GEOLOGY | THE GEOLOGICAL SOCIETY OF AMERICA®

https://doi.org/10.1130/G49090.1

Manuscript received 24 March 2021
Revised manuscript received 14 June 2021
Manuscript accepted 17 June 2021

# Current and sea level control the demise of shallow carbonate production on a tropical bank (Saya de Malha Bank, Indian Ocean)

Christian Betzler[1]*, Sebastian Lindhorst[1], Thomas Lüdmann[1], John J. Reijmer[2], Juan-Carlos Braga[3], Or M. Bialik[4], Jesus Reolid[3], Jan Oliver Eisermann[1], Kay Emeis[1,5], Tim Rixen[1,6] and Dass Bissessur[7]

[1]Institut für Geologie, Universität Hamburg, Bundesstraße 55, 20146 Hamburg, Germany
[2]Earth Science Department, Vrije Universiteit Amsterdam, De Boelelaan 1085, 1081 HV Amsterdam, The Netherlands
[3]Departamento de Estratigrafía y Paleontología, Facultad de Ciencias, Universidad de Granada, Avenida de la Fuente Nueva S/N, 18071 Granada, Spain
[4]Department of Geosciences, Faculty of Science, University of Malta, Msida MSD 2080, Malta
[5]Helmholtz-Zentrum Geesthacht, Max-Planck-Straße 1, 21502 Geesthacht, Germany
[6]Leibniz-Zentrum für Marine Tropenforschung, Fahrenheitstraße 6, 28359 Bremen, Germany
[7]Department for Continental Shelf, Maritime Zones Administration and Exploration, 12 Intendance Street, Port-Louis 11328, Mauritius

## ABSTRACT

**Carbonate platforms are built mainly by corals living in shallow light-saturated tropical waters. The Saya de Malha Bank (Indian Ocean), one of the world's largest carbonate platforms, lies in the path of the South Equatorial Current. Its reefs do not reach sea level, and all carbonate production is mesophotic to oligophotic. New geological and oceanographic data unravel the evolution and environment of the bank, elucidating the factors determining this exceptional state. There are no nutrient-related limitations for coral growth. A switch from a rimmed atoll to a current-exposed system with only mesophotic coral growth is proposed to have followed the South Equatorial Current development during the late Neogene. Combined current activity and sea-level fluctuations are likely controlling factors of modern platform configuration.**

## INTRODUCTION

Carbonate platforms are edifices kilometers high and hundreds of kilometers wide produced mostly by shallow-water organisms, such as reef-building zooxanthellate corals, and by their detritus. Platforms thrive for millions of years in the tropical belt of the oceans, many isolated from continental areas. Coral reefs reach sea level, mainly along the platform rims, such as, e.g., in the Indo-Pacific biogeographic region. Light availability as well as water temperature, turbidity, salinity, nutrients, and current velocity determine the depths at which corals and their photosynthetic symbionts thrive (Schlager, 2005). Coral reefs, amongst the most productive marine ecosystems, flourish in oligotrophic waters.

Sea-level change exerts a fundamental control on reef development at geological time scales (Webster et al., 2018). Reefs migrate sea-ward and platform-ward following falling or rising sea level, whereas a sea-level rise outpacing reef growth interrupts reef development. In the Indo-Pacific biogeographic region, reefs that are now submerged and do not reach sea level are typically structures of Pleistocene age with a thin coralgal cover deposited during a brief episode of recolonization in deglacial time (Montaggioni, 2005). Apart from sites subject to tectonic uplift, incipient buildups that formed before 19 kyr B.P. were drowned. Some reefs were able to keep up with deglacial sea-level rise, but others, for reasons that are not fully understood, were not (Montaggioni, 2005; Woodroffe and Webster, 2014; Webster et al., 2018). The latter are today the sites of many mesophotic coral ecosystems.

The Saya de Malha Bank in the Indian Ocean lies in the window of optimal conditions for shallow-water reef development, but the carbonate platform today is mostly populated by mesophotic coral ecosystems. Using geophysical, oceanographical, and sedimentological data, we studied how ocean currents shape this platform and how—along with sea-level changes—they impede shallow-water reef growth. This has implications for other cases of carbonate platforms in the geological record where reefs do or did not grow to sea level, i.e., those that are fully or partially drowned.

## GEOLOGICAL AND OCEANOGRAPHICAL SETTING

Indian Ocean Cenozoic isolated carbonate platforms grow on volcanic ridges generated by Indian and African plate drift over the Réunion hotspot (Purdy and Bertram, 1993). The Indian plate platforms are the Maldives, the Laccadive Islands, and the Chagos Archipelago. On the African plate, the Mascarene Plateau, with the Saya de Malha Bank and Nazareth Bank, is located between 4°S and 20°S (Fig. 1A). Saya de Malha Bank covers an area of 40,000 km$^2$ and consists of the smaller North Bank and the larger South Bank, the latter of which is the focus of this study.

