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Last interglacial reef facies and late Quaternary subsidence in the Maldives, Indian Ocean

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ABSTRACT

To date, there is hardly any knowledge of facies and age of Pleistocene reef limestone in the Maldives. Likewise, there are no robust estimates of Quaternary subsidence in this major shallow-water carbonate platform and reef area. In a core recovered on the windward margin of Rasdhoo Atoll in the central part of the archipelago, Pleistocene coralgal grainstone facies belonging to marine isotope stage (MIS) 5e were recovered underlying a Holocene reef succession, 14.5 m below modern sea level. Based on the occurrence of shallow-water stony corals such as *Isopora palifera* and possibly *Acropora* gr. *robusta*, high-energy coralline algae including *Porolithon onkodes*, in part associated with vermetids, and grain-supported limestone texture, the paleoenvironment is interpreted as a shallow back reef area with a paleo-waterdepth of < 10 m. Based on a reliable U-series age from a Pleistocene acroporid coral of 136.9 kyr BP and assuming a + 7.5 m higher-than-present peak sea level during MIS 5e, late Quaternary subsidence is estimated to 0.09 m/kyr (minimum)–0.16 m/kyr (maximum value). A sea level of +2.5 m during the early MIS 5e would reduce the rates to 0.05 m/kyr (minimum)–0.12 m/kyr (maximum). These numbers are significant for reconstructions of depositional environments of this major carbonate platform area in the Quaternary. The subsidence estimates are not as crucial for historical reconstruction of relative sea level and for predictions of the near future in this low-lying archipelago, because they will add only a minor portion to the predicted rates of 21st century sea-level rise.

1. Introduction

The Maldives archipelago is located in the northwestern Indian Ocean and consists of some 1200 sand and rubble islands the elevation of which does not exceed 5 m (Purdy and Bertram, 1993; Naseer and Hatcher, 2004). Therefore, the Republic of Maldives is considered the flattest country on earth. Islands cover some 160 km^2 in total, and are located on the reef margins and on lagoonal reefs of 25 atolls that cover some 21,370 km^2 (Gischler et al., 2014). Because of their low elevation, the islands and their approximately 420,000 inhabitants are threatened by sea-level rise (Singh et al., 2001; Khan et al., 2002; Woodworth, 2005), waves and swells (Harangozo, 1992), and tsunamis (Kench et al., 2006). The late Holocene sea-level history is not very well constrained due to the relatively low amount of data (Woodroffe, 2005). The late Holocene sea-level data of Mörner (2004) and Mörner et al. (2004), which is based largely on the dating of island sediments is disputed (Kench et al., 2005; Mörner and Tooley, 2005). More reliable Holocene sea-level curves, based on age data of corals recovered from drill cores, show a steep rise from 9 to 6 kyr BP and a subsequent decrease of the rate of sea-level rise (Gischler et al., 2008; Kench et al., 2009). Kench et al. (2009) suggested a slight (ca. 0.5 m) higher-than-present sea level from 4 to 2 kyr BP based on limited microatoll data from the central part of the archipelago. This appears to confirm a sea-level reconstruction based on an elevated fossil coral from the southern part of the Maldives (Woodroffe, 1992, 2005). Sea-level data from other reefal archipelagoes in the western Indian Ocean are not entirely conclusive with regard to a late Holocene highstand (Camoin et al., 2004; Woodroffe et al., 2015). A late Holocene highstand is evident based on microatoll data from Cocos-Keeling Atoll in the eastern Indian Ocean (Woodroffe, 2005, and references therein). Sea levels of the last glacial maximum and the postglacial-to-Holocene period have been identified in the Maldives in the form of so far undated submarine terraces on outer slopes down to 130 m water depth (Anderson, 1998; Fürstenau et al., 2010; Rovere et al., 2018).

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None of the existing Quaternary sea-level reconstructions in the Maldives have been corrected for the effect of subsidence. Deep exploration drilling has shown that the 55 Myr old volcanic edifice of the Maldives is overlain by some 2.1 km of platform carbonates (Purdy and Bertram, 1993; Aubert and Droxler, 1996). The resulting average long-term subsidence rate is 0.038 m/kyr. However, Quaternary deposits were not sampled by these deep drillings. Pleistocene reef limestone has been recovered in shallow core holes below Male island, located at the southern end of North Male Atoll (Woodroffe, 1992), and below Hulhudhoo island, at the southern end of South Malosmadhullo Atoll (Kench et al., 2009). However, their facies and age were not investigated. Gischler et al. (2008) recovered Pleistocene reef limestone below Rasdhoo Atoll, provided a brief facies description, the first age data, and speculated about late Quaternary subsidence rate. Still, no systematic and rigorous facies analysis including identifications of depth-diagnostic corals and coralline algae were made. For these reasons, this study was designed to describe in detail facies and interpret paleo-bathymetry of one of the rare occurrences of Pleistocene shallow-water limestone from the Maldives with the aim of producing a robust estimate of subsidence of this major carbonate platform area.

2. Setting

The Maldives archipelago is some 900 km long and some 150 km wide covering an area of > 100,000 km^2 (Fig. 1A). There are 25 atolls that form a double row in the central part of the archipelago enclosing the up to 400 m deep area of the Inner Sea (Purdy and Bertram, 1993). More than 2 km of carbonate accretion over the volcanic basement of the Maldives since the Eocene has been controlled by an interplay of subsidence and sea-level fluctuations (Purdy and Bertram, 1993; Aubert and Droxler, 1996), causing phases of aggradation, progradation, retrogradation, and drowning. More recently, Betzler et al. (2013) and Lüdmann et al. (2013) have shown that in addition to sea level, strong bottom currents have been integral for the development of platform architecture and the formation of periplatform sediments during the Neogene.

