waves, but especially tsunami waves produce slope failures.

In contrast to many other tropical reef areas, the cyclone activity in the northern Indian Ocean, especially in the Arabian Sea, is relatively low (Sing et al., 2000; Webster et al., 2005). The location close to the

* Corresponding author. Tel.: +49 69 798 40174.
E-mail address: klostermann@em.uni-frankfurt.de (L. Klostermann).

0025-3227/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.margeo.2013.11.014

equator prevents major parts of the Maldives from being hit by strong cyclones (e.g., Woodroffe, 1992), which largely excludes storms as triggers of coarse-grained event layer formation. Therefore, the objectives of this study are to identify coarse-grained event layers in fine-grained lagoonal successions of a Maldivian atoll, relate these layers to paleotsunamis, and evaluate the quality of this tsunami archive.

2. Regional setting

The Maldivian archipelago, located in the Indian Ocean southwest of India (7°N to 1°S at 73°E), forms an elongated chain of twenty-one atolls and four reef-fringed islands (Fig. 1). The entire Maldives carbonate platform covers an area of 107,500 km^2 including reefs, lagoons, seaways, and some 1200 islands with a maximum elevation of 5 m above sea level. Rasdhoo Atoll is located in the central part of the archipelago, has a diameter of 9.25 km, and covers 62 km^2. The lagoon is up to 40 m deep and harbors numerous patch reefs. Three channels interrupt the marginal reef, connecting the interior lagoon with the open ocean. Modern reef facies are coralgal grainstones and lagoonal facies include wackestone, mudstone, and hardgrounds in the vicinity of channels (Gischler, 2006).

Climate and hydrography in the Maldives is strongly influenced by the Indian Monsoon (Storz and Gischler, 2011). During May to September, strong winds from the southwest, increased precipitation and storms predominate, whereas from November to March, weaker winds from the NE with lower rainfall frequency characterize the study area. Two tropical storms (1991, 2006) and three tropical depressions (1992, 1993) have crossed the northern part of the Maldives archipelago since 1945 according to the Joint Typhoon Warning System (http://www.usno.navy.mil/JTWC) and the tropical cyclone dataset (http://www.nhc.noaa.gov/ data).

3. Methods

During an expedition in November–December 2010, forty-two stations in the Rasdhoo Atoll lagoon were selected for coring with a Rossfelder electrical vibracorer connected to 6 m-long aluminum pipes. The ten cores investigated here are located along the margin and in the center of the lagoon. Water depths range from 12.6 to 20 m at the marginal coring sites (1, 12, 18, 19, and 26) and from 28.5 to 37.5 m at the central coring sites (8, 24, 39, 31, and 34). Cores 8, 12, 18, 19, 24, 29, 31, and 34 were sampled at 10 cm-intervals and cores 1 and 26 with varying sample distances. All samples (n = 203) were sieved through 0.125 mm and 2 mm sieves. Thin-sections (n = 133) of the 2–0.125 mm grain-size fraction were investigated with a polarization microscope and the composition was quantified by point-counting two-hundred components per section (van der Plaas and Tobi, 1965). We described the sediments according to the carbonate nomenclature of Dunham (1962), which was extended by Embry and Klovan (1972). Even though the nomenclatures were developed for rocks, they have been commonly used in sediments among carbonate sedimentologists since several decades. We chose 50% "mud" (grain-size fraction <125 μm) as the boundary between mud-supported and grain-supported textures. Facies were defined based on a cluster analysis of the composition and texture data (dendrogram not shown; detailed sedimentological results will be published elsewhere). Corals were identified using the reports of Pillai and Scheer (1976) and Ciarapica and Passeri (1993), and the compendium of Veron (2000). Thirty-six samples of bulk sediment and one shell sample were dated radiometrically with accelerated mass spectroscopy (AMS) and eight corals were dated using the standard radiocarbon ^{14}C-method by Beta Analytic Inc., Miami, Florida (Table 1).

4. Results and interpretation

We identified six event horizons (Fig. 2) with age ranges of 420–890 yrs BP (event 1), 890–1560 yrs BP (event 2), 2040–2340 yrs BP (event 3), 2420–3380 yrs BP (event 4), 3890–4330 yrs BP (event 5), and 5480–5760 yrs BP (event 6) that are characterized by (1) mm-thin coarse-grained, reef-derived layers within finer-grained background sedimentation and by (2) cm-thick layers of allochthonous shallow-water corals such as *Acropora* sp., *Pachyseris* sp., *Seriatopora* sp., *Merulina* sp., *Cyphastrea* sp., *Goniopora* sp., and fungiids (Table 2). Spatial patterns of distribution of event layers in the Rasdhoo lagoon are limited. Event layers 1 and 4 cover the eastern and northeastern parts of the lagoon, respectively. Event layers 1 and 4 have the greatest lateral extents (Figs. 1, 2). We interpret these event horizons as tsunami deposits.

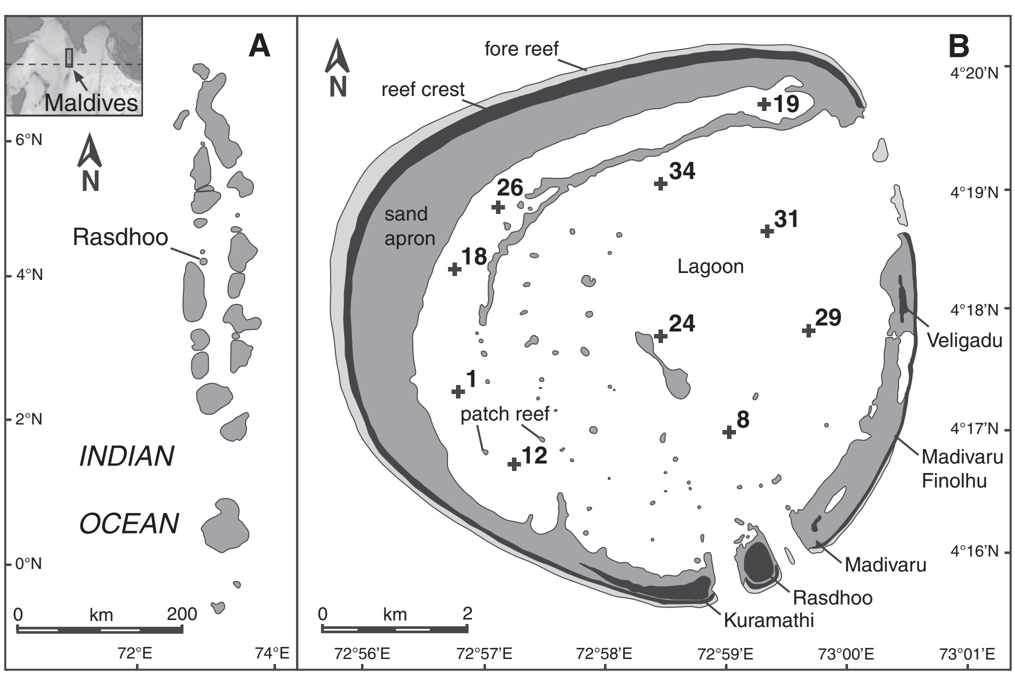

Fig. 1. A. Location of the Maldivian archipelago and Rasdhoo Atoll in the Indian Ocean. B. Locations of ten investigated core stations within Rasdhoo Atoll lagoon.