The South Bank has a west-east extent of 230 km and a north-south extent of 290 km. It is fringed by a horseshoe-shaped submerged reef rim, which lies at a minimum water depth of 8 m and opens to the south (Fig. 1B) (Fedorov

---

*E-mail: christian.betzler@uni-hamburg.de

CITATION: Betzler, C., et al., 2021, Current and sea level control the demise of shallow carbonate production on a tropical bank (Saya de Malha Bank, Indian Ocean): Geology, v. 49, p. 1431–1435, https://doi.org/10.1130/G49090.1

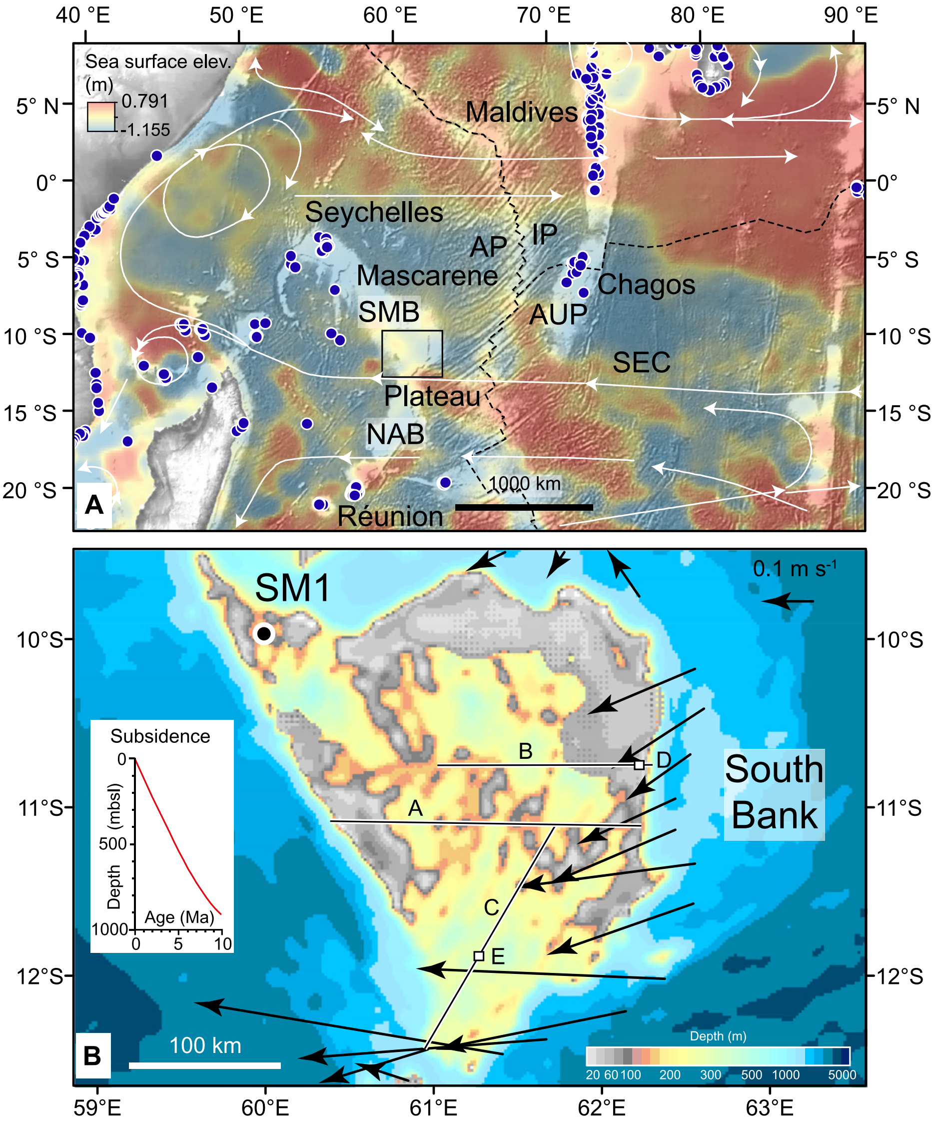

**Figure 1. (A) Indian Ocean circulation (white arrows) (Schott et al., 2009) with June 2004 sea-surface elevation (Zlotnicki et al., 2019), tracing current speed and shallow-water reefs (blue dots; data from http://www.reefbase.org). SMB—Saya de Malha Bank; NAB—Nazareth Bank; SEC—South Equatorial Current. (B) Bathymetry of SMB (data from https://www.gebco.net) with location of petroleum well SM-1. Inset: Curve shows subsidence during the past 10 m.y. for the southern part of Saya de Malha Bank (after Coffin, 1992). mbsl – meters below sea level. Arrows show direction and speed of currents at water depth of 27 m (New et al., 2007). Lines A–C show locations of seismic lines in Figure 2; white squares D and E show locations of seafloor views in Figure 2. Stippled lines shows plate boundaries between the African Plate (AP), Indian Plate (IP), and Australian Plate (AUP).**

et al., 1980). In petroleum well SM-1 (3264 m depth; Fig. 1B), Paleocene to Quaternary neritic to shallow-water carbonates overlie 45 Ma basalts (Meyerhoff and Kamen-Kaye, 1981). The subsidence of the region is thermally controlled (Fig. 1B), as determined based on backtracking Ocean Drilling Program sites using an Airy isostatic model (Coffin, 1992). Through use of a low-resolution seismic line (Purdy and Bertram, 1993), the bank's succession was interpreted as an atoll, which eventually drowned.