Rasdhoo Atoll belongs to the group of smaller atolls in the Maldives, and is located in the western part of the archipelago. It is 62 km^2 in size and has a ring-shaped reef margin encircling an up to 40 m deep lagoon with small, pinnacle-shaped patch reefs (Fig. 1B). The reef margin consists of a sloping forereef with spurs and grooves, a very shallow reef crest, and a wide sand apron up to 5 m deep that abruptly drops to the lagoon floor. There are five rubble-sand islands on the margin, which is connected to the surrounding ocean by two channels. Surface sediments include coral grainstone at the margin and on lagoonal reefs, and mollusk wackestone-to-packstone, and mudstone within the lagoon (Gischler, 2006). Holocene marginal reefs are largely composed of acroporid corals and lagoonal reefs of massive *Porites*. Reef thickness ranges from 14.5 m to > 22 m, and Holocene accretion rates have exceeded 15 m/kyr (Gischler et al., 2008). Lagoonal sediments include mollusk-rich, coral-rich, and foraminifer-rich floatstone, rudstone, and wackestone, as well as mudstone (Storz et al., 2014; Klostermann and Gischler, 2015) with intercalated event (tsunami) deposits (Klostermann et al., 2014). Lagoonal sediment thickness exceeds 6 m in the western part of the atoll. A total of 99 coral species (Scheer, 1974) and 218 benthic foraminiferal species in six assemblages (Parker and Gischler, 2011) have been reported from Rasdhoo Atoll.

3. Materials and methods

Core Rasdhoo 1 (04°18′03″N, 72°55′56″E), the lower part of which was analyzed in detail here, was recovered in March 2007 with a portable, rotary drill system and 1.5 m long wireline core barrel, at 1 m below modern average sea level on the western atoll margin of Rasdhoo Atoll (Fig. 1B). The drilling penetrated a 13.5 m-thick Holocene acroporid-rich succession that is 8215 ± 185 kyrs cal BP at the base (Gischler et al., 2008). The underlying Pleistocene succession sampled (Fig. 2) is 3.5 m thick. Recovery in the Pleistocene ranged from 85 to 100% (mean 95%). One reliable and two moderately reliable U-series ages have been obtained previously (Gischler, 2008; Gischler et al., 2008). The reliable age of 136.9 ± 2.0 kyrs BP stems from an acroporid coral that contained 99% aragonite (Table 1). Two additional U-series

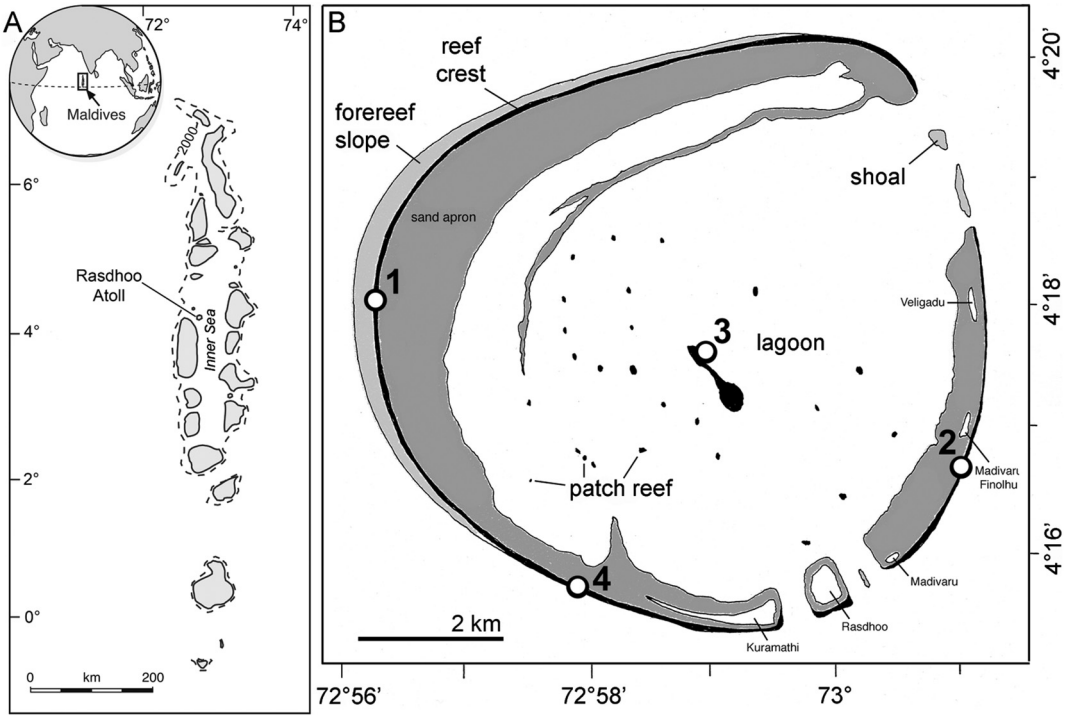

Fig. 1. Location map of the Maldives archipelago (A) and drill site 1 on western margin of Rasdhoo Atoll (B). Drill cores 2–4 did not reach the Pleistocene. Modified from Gischler et al. (2008) and Parker and Gischler (2011).