Saya de Malha Bank lies in the direct path of the South Equatorial Current, which between 10°S and 16°S flows at 0.3–0.7 m s$^{-1}$ (Fig. 1B) (New et al., 2007). Barotropic tidal currents can add 0.35 m s$^{-1}$ in the east-west direction during spring tides. The main flow of the South Equatorial Current is diverted north and south of the bank, and is strongest between 11°S and 13°S where it is funneled between Saya de Malha and Nazareth Banks (Fig. 1). The current transports ~50 Sv (sverdrup; 50 × 10$^6$ m$^3$ s$^{-1}$), primarily driven by the strong southeast trade winds. In the upper well-mixed layer (50–100 m), the currents are nearly uniform and weaken toward water depths of 500–1000 m.

## METHODS

We acquired seismic reflection data using a 144-channel 600 m digital Hydroscience Technologies Inc. streamer. The Ocean Floor Observation System (OFOS) video sled was equipped with a photo and a video camera. The water column was measured by a SeaBird SBE911plus conductivity, temperature, and depth (CTD) meter with O$_2$ sensors. Rosette water samples for nutrient analyses were filtered through disposable syringe filters and immediately analyzed using a continuous flow injection system (SKALAR SANplus System/08529). For further details on methods, see Lindhorst et al. (2019).

## RESULTS AND INTERPRETATION

### Geology and Seismic Stratigraphy

The seismic data we collected in 2019 allow a subdivision of the Saya de Malha Bank succession into three units (Fig. 2). The base of the lowermost unit 1 is not imaged in the profiles; at the top, it is delimited by an unconformity at 0.9–1.2 s two-way traveltime, which corresponds to a depth of 1.3–1.6 km below seafloor, using International Ocean Discovery Program (IODP) data from seismically comparable Maldives carbonates (Lüdmann et al., 2013; Betzler et al., 2018). The nature of unit 1 is not fully interpretable with the available data because the reflection pattern is mainly chaotic.

In unit 2, a basin was imaged, which was laterally infilled by progradational clinoform strata (Figs. 2A and 2B). Clinoform bottomsets pass into subhorizontal and subparallel layering. In the topset, layering is subhorizontal and laterally discontinuous. In view of the isolated nature of Saya de Malha Bank without any siliciclastic input, the architecture is interpreted to reflect a flat-topped carbonate platform (Eberli and Ginsburg, 1987). Such platforms have an edge formed by reefs or shoals, inclined slopes, and flat-lying inner platform deposits. The carbonate edifice enclosed a basin several tens to hundreds of meters deep and at least 60 km wide (Figs. 2A and 2B). Locally in the basin, there are isolated buildups as much as 5 km wide, which rest on the unconformity separating units 1 and 2. The progradation of the inner platform edge toward the inner basin was not controlled by margin orientation (Figs. 2A–2C), which favors the interpretation that Saya de Malha Bank was an atoll at the time of unit 2 deposition (Purdy and Bertram, 1993).

The growth mode illustrated by unit 2 terminated at a pronounced and platform-wide seismic reflection (drowning unconformity, DU) (Fig. 2). Above horizon DU, the succession is layered (unit 3), reaching up to the seafloor and thinning out toward the south. In northeast-southwest–oriented sections, unit 3 has a backstepping carbonate ramp–like geometry (Fig. 2C). The layered sedimentation pattern of unit 3 is interrupted by flat-topped minor bodies as much as 12 km wide, which reach up to a water depth of 20 m (Fig. 2A). These bodies are wide near the bank margins

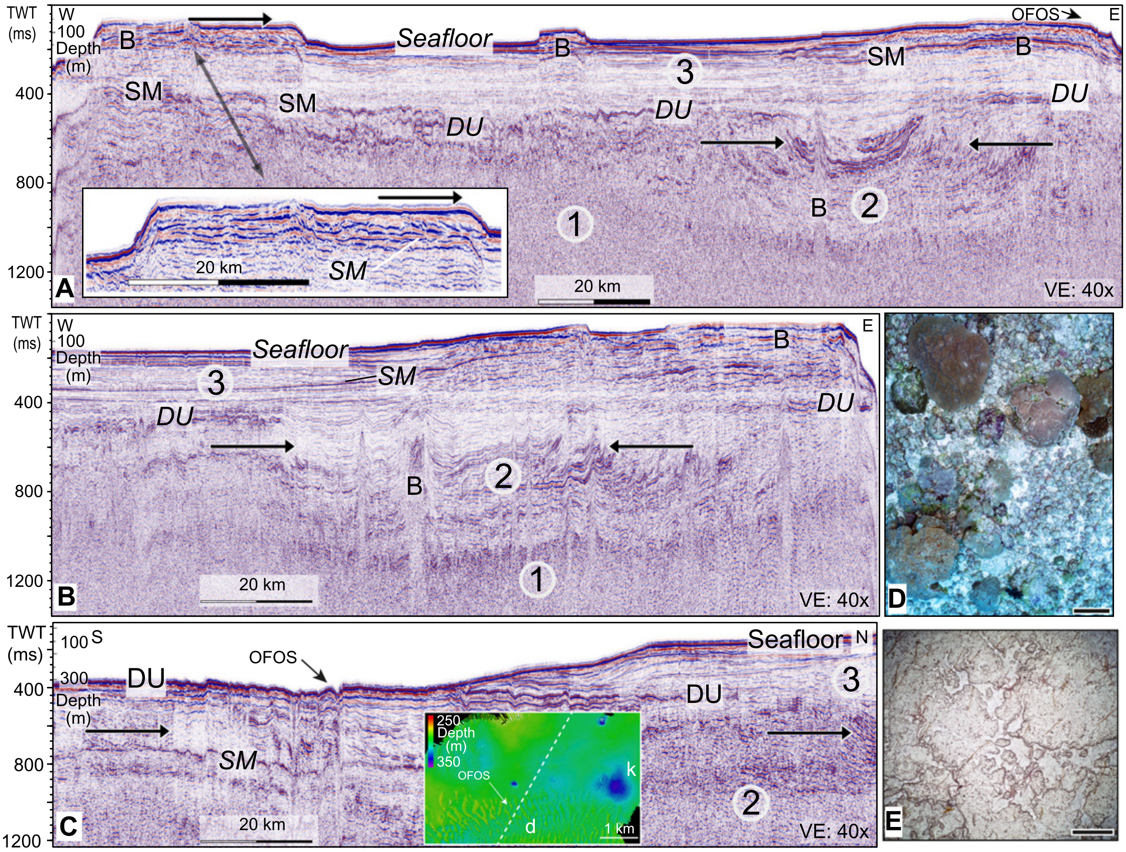

**Figure 2. Seismic profiles of the Saya de Malha Bank, Indian Ocean (locations in Fig. 1B) with clinoform progradations (arrows) and drowning unconformity (DU). Circled numbers 1, 2, and 3 are stratigraphic units (see text). TWT—two-way traveltime; VE—vertical exaggeration. (A) West-east line. B—carbonate banks; SM—seafloor multiple. Inset: Detail showing progradation in carbonate body. (B) West-east line. OFOS (Ocean Floor Observation System) indicates the location of image shown in D. (C) SSW-NNE line with DU hardground and sediment cover thickening toward the north. OFOS indicates the location of image shown in E. Inset shows multibeam imagery and path of the seismic profile (stippled line) (d—submarine dunes; k—karst collapse). (D) Photo of mesophotic coral ecosystem (water depth: 30 m) with coralline red algae. Scale bar: 40 cm. (E) Photo of DU hardground (water depth: 302 m). Scale bar: 40 cm.**

and narrow in the bank interior. Some show an internal stratification (Fig. 2A), with a succession of parallel to subparallel strata in the center and some inclined and prograding strata toward the margins. At present, the surfaces of the bodies are populated by mesophotic coral ecosystems with red algae, corals, and green algae (Fig. 2D). The rims of the marginal bodies facing the open sea are located farther platform-inward compared to the outer platform margins of unit 2; i.e., the edges of these relict banks stepped back over time.

The establishment of the horseshoe-shaped bank rim appears to correlate with changes in the stratal patterns above horizon DU. In northeast-southwest–oriented seismic lines (Fig. 2C), it is apparent that horizon DU crops out at the seafloor as a hardground dissected by fissures (Fig. 2E), in parts infilled by soft sediment. The hardground has a local cover of submarine dune fields (Fig. 2C). The surface also displays large and scattered circular to subcircular depressions (Fig. 2C) as much as 1 km wide and as much as 160 m deep, which are interpreted as karst features.

### Oceanography

Temperature, salinity, and oxygen concentrations over the Saya de Malha Bank indicate tropical surface waters of low salinity, and more saline water of Arabian Sea provenance near the surface (Fig. 3A). Salt-rich subtropical surface water and Indonesian Throughflow water that is low in oxygen mix at ~200 m water depth (Figs. 3A and 3B). Below, there is the relatively oxygen-rich Southern Indian Central Water (300–500 m water depth), in turn underlain by oxygen-poor Red Sea–Persian Gulf Intermediate Water. In October 2019, during R/V *SONNE* cruise SO270 (Lindhorst et al., 2019), the mean sea-surface temperature was 26.9 °C. This temperature, and the mean salinity of 34.8 psu (practical salinity units), the low productivity, and the phosphate concentration of 0.11 μM (Figs. 3C and 3D) are well within the tolerance limits of coral reefs.

Zones of the Saya de Malha Bank impacted by the highest current velocities (Fig. 1B) coincide with the areas where horizon DU is at the seafloor (Figs. 2C and 2E). In spite of the blocking position of the bank in the massive South Equatorial Current water flow, there is no indication of topographic upwelling of nutrient-rich sub-thermocline waters into the euphotic zone (Figs. 3C and 3D). Instead, low phosphate and chlorophyll-alpha concentrations in the waters over the bank mark the region as being nutrient limited, with only low levels of pelagic productivity.

## DISCUSSION

The depositional geometries (Fig. 2) of the Saya de Malha Bank indicate that the present-day platform state of partial drowning was established during the younger Neogene. The platform factory eventually changed from shallow-water carbonate growth—with the platform top at or near sea level—to a mode with carbonate producers unable to fill the available accommodation at any location of the platform.

Because no rock or well data are available, age interpretation for horizon DU formation relies on indirect evidence. The thermally controlled subsidence rate for this part of the Mascarene Plateau was ~0.1 m k.y.$^{-1}$ for the past 7 m.y. (Coffin, 1992) (Fig. 1B). Assuming that horizon DU traces the pre-drowning top of the shallow-water carbonate platform, the surface thus would have formed during the Pliocene. This is endorsed by data from the conjugate margin (Indian plate) with a similar thermal history. Industry well NMA1, located in the Maldives at a depth of 300–330 m below sea level, recovered a facies of an early Pliocene drowning event (Aubert and Droxler, 1992). Correlation with seismic horizons and ages of sediments recovered during IODP Expedition 359 (Lüdmann et al., 2013) delimits this interval with sequence boundaries formed at 2.1 and 3.0 Ma (Betzler et al., 2018).

The most straightforward explanation for the Saya de Malha Bank drowning thus appears to be the response to a sea-level rise. Other isolated carbonate platforms such as the Bahamas, the Maldives, or the platforms off northeastern Australia also record this episode of high Pliocene eustatic sea level (Eberli and Ginsburg, 1987;

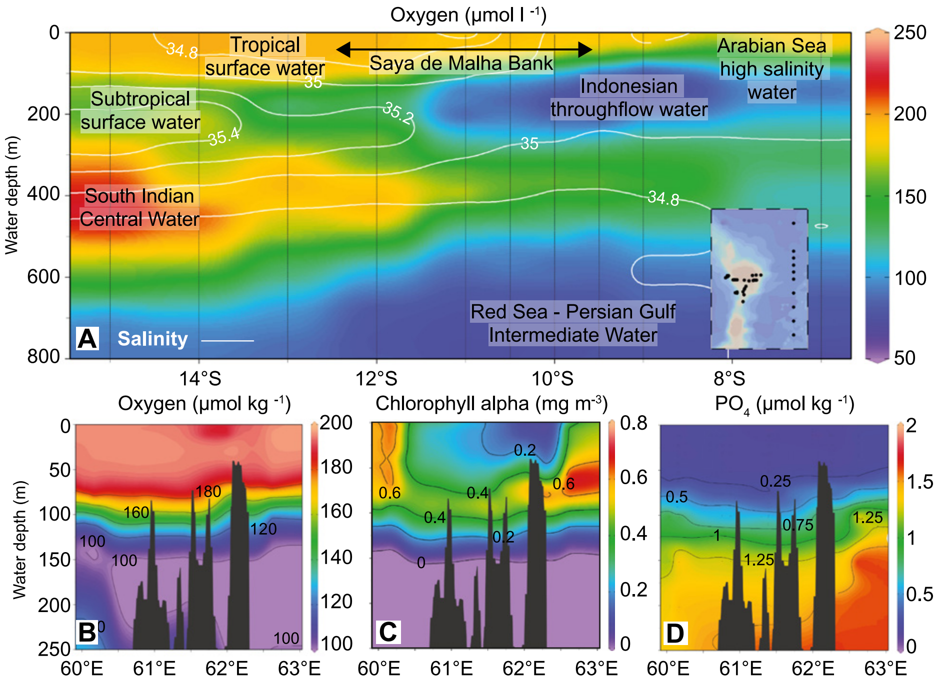

**Figure 3. (A) Salinity (color scale) and oxygen (white contours) concentrations in the upper water column of the Indian Ocean along a conductivity, temperature, and depth (CTD) transect at 65°E (CTD station positions in inset). SMB—Saya de Malha Bank. (B,C) Oxygen content and chlorophyll alpha concentration from CTD casts, and (D) phosphate concentrations in discrete samples. Sections were produced with Ocean Data View software (Schlitzer, 2016). Black areas indicate seafloor relief.**

Aubert and Droxler, 1992; Betzler et al., 2000; McNeill et al., 2001; Reijmer et al., 2002). Subsequent recovery of these platforms with recent shallow-water carbonate sedimentation, however, indicates that in addition to sea-level fluctuations, other factors controlled Saya de Malha Bank drowning.

Nutrient injection into shallow water has been invoked as a drowning trigger (Hallock and Schlager, 1986), but it has also been shown that coral reefs adapt to changes in trophic state (Morgan et al., 2016). At present, the low phosphate and chlorophyll-alpha concentrations in the water column on and around the bank (Fig. 3) are not indicative of nutrient control. Conditions of low productivity in the Indian Ocean can also be traced back for the past ∼4 m.y. by carbonate mass accumulation rates (Dickens and Owen, 1999). For the period before 4 Ma, the same data indicate more elevated surface-water productivity.

Ocean currents can trigger drowning (Isern et al., 2004; John and Mutti, 2005; Betzler et al., 2009; Eberli et al., 2010; Purkis et al., 2014; Reolid et al., 2020; Ling et al., 2021), and the present-day oceanographic conditions around Saya de Malha Bank introduce the South Equatorial Current as a major player in platform evolution. Today, the bank is sculpted by the current, with sediment winnowing at its southern tip (Figs. 2C and 2E). The South Equatorial Current established at 3.3 Ma (Auer et al., 2019), and accelerated currents through trade-wind intensification started at ca. 3 Ma as documented in upwelling records of the Benguela Current (Marlow et al., 2000), which is connected to the South Equatorial Current through the Agulhas leakage (Durgadoo et al., 2017).

Whether a shallow-water carbonate factory keeps up with sea-level rise depends on the amplitudes and frequencies of sea-level changes, but also on the antecedent topography. Coral colonization of a substrate during a rapid sea-level rise is possible only when there is substrate for corals to grow in the upper photic zone, as documented by many backstepping and submerged reef terraces around modern carbonate platforms (Woodroffe and Webster, 2014). Flat-topped platforms do not provide these conditions, and thus, under elevated rates of sea-level rise as high as 19 mm $yr^{-1}$ (Montaggioni and Martin-Garin, 2020), can drown if the sediment production rate of the carbonate factory is too low to infill accommodation. The seismic evidence of relict banks with margin progradation (Fig. 2A) in this context reflects ephemeral past stages with bank-top carbonate production and export; i.e., short episodes when the bank tops were at sea level.

The onset of eccentricity-driven sea-level fluctuations at ca. 3 Ma resulted in high amplitudes and rates of change, which later during the Pleistocene became even more pronounced. This induced a change from flat-topped banks to atolls on many Pacific and Indian Ocean carbonate platforms (Droxler and Jorry, 2021). In the case of Saya de Malha Bank, however, the South Equatorial Current prevented the reefs from forming a closed rim, thus drowning the bank, which from then on was populated only by shallow-water reefs during short periods of lowered sea level.

The Saya de Malha Bank drowning is therefore not attributed to one factor alone. It was rather a combination of two processes, i.e., sea-level change and current intensification, which were the reasons that the reef systems, although situated in a suitable setting, did not produce sufficient sediment to infill the available accommodation. These findings are applicable to other drowned Tertiary platforms in the Indo-Pacific region, such as, e.g., in the South China Sea. Nutrient injection into shallow waters, a process invoked as a platform-drowning trigger elsewhere, is not seen as relevant in the case of the Saya de Malha Bank drowning.

## ACKNOWLEDGMENTS

The German Federal Ministry of Education and Research (BMBF) is funding the project MASCARA (grants 03G0270A and 03G0270B). We are grateful to Captain Mallon, the officers, and crew of R/V *SONNE* for their excellent support. Many thanks to the technicians of the cruise SO270 scientific party. The Joint Commission of the Extended Continental Shelf, Mascarene Plateau Region, is thanked for allowing work in the Joint Management Area between Mauritius and Seychelles; and the Department for Continental Shelf, Maritime Zones Administration and Exploration (Mauritius) allowed work in the Republic of Mauritius Exclusive Economic Zone. Schlumberger is thanked for the grant to use Petrel software. We thank Sam Purkis, an anonymous reviewer, and editor Kathleen Benison for insightful and constructive comments.

## REFERENCES CITED

Aubert, O., and Droxler, A.W., 1992, General Cenozoic evolution of the Maldives carbonate system (equatorial Indian Ocean): Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine, v. 16, p. 113–136.

Auer, G., et al., 2019, Timing and pacing of Indonesian Throughflow restriction and its connection to late Pliocene climate shifts: Paleoceanography and Paleoclimatology, v. 34, p. 635–657, https://doi.org/10.1029/2018PA003512.

Betzler, C., Kroon, D., and Reijmer, J.J.G., 2000, Synchroneity of major Late Neogene sea level fluctuations and paleoceanographically controlled changes as recorded by two carbonate platforms: Paleoceanography, v. 15, p. 722–730, https://doi.org/10.1029/1999PA000481.

Betzler, C., Hübscher, C., Lindhorst, S., Reijmer, J.J.G., Römer, M., Droxler, A.W., Fürstenau, J., and Lüdmann, T., 2009, Monsoonal-induced partial carbonate platform drowning (Maldives, Indian Ocean): Geology, v. 37, p. 867–870, https://doi.org/10.1130/G25702A.1.

Betzler, C., et al., 2018, Refinement of Miocene sea level and monsoon events from the sedimentary archive of the Maldives (Indian Ocean): Progress in Earth and Planetary Science, v. 5, 5, https://doi.org/10.1186/s40645-018-0165-x.

Coffin, M.F., 1992, Emplacement and subsidence of Indian Ocean plateaus and submarine ridges, *in* Duncan, R.A., et al., eds., Synthesis of Results form Scientific Drilling in the Indian

Ocean: American Geophysical Union Geophysical Monograph 70, p. 115–125, https://doi.org/10.1029/GM070p0115.

Dickens, G.R., and Owen, R.M., 1999, The Latest Miocene–Early Pliocene biogenic bloom: A revised Indian Ocean perspective: Marine Geology, v. 161, p. 75–91, https://doi.org/10.1016/S0025-3227(99)00057-2.

Droxler, A.W., and Jorry, S.J., 2021, The origin of modern atolls: Challenging Darwin's deeply ingrained theory: Annual Review of Marine Science, v. 13, p. 537–573, https://doi.org/10.1146/annurev-marine-122414-034137.

Durgadoo, J.V., Rühs, S., Biastoch, A., and Böning, C.W.B., 2017, Indian Ocean sources of Agulhas leakage: Journal of Geophysical Research: Oceans, v. 122, p. 3481–3499, https://doi.org/10.1002/2016JC012676.

Eberli, G.P., and Ginsburg, R.N., 1987, Segmentation and coalescence of Cenozoic carbonate platforms, northwestern Great Bahama Bank: Geology, v. 15, p. 75–79, https://doi.org/10.1130/0091-7613(1987)15<75:SACOCC>2.0.CO;2.

Eberli, G.P., Anselmetti, F.S., Isern, A.R., and Delius, H., 2010, Timing of changes in sea-level and currents along Miocene platforms on the Marion Plateau, Australia, *in* Morgan, W.A., et al., eds., Cenozoic Carbonate Systems of Australasia: SEPM (Society for Sedimentary Geology) Special Publication 95, p. 219–242, https://doi.org/10.2110/sepmsp.095.219.

Fedorov, V.V., Rubinshteyn, I.G., Danilov, I.V., and Lanin, V.I., 1980, Bottom landscapes of Saya de Malha Bank in the Indian Ocean: Oceanology (Moscow), v. 20, p. 434–439.

Hallock, P., and Schlager, W., 1986, Nutrient excess and the demise of coral reefs and carbonate platform: Palaios, v. 1, p. 389–398, https://doi.org/10.2307/3514476.

Isern, A.R., Anselmetti, F.S., and Blum, P., 2004, A Neogene carbonate platform, slope, and shelf edifice shaped by sea level and ocean currents, Marion Plateau (northeast Australia), *in* Eberli, G.P., et al., eds., Seismic Imaging of Carbonate Reservoirs and Systems: American association of Petroleum Geologists Memoir 81, p. 291–307.

John, C.M., and Mutti, M., 2005, Relative control of paleoceanography, climate, and eustasy over Heterozoan carbonates: A perspective from slope sediments of the Marion Plateau (ODP LEG 194): Journal of Sedimentary Research, v. 75, p. 216–230, https://doi.org/10.2110/jsr.2005.017.

Lindhorst, S., et al., 2019, Saya de Malha carbonates, oceanography and biogeochemistry (western Indian Ocean), cruise no. SO270, 2019-09-06–2019-10-23, Hong Kong (China)–Port Louis (Mauritius): Bonn, Gutachterpanel Forschungsschiffe, 102 p., https://doi.org/10.2312/cr_so270.

Ling, A., Eberli, G.P., Swart, P.K., Reolid, J., Stainbank, S., Rüggeberg, A., and Betzler, C., 2021, Middle Miocene platform drowning in the Maldives associated with monsoon-related intensification of currents: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 567, 110275, https://doi.org/10.1016/j.palaeo.2021.110275.

Lüdmann, T., Kalvelage, C., Betzler, C., Fürstenau, J., and Hübscher, C., 2013, The Maldives, a giant isolated carbonate platform dominated by bottom currents: Marine and Petroleum Geology, v. 43, p. 326–340, https://doi.org/10.1016/j.marpetgeo.2013.01.004.

Marlow, J.R., Lange, C.B., Wefer, G., and Rosell-Melé, A., 2000, Upwelling intensification as part of the Pliocene-Pleistocene climate transition: Science, v. 290, p. 2288–2291, https://doi.org/10.1126/science.290.5500.2288.

McNeill, D.F., Eberli, G.P., Lidz, B.H., Swart, P.K., and Kenter, J.A.M., 2001, Chronostratigraphy of a prograded carbonate platform margin: A record of dynamic slope sedimentation, western Great Bahama Bank, *in* Ginsburg, R.N., ed., Subsurface Geology of a Prograding Carbonate Platform Margin, Great Bahama Bank: Results of the Bahamas Drilling Project: SEPM (Society for Sedimentary Geology) Special Publication 70, p. 101–134, https://doi.org/10.2110/pec.01.70.0101.

Meyerhoff, A.A., and Kamen-Kaye, M., 1981, Petroleum prospects of Saya de Malha and Nazareth Banks, Indian Ocean: American Association of Petroleum Geologists Bulletin, v. 65, p. 1344–1347, https://doi.org/10.1306/03B594AE-16D1-11D7-8645000102C1865D.

Montaggioni, L.F., 2005, History of Indo-Pacific coral reef systems since the last glaciation: Development patterns and controlling factors: Earth-Science Reviews, v. 71, p. 1–75, https://doi.org/10.1016/j.earscirev.2005.01.002.

Montaggioni, L.F., and Martin-Garin, B., 2020, Quaternary development history of coral reefs from West Indian islands: A review: International Journal of Earth Sciences, v. 109, p. 911–930, https://doi.org/10.1007/s00531-020-01839-3.

Morgan, K.M., Perry, C.T., Smithers, S.G., Johnson, J.A., and Daniell, J.J., 2016, Evidence of extensive reef development and high coral cover in nearshore environments: Implications for understanding coral adaptation in turbid settings: Scientific Reports, v. 6, 29616, https://doi.org/10.1038/srep29616.

New, A.L., Alderson, S.G., Smeed, D.A., and Stansfield, K.L., 2007, On the circulation of water masses across the Mascarene Plateau in the South Indian Ocean: Deep-Sea Research: Part I, Oceanographic Research Papers, v. 54, p. 42–74, https://doi.org/10.1016/j.dsr.2006.08.016.

Purdy, E.G., and Bertram, G.T., 1993, Carbonate concepts from the Maldives, Indian Ocean: American Association of Petroleum Geologists Studies in Geology 34, 56 p.

Purkis, S., Kerr, J., Dempsey, A., Calhoun, A., Metsamaa, L., Riegl, B., Kourafalou, V., Bruckner, A., and Renaud, P., 2014, Large-scale carbonate platform development of Cay Sal Bank, Bahamas, and implications for associated reef geomorphology: Geomorphology, v. 222, p. 25–38, https://doi.org/10.1016/j.geomorph.2014.03.004.

Reijmer, J.J.G., Betzler, C., Kroon, D., Tiedemann, R., and Eberli, G.P., 2002, Bahamian carbonate platform development in response to sea-level changes and the closure of the Isthmus of Panama: International Journal of Earth Sciences, v. 91, p. 482–489, https://doi.org/10.1007/s00531-001-0235-x.

Reolid, J., Betzler, C., Braga, J.C., Lüdmann, T., Ling, A., and Eberli, G.P., 2020, Facies and geometry of drowning steps in a Miocene carbonate platform (Maldives): Palaeogeography, Palaeoclimatology, Palaeoecology, v. 538, 109455, https://doi.org/10.1016/j.palaeo.2019.109455.

Schlager, W., 2005, Carbonate Sedimentology and Sequence Stratigraphy: SEPM (Society for Sedimentary Geology) Concepts in Sedimentology and Paleontology 8, 200 p., https://doi.org/10.2110/csp.05.08.

Schlitzer, R., 2016, Ocean Data View: http://odv.awi.de (accessed August 2020).

Schott, F.A., Xie, S.-P., and McCreary, J.P., 2009, Indian Ocean circulation and climate variability: Reviews of Geophysics, v. 47, RG1002, https://doi.org/10.1029/2007RG000245.

Webster, J.M., et al., 2018, Response of the Great Barrier Reef to sea-level and environmental changes over the past 30,000 years: Nature Geoscience, v. 11, p. 426–432, https://doi.org/10.1038/s41561-018-0127-3.

Woodroffe, C.D., and Webster, J.M., 2014, Coral reefs and sea-level change: Marine Geology, v. 352, p. 248–267, https://doi.org/10.1016/j.margeo.2013.12.006.

Zlotnicki, V., Qu, Z., and Willis, J., 2019, MEaSUREs gridded sea surface height anomalies (version 1812): U.S. National Aeronautics and Space Administration, Physical Oceanography Distributed Active Archive Center, https://doi.org/10.5067/SLREF-CDRV2 (accessed March 2021).

Printed in USA